The Analysis of Stable Isotopes from California Coastal Archaeological Sites: Implications for Understanding Human Cultural Developments and Environmental Change

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The analysis of stable isotopes from a variety of materials has revolutionized our understanding of ancient nvironmental and cultural change. Stable oxygen isotope analysis of marine shells, for example, provides important information on ancient sea surface temperatures, the presence of El Niño events, and seasonality data. Although several studies have analyzed stable isotopes from California archaeological sites, the technique remains under-explored. Through preliminary stable isotope analysis of California mussel and red and black abalone shells from two sites on Santa Rosa and San Miguel islands, we demonstrate the significance of these data for documenting cultural and environmental change.

Several researchers have conducted stable isotopic analysis of shell, bone, and other materials from coastal California archaeological sites (e.g., Burton et al. 2002; Glassow et al. 1994; Goldberg 1993; Jones and Kennett 1999; Kennett 2003, 2005; Koerper and Killingly 1998; Newsome et al. 2004). This technique has proven especially useful as a way to understand paleoenvironmental conditions (e.g. sea surface temperature [SST]), site seasonality, and human subsistence. Although these studies have demonstrated the utility and importance of this technique, stable isotopic analysis remains an underused analytical tool despite becoming increasingly affordable over the years. Presented here are a variety of isotope data gathered from California mussel (*Mytilus californianus*) and red and black abalone (*Haliotis rufescens* and *H. cracherodii*) shells from California Channel Island middens. These data demonstrate the potential for using stable isotopic studies as a routine part of midden analysis for California archaeological sites.Stable Isotopes: Methods and Applications

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Coastal sites are often typified by shell middens, dense layers of shellfish and other faunal remains from short- or long-term harvesting episodes. These shells are composed of calcium carbonate, which can yield isotopic values for both carbon and oxygen (McCrea 1950). Oxygen values are the most helpful for marine-based studies, as they can be directly linked to marine temperatures at the time of carbonate crystallization (Epstein 1951; Epstein et al. 1953; Grossman and Ku 1986). This temperature-focused work has been conducted on species such as California mussel (Glassow et al. 1994; Kennett 2003, 2005) and foraminifera (Kennett 2005; Kennett and Kennett 2000) to determine temperature fluctuations throughout the Holocene (see Kennett 2005). Oxygen isotopes are affected by more than simply water temperature at the time of crystallization; they also provide information about water characteristics like (Seward 1978). Carbon and nitrogen also provide interesting data that can help document aspects of human subsistence, environmental change, and foraging behavior (e.g., Burton et al. 2002; Goldberg 1993; Newsome et al. 2004).

Here, three shellfish species (California mussel and red and black abalone) are tested to observe the temperatures at which these species were living. These data help establish if there was any difference in the bathymetric positioning of the species (i.e., intertidal vs. subtidal), and also help infer any associated human subsistence strategies.

Care must be taken when dealing with shellfish materials, however, as they may yield erroneous results if mishandled or misunderstood. The McCrea method (1950) requires that samples be prepared prior to acidification and CO_2 sequestration to ensure the removal of organic carbons and diagenetic secondary crystallization that may alter the isotopic values and give false results. A variety of methods have been used to combat these problems, but no formal consensus has been reached for how materials should be handled prior to running through the carbonate line. Diagenetic effects can be cured primarily by a vigorous surface scrape to remove the upper layer of calcite (after removal of the periostracum). Some researchers have used an HCl solution to accomplish this task, but the porous nature of the shells studied and the lack of prejudice for HCl dissolving primary or secondary carbonates make this potentially problematic. Organic carbons may be removed by immersion in a 1.5 percent sodium hypochlorite solution for at least 24 hours. A combination of surface scrapes and sodium hypochlorite baths should remove most, if not all, diagenetic effects and any organic matter present.

Drilling strategies differ depending on research goals, but generally should be done with a focus on preventing sample contamination and alteration. Avoiding mixing carbonate species (such as calcite and aragonite; see Kennett 2003; Rick et al. 2006) and drilling at low speeds to avoid high temperatures (lowering the risk of altering minerals such as calcite) will ensure more accurate results. For organisms with mixed carbonate shells (such as mussels and abalones that lay down both inner aragonite and outer calcite layers), it is important to sample only the outer calcite part of the shell. The shell interior is subject to an isolated environment that may skew isotopic results and should be avoided (see Keith et al. 1964; Rick et al. 2006).

