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Confirmation of Middle Holocene Ocean Cooling Inferred from Stable Isotopic Analysis of Prehistoric Shells from Santa Cruz Island, California

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Abstract. Archaeological sites dating from 5,900 to 4,500 yr ago on the northern Channel Islands of southern California contain abundant shells of red abalone (*Haliotis rufescens*), a cool-water mollusk, and generally lack shells of black abalone (*H. cracherodii*), a warmer-water form. This implies the existence of cooler intertidal sea-water temperatures 5,900–4,500 yr ago during the accumulation of these deposits. This hypothesis has been tested using oxygen isotopic analyses of California mussel (*Mytilus californianus*) shells from a red- abalone midden on Santa Cruz Island and on modern shells from the adjacent intertidal zone. The study reveals that average intertidal water temperatures (~12.9° C) then were ~2.5° C cooler than today (~15.5° C). Analyses also suggest larger middle Holocene annual sea surface temperature differences and perhaps greater seasonal variability compared with today. Carbon isotopic fluctuations during shell growth in the modern *M. californianus* clearly record seasonal changes in the intensity of upwelling. Higher inferred upwelling, marked by lower $\delta^{13}C$ values in the shells, occurred during cooler-water months marked by higher $\delta^{18}O$ values. The stable isotopic data in the archeological material indicate significant variability in the seasonality of inferred upwelling. Colder conditions and more variable climatic and oceanic conditions during this middle Holocene interval may have significantly influenced human maritime adaptations.

Keywords: Santa Cruz Island, California; Santa Barbara Channel; prehistory; archaeology; paleoenvironmental change; climatic change; sea-surface temperature change; oxygen isotopic analysis; carbon isotopic analysis.

Background and Objectives

Early and middle Holocene shell middens on the northern Channel Islands of California contain abundant red-abalone (*Haliotis rufescens*) shells. In island sites dating after ~4,500 CYBP (calendar years before present) red-abalone shells typically are much less abundant, and black abalone (*Haliotis cracherodii*) is the prevalent abalone species represented (Glassow 1993a). Based on earlier work by Hubbs (1958, 1967), Glassow (1993a) proposed that the prevalence of red-abalone shells in island sites during 2 main intervals of time (~8,100–7,300 CYBP and ~5,900–4,500 CYBP) resulted from cooler intertidal temperatures equivalent to latitudes of central and northern California today. Following ~4,500 CYBP, black abalone became the dominant abalone species in shell-midden deposits, reflecting warmer intertidal conditions. Black abalone is the dominant form in the intertidal zone today in southern California, while red abalone occurs subtidally. To the north of Monterey, California, red abalone is dominant and black abalone less frequent in the intertidal zone.

The selection of intertidal shellfish by prehistoric peoples depended on a number of factors, including abundance, availability, and ease of collection. Thus, some archaeologists have challenged the hypothesis that the prevalence of red-abalone shells in early to middle Holocene midden deposits resulted from changes in molluscan distribution related to cooling. Salls (1992) argued that overexploitation or factors other than temperature change accounted for red abalone abundance in prehistoric middens on the islands off southern California. However, a sea-surface paleotemperature record based on changes in microfossils for the Santa Barbara Channel spanning the last 8,000 yr (Pisias 1978) reveals water-temperature changes of sufficient magnitude (up to 10° C) to have caused changes in intertidal shellfish distribution and abundance.

The middle Holocene interval between 5,400 and 4,300 CYBP was marked by 3 intervals sufficiently cool (~14° C) to support abundant red abalone in the intertidal zone (Pisias 1978). This period was preceded by an interval of ~600 yr when average water temperatures were between ~18 and 23° C. Most known red-abalone middens on the Channel Islands date to the cool interval between 5,900 and 4,500 CYBP. The age of these middens is based on 10 radiocarbon dates calibrated using curves produced by Stuiver and Braziunas (1993). Our analysis concerns one of 8 red-abalone middens known from Santa Cruz Island.

Oxygen isotopic analysis of marine shells is a well-established method for reconstructing nearshore surface water temperatures (Epstein et al. 1951, 1953; Craig et al. 1965). In southern California, the most useful species employed for such studies is *Mytilus californianus* (the California mussel; Killingley and Berger 1979; Killingley 1981; Koerper et al. 1985). Since this form is common in the red-abalone middens, oxygen isotopic analysis has been used to determine if water temperatures were cooler during this interval compared with the present time.

The study had several other objectives: (1) to identify patterns of seasonal variation in modern California mussel shells for comparison with shells from midden deposits (Killingley 1981; Killingley and Berger 1979); (2) to compare seasonal variability in water temperature between the middle Holocene and present; (3) to determine the season during which prehistoric peoples collected the California mussels (Shackleton 1973; Killingley 1981); (4) to investigate the relationship between carbon and oxygen isotopic variations, and to test the hypothesis that carbon isotopic fluctuations reflect changes in intensity of upwelling (Killingley and Berger 1979); and (5) to help resolve differences in age assignments of the mid-Holocene cold-water interval in the region (Pisias 1978).

The shells used for the stable isotopic analyses are from a red-abalone midden at Site CA-SCRI-333, near Forneys Cove at the western tip of Santa Cruz Island (Fig. 1). Wilcoxon (1993) collected the shells from a ~40-cm thick, red-abalone midden layer ~190 cm below the sur-

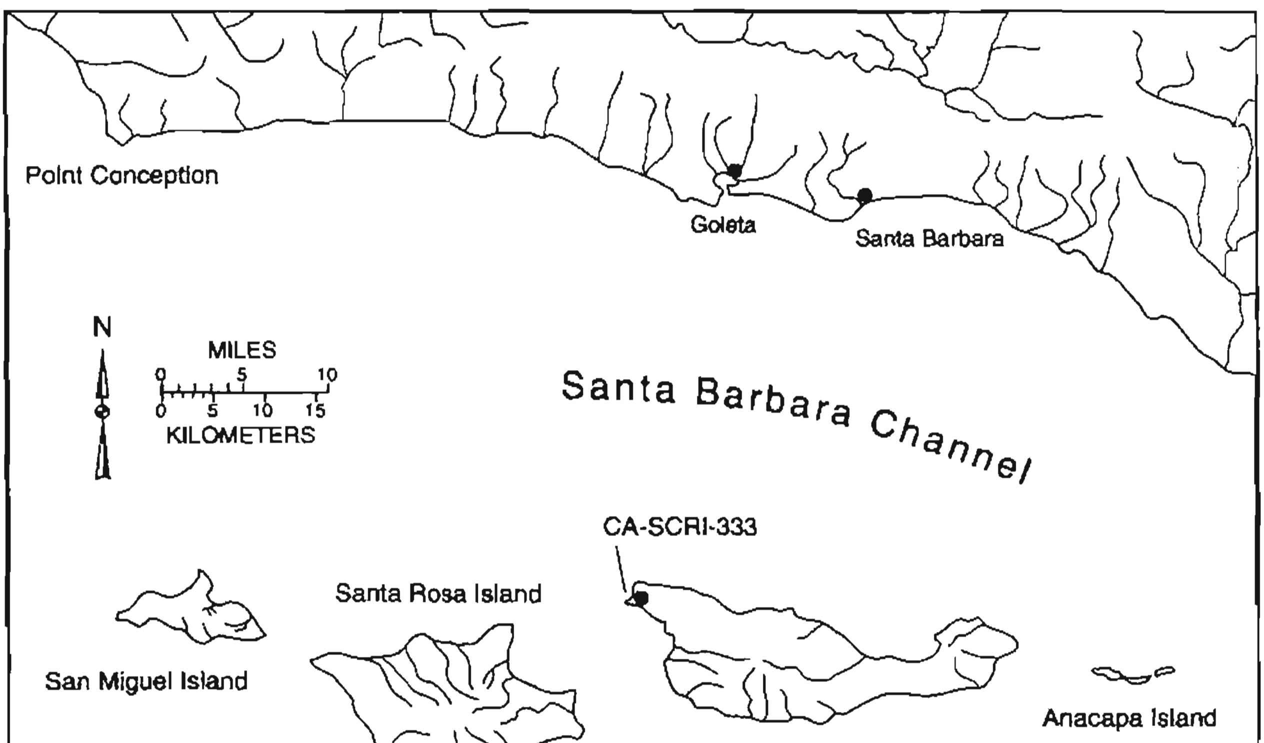

Figure 1. Map of the Santa Barbara Channel Region showing location of the prehistoric shell midden (Site CA-SCRI-333) examined on western Santa Cruz Island. Living *Mytilus californianus* specimens were collected for isotopic studies from the intertidal zone adjacent to this midden. Drafted by D. Brandts.

face in a test unit. This midden, the lowermost encountered in the test unit, contains both California mussel and red-abalone shells in a matrix of dune sand. The red-abalone shells are so abundant as to form a layer of contiguous shells. Calibrated radiocarbon dates of this layer are 5,739 (±1 σ error: 5,907–5,601) and 5,029 (±1 σ error: 5,241–4,869) CYBP (Wilcoxon 1993:148). The red-abalone midden is overlain by a layer of almost pure dune sand. Above this, from ~100 cm to the ground surface, is a dense midden deposit composed of abundant mussels and less-common, black-abalone shells within a sooty soil matrix. Eight radiocarbon dates from this layer range from 4,500 to 1,300 CYBP.

Red-abalone middens elsewhere on Santa Cruz Island are located in similar depositional settings. Some of the middens occur in isolated layers ~20 cm thick within alluvium or dune deposits, while others are overlain by deposits similar to those at Site CA-SCRI-333. Red-abalone middens at a site on Santa Rosa Island and another on San Miguel Island have also been dated close to 5,000 yr ago. Others from these 2 islands are older (Glassow 1993a; J. M. Erlandson 1992, pers. comm.).

Methods

Site CA-SCRI-333 is the only site on the northern Channel Islands dating to the period of interest with a sizable collection of whole California mussel valves. Midden deposits were excavated in 10-cm levels, and whole valves were collected from the red- abalone layer. We selected 7 well-preserved mussel valves for oxygen and carbon isotopic analysis from levels between 200 and 220 cm below surface. Living specimens of *M. californianus* were collected in May 1987 and January 1992 from the intertidal zone 150 m west of this prehistoric midden to study relationships between changing environmental conditions and oxygen and carbon isotopic variations recorded in the shells.