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To demonstrate the utility of stable isotope analysis, we present data collected from three species of shellfish from CA-SRI-191, located on eastern Santa Rosa Island (see Rick et al. 2006) and SMI-172, found on the eastern tip of San Miguel Island (Figure 1). Two middens are present at SRI-191, a red abalone midden dated to 6120 to 5840 cal BP (Unit 1) and a mussel and urchin deposit dated to 4400 to 4260 cal B.P. (Unit 2; see Rick et al. 2006). SMI-172 represents a single-component red abalone midden dated between about 6440 and 6270 cal B.P. The shells tested (California mussel and black and red abalone from SRI-191; California mussel and red abalone from SMI-172) were prepared in the manner discussed above, and drilled in a way that ensured the collection of exterior calcite only, using a Merchantek MicroMill with a carbide bur bit. Powdered samples were run through a carbonate line according to the McCrea method (1950), and sequestered CO_2 was run through a Finnigan MAT 252 mass spectrometer. Results are reported as ä-values in permil (‰) notation on the PDB scale (Table 1). Temperatures were derived using the Epstein et al. (1953) equation for calcite (equation 1), using a water value of -.32 permil (based on an ocean water sample taken from the mouth of Old Ranch Canyon, Santa Rosa Island).

$$T(°C) = 16.4 - 4.2(\delta^{8}O_{cc(PDB)} - \delta^{18}O_{water(SMOW)}) + .13(\delta^{18}O_{cc(PDB)} - \delta^{18}O_{water(SMOW)})^2 \quad \text{(equation 1)}$$

Carbon and oxygen isotopic values and inferred temperatures obtained from the shells from SRI-191 and SMI-172 are plotted in Figure 2. Note the wide range of values exhibited by California mussel. This is due to the diversity of temperatures that mussels are capable of feeding in. Their values generally do not, however, overlap with those of red abalone to any significant degree. Increasing ˜-values for oxygen correspond to decreasing temperature values, demonstrating that the red abalones generally lived in a cooler temperature region, and therefore were deeper than the California mussels. Black abalones fit in between these two species at SRI-191. In the Santa Barbara Channel today, California mussels are often found in the intertidal zone near the surface, while black and red abalones are intertidal and subtidal, respectively (Ault 1985; Shaw et al. 1988). All three species, however, may occasionally overlap in these habitats (Ault 1985; Morris et al. 1980). The isotopic values and corresponding temperatures are similar with the modern habitation zones of these shellfish, suggesting that people at SRI-191 and SMI-172 exploited both the intertidal and shallow subtidal zones to obtain shellfish.

Isotopic values and their associated temperatures for California mussel from the two units at SRI-191 are given in Table 1. There is an average difference of nearly 2° C between the temperatures exhibited by mussels found in the red abalone midden versus those from the mussel and urchin midden (Unit 2). These data illustrate a change in SST between occupations of the site on the order of those recorded by Kennett (2005; Kennett et al. 2006) using foraminiferal data.

Individual shells from Unit 1 at SRI-191 show relatively limited variability, with a range of 10.8° to 14° C. This is in great contrast to the three mussels tested from Unit 2, which have a temperature range of 10.5° to 17.0° C. The second shell of Unit 2 (TMSBSI2) shows over 6° C of variability throughout the isotopic history of the shell. These short-term temperature fluctuations may be evidence of greater El Niño frequency after about 5,000 years ago, though more work must be done to test this. Elsewhere it has been argued that El Niño was reduced during much of the Middle Holocene (Sandweiss et al. 2001), but may have increased in the latter half around 5000-4000 cal BP (Kennett et al. 2006; Masters 2006). The lack of variability in temperature values from California mussels in Unit 1 (~6000 cal BP) compared to the great variability in Unit 2 (~4300 cal BP) suggests that El Niño may indeed have increased after 4500 cal BP. These data suggest that fluctuations in El Niño frequencies over time may be recorded archaeologically and determined isotopically.

Figure 1: Map of San Miguel and Santa Rosa islands showing the location of the two sites discussed in the text.