Shell surfaces were scraped to remove any extraneous organic material, including the periostracum (Fig. 2), that might contaminate the samples. The shells were rinsed in deionized water and dried at 85° C. This process was repeated until all visible organic material was removed.

Each valve was sectioned lengthwise to expose the crystalline structure. To determine the oxygen and carbon isotopic variation throughout the life of the mussel, calcite samples were taken using a 0.5-mm drill bit at 2-mm increments along the direction of shell growth from the margin to the hinge (Fig. 2). Because calcite and aragonite yield different oxygen isotopic values, we avoided sampling the underlying nacreous layer, which is aragonitic in composition (Fig. 2).

Powdered calcite samples (~0.3 mg) were loaded

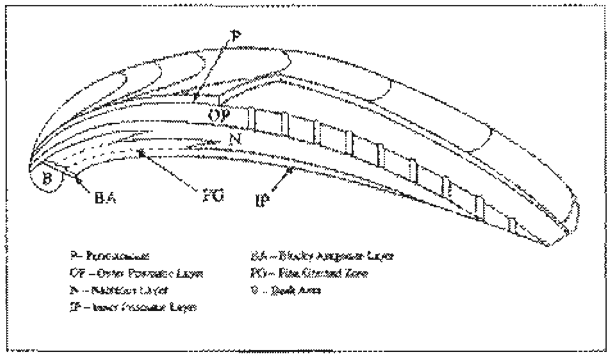

Figure 2. Cross-section of a *Mytilus californianus* shell (California mussel) showing structural features. The crystalline structure of California mussels is complex, consisting of 2 types of carbonate: calcite and aragonite. Three-dimensional view of shell based on Dodd (1964:1067) with modifications. Drafted by M. Kennett.

into small copper "boats" and roasted at 375° C for 1 hr under vacuum to remove organic contaminants, and reacted in orthophosphoric acid at 90° C with an on-line automated carbonate CO_2 preparation device; the evolved CO_2 was analyzed by means of a Finnegan/MAT-251 light stable isotopic mass spectrometer. Instrument precision for these analyses was ±0.11‰ (<0.5° C) for $\pm^{18}O$ and ±0.9‰ for $\delta^{13}C$. All measurements are calibrated to Peedee belemnite (PDB), the internationally accepted

$$\delta^{18}O‰ = \left[\frac{\delta^{18}Osample}{\delta^{18}Ostandard} - 1\right] x1000$$

$$\delta^{13}C‰ = \left[\frac{\delta^{13}Csample}{\delta^{13}Cstandard} - 1\right] x1000$$

standard, and are expressed in δ (delta) notation, where:

Water temperatures were calculated using the palaeotemperature equation of Epstein et al. (1951, 1953; see also Craig et al., 1965) and applied to the calcite of *M. californianus* by Killingley (1981; Killingley and Berger 1979);

$$T(°C) = 16.4 - 4.2(\delta c - \delta w) + 0.13(\delta c - \delta w)^2$$

where $\delta c = \delta^{18}O_{PDB}$ of the calcite and $\delta w = \delta^{18}O_{SMOW}$ of the water.

Postdepositonal contamination of the shell carbonate of archaeological specimens was one of our primary concerns. Although the shells from Site CA-SCRI-333 appeared to be well preserved, we performed 2 procedures to screen archaeological specimens for diagenesis. A modern and an archaeological shell were examined using a scanning electron microscope. Microscopic inspection of the crystalline structure of the archaeological shells indicated that they are well preserved. Modern and archaeological shells also were examined using X-ray diffraction. The crystal lattice of *M. californianus* is complex, consisting of 2 forms of calcium carbonate: aragonite and calcite. The results of our X-ray diffraction study indicate that the primary aragonite in the archaeological specimens is intact and that secondary deposits of calcite are absent.

Outer surfaces, including the growth margin of fossil shells, are particularly subject to recrystalization associated with chemical exchange with percolating ground water (Shackleton 1973; Bailey et al. 1983). We etched the surface of each archaeological specimen with a dilute solution of HCL to remove any diagenetically altered carbonate as recommended by Bailey et al. (1983).

In order to compare paleotemperature records calculated from oxygen isotopic values with modern ocean temperatures, we used average monthly sea-surface temperatures for the north-central coast of Santa Cruz Island provided by J. M. Engle (1993, pers. comm.).

Results

Variations in oxygen isotopic ($\delta^{18}O$) values were exhibited in all 10 mussel shells sampled, interpretable as seasonal and annual variations in water temperature (Figs. 3 and 4). Specifically, most shell profiles exhibit contiguous series of $\delta^{18}O$ values that increase and decrease in relatively regular cycles, even though there is considerable variation in the breadth and magnitude of the cycles. Only shell 3y departs from this pattern, perhaps because its growth was slow enough that a year's accumulation is represented by only 2 or 3 calcite samples.

The accuracy of the temperature records inferred from oxygen isotopes in modern shells was evaluated by comparison with monthly sea-surface temperatures of waters adjacent to north-central Santa Cruz Island. The range of temperature variations in the records derived from 2 shells collected in May 1987 (shells 18 and 19) is similar to that of measured water- temperature variations at Santa Cruz Island during the 3.5-yr period represented by the shell profiles (Table 1). However, the temperature ranges inferred from these 2 shells is ~1° C cooler than the measured water-temperature ranges. This may have resulted from the shells being collected from western Santa Cruz Island, whereas the sea-surface temperature record is of waters adjacent to north-central Santa Cruz Island. Significantly, the shell profiles do not record the relatively long periods of low water temperatures during the winter months seen in the water-temperature record (Fig. 5). This discrepancy is probably due to slower shell growth rates during cooler months compared to higher growth rates during warmer months.

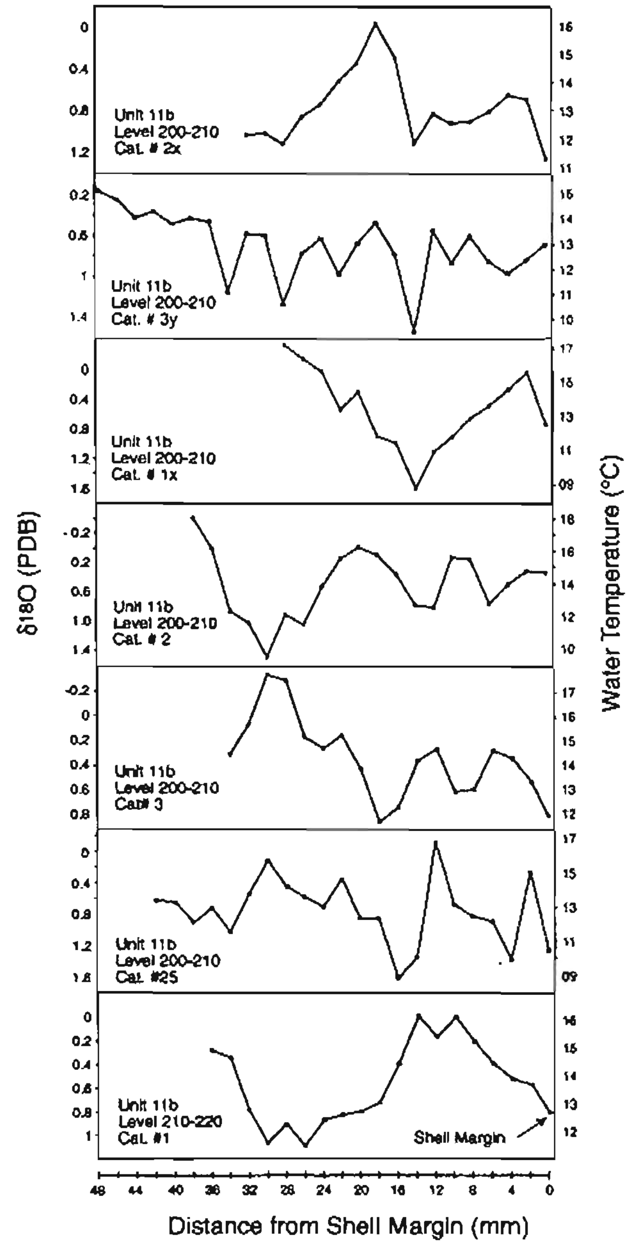

Figure 3. Oxygen isotopic variation along the growth axis of 7 shells of *Mytilus californianus* collected from levels rich in red abalone (200–220 cm) in a prehistoric shell midden (Site CA-SCRI-333) on western Santa Cruz Island. Calcite samples taken every 2 mm along growth axis. Oxygen isotopic values are relative to Pee Dee Belemnite (PDB). Paleotemperature curve is calculated using the equation of Epstein et al. (1951, 1953; also see Craig et al. 1965) as applied to the calcite of *M. californianus* by Killingley and Berger (1979). Shell margins, representing time of collection, are shown to the right.

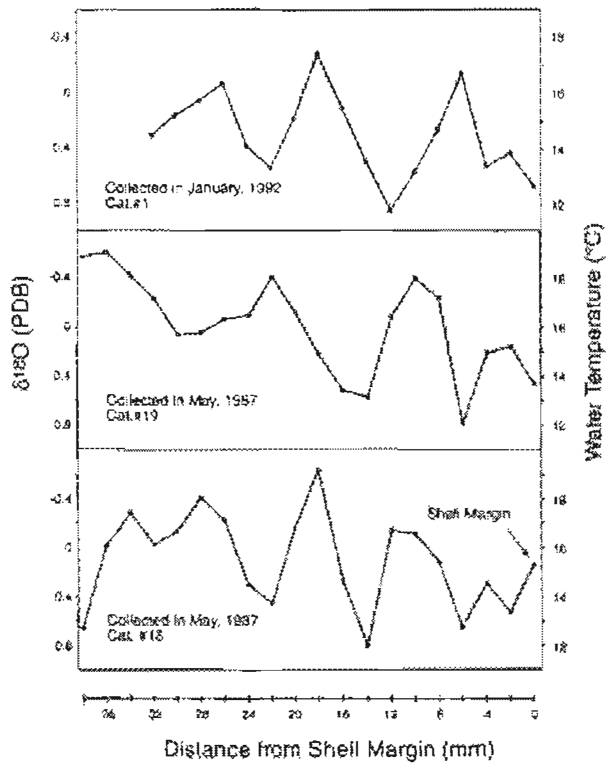

Figure 4. Oxygen isotopic variation of 3 modern *Mytilus californianus* collected in the intertidal zone 150 m west of archaeological site CA-SCRI-333 on western Santa Cruz Island. Temperature curve is calculated using the equation of Epstein et al. (1951, 1953; also see Craig et al. 1965) as applied to the calcite of *M. californianus* by Killingley and Berger (1979). Shell margins, representing time of collection, are shown to the right.

Table 1. Surface water temperatures adjacent to north-central Santa Cruz Island for the 11-yr period between 1982 and 1992 (data provided by J. M. Engle).

Year	Mean	Maximum	Minimum	Range
1982	15.17	18.9	12.4	6.5
1983	16.97	20.5	14.1	6.4
1984	16.23	20.6	13.7	6.9
1985	15.25	18.1	13.0	5.1
1986	15.89	17.8	14.0	3.8
1987	15.93	18.5	13.5	5.0
1988	15.36	18.1	13.4	4.7
1989	15.09	17.6	12.3	5.3
1990	16.03	18.6	13.1	5.5
1991	15.00	17.2	12.9	4.3
1992	16.52	18.4	14.0	4.4
Average	15.77	–	–	5.3

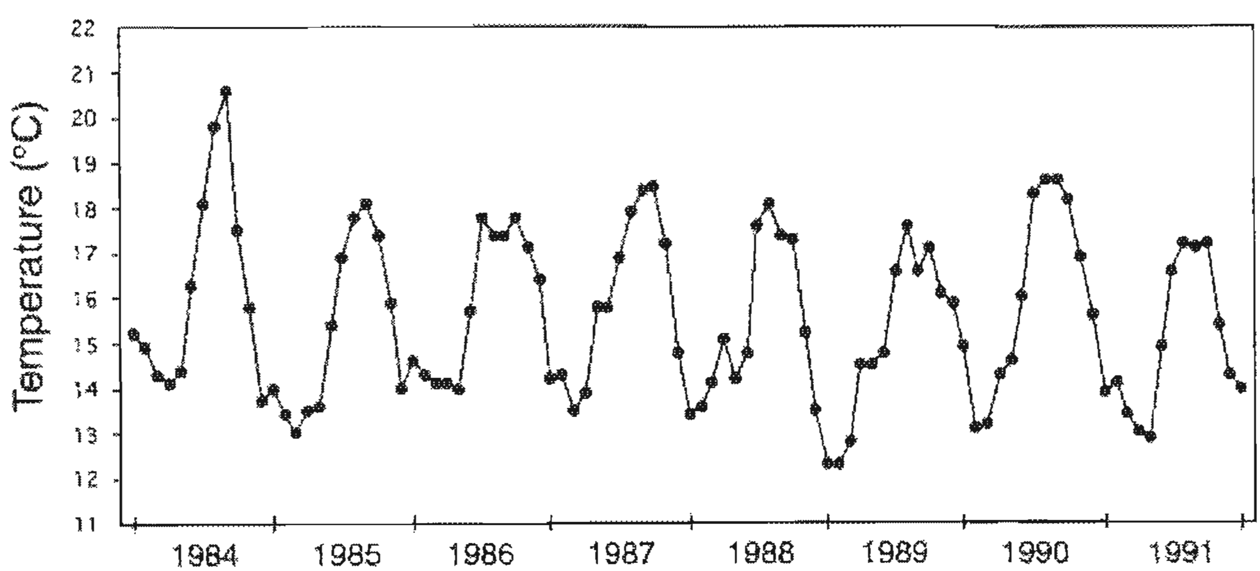

Figure 5. Monthly surface water temperatures for north central Santa Cruz Island between January 1984 and January 1992 (data provided by J. M. Engle).

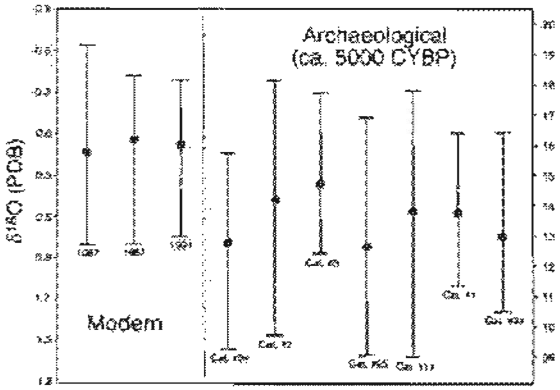

Figure 6. Range and mean $\delta^{18}O$ values of the 3 modern and 7 archaeological specimens of *Mytilus californianus* analyzed in this investigation.

A comparison between the oxygen isotopic profiles of the 2 shells collected in 1987 is also instructive. Not only do the values of respective peaks vary slightly, but proportional distances between peaks vary (Fig. 4). Two factors probably account for these differences: position of samples and differences in growth rates from one year to the next.

The average isotopic temperature values represented by each of the archaeological shells is significantly lower than either the average isotopic temperature of the modern shells (Fig. 6) or the directly measured average annual sea-surface temperature of north-central Santa Cruz Island between 1982 and 1992 (Fig. 5). Specifically, the average of all temperature values derived from the 7 archaeological shells is 12.9° C, whereas the average temperature of all values derived from the 3 modern shells is 15.5° C and the 11-yr Santa Cruz Island surface water-temperature record is 15.8° C. These data indicate that the average intertidal water temperature at the time the red-abalone midden was deposited at Site CA-SCRI-333 was ~2.5° C cooler than today.

The total range of temperature variation in 3 of the 7 archaeological shell profiles (shells 1x, 2, and 25) is relatively large (~7.8–8.8° C; $\delta^{18}O$ 1.84–1.92), whereas the total modern temperature range is smaller (~5.2–6.7° C; Fig. 6). The other archaeological shells exhibit ranges similar to those of the present day. These data suggest greater seasonal water- temperature extremes and interannual variation during the middle Holocene compared with today.

Two criteria are applied in inferring season of collection. The first is the relationship between the temperature value at the shell margin and the temperature range represented along the full length of the shell profile. For example, shell margin temperature values close to the maximum or minimum record collection during the warmest or coldest months, respectively. The second criterion is the direction of temperature change close to the

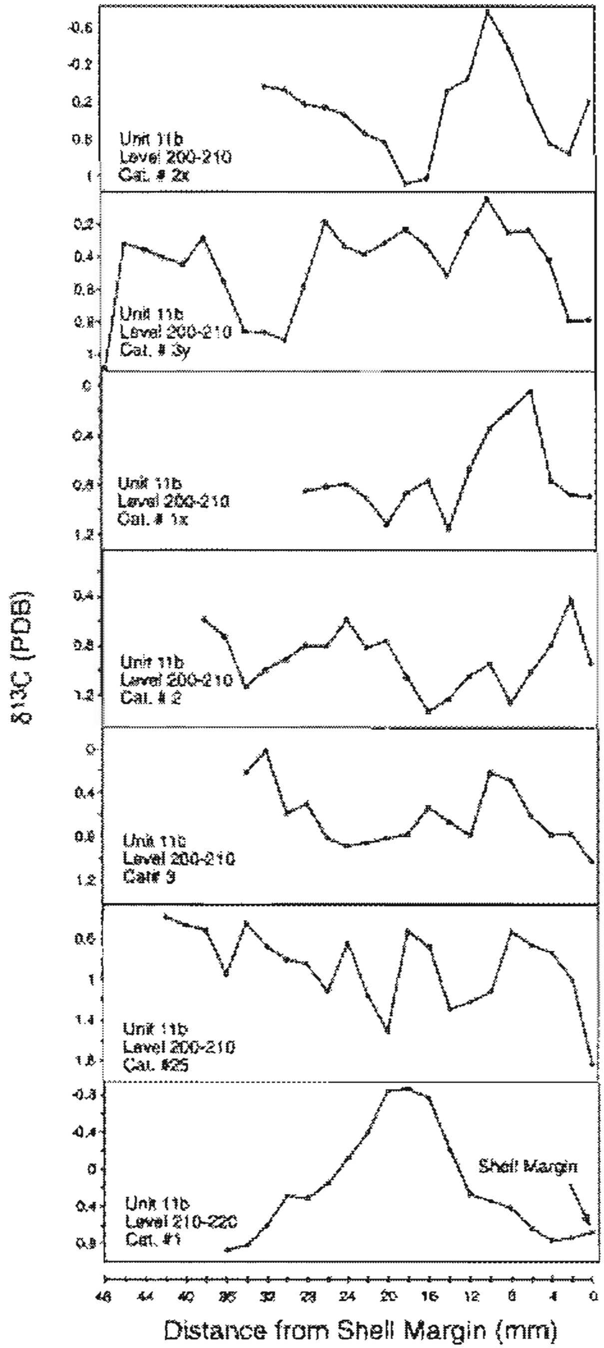

Figure 7. Carbon isotopic ($\delta^{13}C$) variation along the growth axis of 7 shells of *Mytilus californianus* collected from red abalone-rich levels (200–220 cm) in a prehistoric shell midden (Site CA-SCRI-333) on western Santa Cruz Island. Calcite samples taken every 2 mm along growth axis. Carbon isotope values are relative to Pee Dee Belemnite (PDB). Shell margins, representing time of collection, are shown to the right.

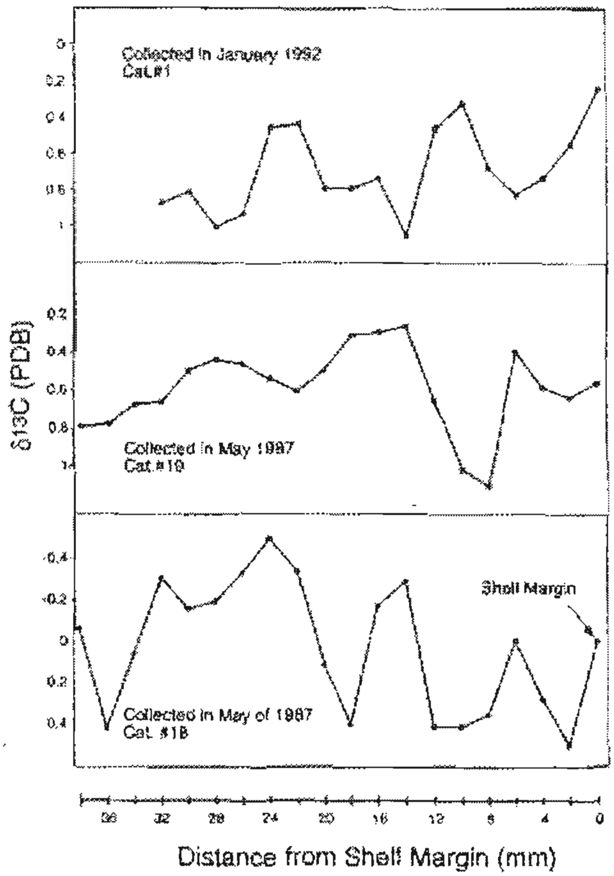

Figure 8. Carbon isotope ($\delta^{13}C$) variation of 3 modern *Mytilus californianus* collected in the intertidal zone of western Santa Cruz Island 150 m west of Site CA-SCRI-333. Shell margins, representing time of collection, are shown to the right.

shell margin. Increasing $\delta^{18}O$ values toward the shell margin indicate decreasing temperatures toward cooler months. Decreasing values toward the shell margin are indicative of increasing temperatures toward warmer months. Shell margin values of shells 1, 2x, 3, and 25 (Fig. 3) indicate collection during cold months, shell 1x in late fall, and shells 2 and 3y probably during summer. Thus, it is clear that the shells were collected at different times throughout the year.

Variation in carbon isotopic ($\delta^{13}C$) values across the shell profiles are cyclic like the oxygen isotopic record (Figs. 7 and 8). Oxygen and carbon isotopic changes are inversely correlated in the modern shells (Figs. 4 and 7). This suggests regular seasonal variation in upwelling strength and also maximum upwelling during the spring. Such an inverse relationship is not evident in the archaeological shells (Figs. 3 and 8). In the profiles of shells 2x, 3, and 25, a majority of the high values in $\delta^{13}C$ correlate with relatively cool temperatures. However, in shells 1 and 1x high $\delta^{13}C$ values generally occur at times of increasing temperature. The other shell profiles show no correlations between changes in the oxygen and carbon isotopic record.

Discussion

The oxygen isotopic data indicate that the red-abalone middens of the northern Channel Islands accumulated during a period or periods when intertidal water temperatures were ~2.5° C cooler than today. Such cool surface water temperatures are typical of present-day southern Monterey Bay (Scripps 1973–1983). Cool water temperatures suggest that the Santa Barbara region was under greater influence of the cool California current from the north rather than the warm-water Davidson current from the south. It is therefore likely that red abalone-rich deposits that accumulated at different times during the Holocene also indicate cool water conditions.

Glassow (1993a) proposed that the accumulation of red-abalone middens of the northern Channel Islands resulted from rapid expansion of prehistoric peoples during this cool middle Holocene interval (~5,500–4,500 CYBP). Extending this proposal, we suggest that a change from relatively warm conditions (>20° C) of the early Holocene to cooling during the middle Holocene stimulated productivity of intertidal invertebrate communities. This provided critical food resources that stimulated human population growth. Indeed, it is possible that the warm conditions prior to 5,500 CYBP had significantly reduced the productivity of both abalones and California mussels. At the present time, California mussels are not very abundant on the southern Channel Islands (except San Nicolas Island), where surface water temperatures are higher than in the Santa Barbara Channel. Such temperatures are similar to those of the early Holocene before 5,500 CYBP (Pisias 1978). Food resources from the intertidal zone would have been relatively poor if mussels were rare and slow-growing. A lack of dense shell middens of several meters' thickness on the southern Channel Islands suggests such low productivity during the Holocene and attests to the relative importance of mussels as a food resource in the north.

The results of our study also reveal that seasonal cyclic variations in oxygen and carbon isotopes are clearly recorded in archaeological mussel shells. The detailed character of the annual cycles is not always completely defined because of the sample resolution. A minimum of 8–10 calcite samples appear necessary for adequate definition of an annual cycle. Either shorter-interval sampling is required, or analyses need to be conducted on shells that grew more rapidly. We suspect that mussels collected prehistorically from optimal habitats (i.e., lower intertidal zones) would best meet this criterion. The resolution of annual cycles identified for a shell profile determines the level of confidence in identifying season of collection.

Both the carbon and oxygen isotopic profiles exhibit greater seasonal and interannual variability compared with modern shells. A greater oxygen isotopic range in 3 of the 7 archaeological shells compared with modern shells suggests that annual variation in temperature was greater than today. Greater variation is also indicated by the mean annual oxygen isotopic temperatures in the archaeological specimens compared with the present day. Mean ocean temperature has been relatively stable during the last decade (Fig. 5). It appears, therefore, that the strength of currents influencing the California Bight from the north and south varied more than today, implying greater climatic variability.

The calibrated radiocarbon dates for the red-abalone midden at Site CA-SCRI-333 (~5,700–5,000 CYBP) reveal a lack of detailed correlation between the middle Holocene cool intervals identified on Santa Cruz Island and the Santa Barbara Basin sediment core (Pisias 1978). Three factors may account for this discrepancy. First, the combined counting and calibration error associated with each of the 2 radiocarbon dates is between 150 and 200 yr at 1 σ standard deviation. Second, the reservoir correction for the dates is only approximate, and could be as much as a few hundred yr in error. Third, the chronology of Pisias (1978) was based on discontinuous varve counts in the absence of radiocarbon dating. Despite these difficulties, we suggest that the red-abalone midden at Site CA-SCRI-333, and most others elsewhere on the island, accumulated during the cool interval between 5,400 and 5,200 CYBP recognized by Pisias (1978). However, some middens may have been deposited during later cooler intervals (~4,300 or ~4,500 CYBP).

Seasonal cycles are clearly exhibited in the carbon isotopic profiles of modern California mussels (Fig. 7). Comparison of carbon and oxygen isotopic variation in the modern shells clearly shows that lower $\delta^{13}C$ values occur during cooler-water months (Figs. 4 and 7). Killingley and Berger (1979) have shown that seasonal $\delta^{13}C$ cycles in *M. californianus* in southern California are related to upwelling cycles of nutrient-rich waters. Relatively low $\delta^{13}C$ values reflect higher rates of upwelling. Based on the stable isotopic and associated oceanographic records, they also show that higher upwelling rates occurred during spring and early summer months, peaking between May and June. Upwelling subsided during July and August at the time of highest ocean temperatures. The isotopic relations exhibited in the modern shells from Santa Cruz Island suggest that maximum upwelling occurs during coolest months and is minimal during warm months. It appears, therefore, that the timing of modern seasonal upwelling between the two regions is similar.

Relations are more complex between carbon and oxygen isotopic fluctuations recorded in the archaeological specimens. Although the $\delta^{13}C$ oscillations are clearly seasonal, there is much more variation in the timing of inferred upwelling based on low $\delta^{13}C$ values. This suggests that the timing of upwelling was highly variable. If so, times of higher biological productivity in surface waters would have been less predictable for people exploiting seasonal marine food resources.

Conclusions

The results of our isotopic analyses indicate that intertidal sea-water temperatures on western Santa Cruz Island were approximately 2.5° C cooler in the middle Holocene during accumulation of the red-abalone middens at Site CA-SCRI-333 and elsewhere on the northern Channel Islands. This cooling was of sufficient magnitude to create large changes in intertidal biota. As a result, red abalones temporarily became an important food resource for local human populations. Other marine foods likewise may have been affected by the cooling. Red abalone abundance may therefore signal broader changes in food resource availability and resulting subsistence practices. The larger implication of our investigation is that changes in the southern Californian marine environment during the Holocene were of sufficient magnitude to influence human maritime adaptations.

This hypothesis differs from that of Salls (1992), who suggested that environmental change during the Holocene was of insufficient magnitude to have caused changes in shellfish exploitation. He proposed that the black abalone was avoided early in Santa Barbara Channel Holocene prehistory because of difficulties in preparing its tough meat for consumption; red abalone was more easily prepared for cooking. Thus, this species was preferred, even though diving was required for its collection at subtidal depths. It is not clear, however, why prehistoric peoples would have abandoned diving for red abalones in favor of collecting black abalones in the intertidal zone. Implicit in Salls' (1992) argument is that red abalones became overexploited. If so, overexploitation would have continued after ~4,500 CYBP, and red-abalone shells would occur in varying abundances in later midden deposits, which is not the case. Salls (1992) also suggested that black abalones may have become rare during the early Holocene because of viral disease restricted to this species. However, there is no evidence that this disease persisted for several thousand years. The stable isotopic data presented in this paper, instead, strongly support the hypothesis that ocean cooling during the middle Holocene led to changes in shellfish exploitation by prehistoric maritime peoples of southern California.

None of the known red-abalone middens of Santa Cruz Island dates to the interval between ~7,300 and 5,900 CYBP. Furthermore, these red-abalone middens are either basal layers of sites occupied later in time or isolated strata in alluvial or dune deposits. This suggests that relatively few humans occupied Santa Cruz Island between ~7,300 and 5,900 CYBP. Such inferred low population density may have been related to relatively warm ocean conditions throughout this interval (Pisias 1978). The high temperatures may have caused decreased intertidal shellfish productivity, lower marine food resources, and reduced accumulation of shell middens. Santa Cruz Island midden deposits older than ~3,000 CYBP are dominated by shellfish remains, reflecting their overriding importance as a food resource (Glassow 1993b). Thus, it would not be surprising that island coastal areas were only sparsely occupied if early Holocene ocean warmth suppressed the productivity of intertidal shellfish.

Our data suggest a greater range of ocean-temperature variation at about 5,000 yr ago compared with today. This pattern needs to be verified by stable isotopic analyses of greater numbers of shells at different intervals during the Holocene.

Oxygen isotopic analysis of archaeological shells provides an independent source of paleotemperature data and, indirectly, additional chronological information. This has assisted correlation of prehistoric occupation data with existing sea-surface paleotemperature records (Pisias 1978). Additional stable isotopic and radiocarbon analyses will lead to further improvements in the chronology of paleoenvironmental change and understanding of the prehistory of maritime peoples of the southern Californian region.

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