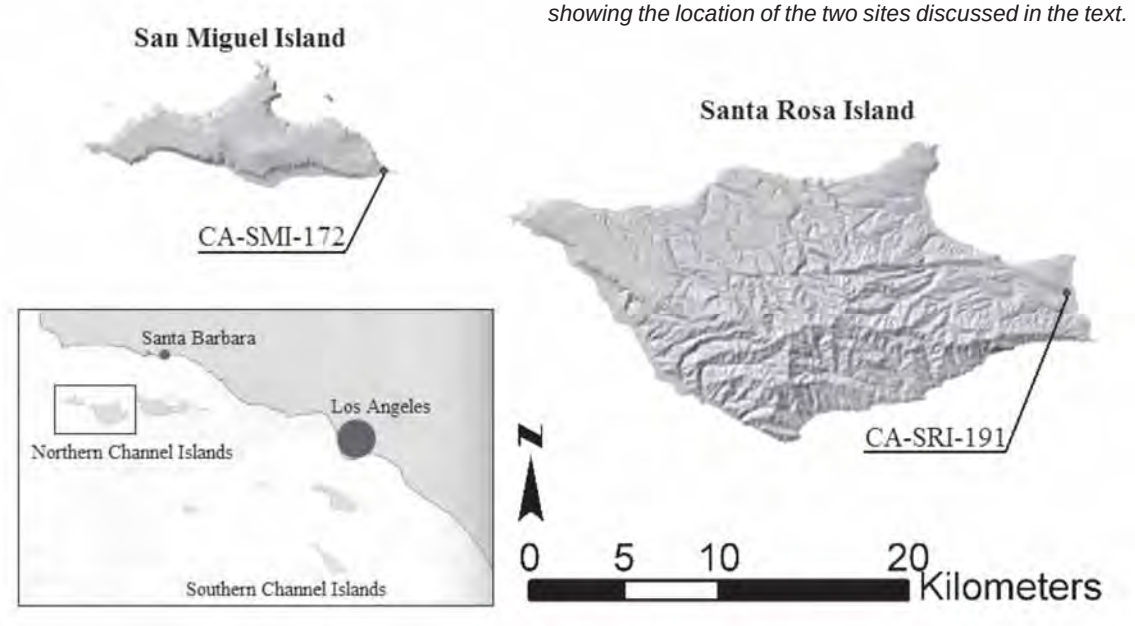

Table 1: Species, sample name, carbon and oxygen isotopic values, and inferred temperatures from sites SRI-191 and SMI-172.

Species	Sample #	$\delta^{13}C_{(PDB)}$	$\delta^{18}O_{(PDB)}$	Inferred T (°C)
Mytilus californianus Unit 1	TMSRAM1cA	2.1	.4	13.5
	TMSRAM1cB	2.0	.5	13.0
	TMSRAM1cC	2.5	.6	12.5
	TMSRAM1cD	2.3	.8	12.0
	TMSRAM1cE	2.5	.7	12.5
Mytilus californianus Unit 1	SRI191U1Cm2cc1	.5	.5	13.0
	SRI191U1Cm2cc2	.5	1.0	11.0
	SRI191U1Cm2cc3	.6	.7	12.0
	SRI191U1Cm2cc4	.4	1.1	11.0
	SRI191U1Cm2cc5	.2	1.1	12.0
Mytilus californianus Unit 1	SRI191U1Cm3cc1	.1	.3	14.0
	SRI191U1Cm3cc2	.1	.8	12.0
	SRI191U1Cm3cc3	.3	1.0	11.0
	SRI191U1Cm3cc4	.2	.9	11.5
	SRI191U1Cm3cc5	.5	.7	12.5
Mytilus californianus Unit 2	TMSBSI1cA	.8	1.1	10.5
	TMSBSI1cB	.4	.2	14.5
	TMSBSI1cC	.5	.3	14.0
	TMSBSI1cD	.6	.1	15.0
Mytilus californianus Unit 2	TMSBSI2cA	.9	-.1	15.5
	TMSBSI2cB	.5	1.0	11.0
	TMSBSI2cC	1.0	-.4	16.5
	TMSBSI2cD	.6	-.5	17.0
	TMSBSI2cE	.7	.5	13.0
Mytilus californianus Unit 2	TMSBSI3cA	-.4	-.1	15.5
	TMSBSI3cB	-.2	.3	14.0
	TMSBSI3cC	.8	.6	12.5
	TMSBSI3cD	.5	.4	13.5
	TMSBSI3cE	.8	.6	12.5
Haliotis cracherodii (Black abalone)	SRI191BA1c1	1.9	.4	13.5
	SRI191BA1c2	1.6	1.0	11.0
	SRI191BA1c3	1.0	1.5	9.0
	SRI191BA1c4	1.4	1.6	8.5
	SRI191BA1c5	1.8	1.4	9.5
Haliotis rufescens (Red abalone)	JASRAMTSc1	1.7	1.4	9.5
	JASRAMTSc2	1.4	1.7	8.5
	JASRAMTSc3	1.7	1.5	9.0
	JASRAMTSc4	1.5	2.2	6.5
	JASRAMTSc5	1.7	2.1	7.0
Haliotis rufescens (Red abalone)	JASRAMRA1c1	1.2	1.9	7.5
	JASRAMRA1c2	1.5	1.3	10.0
	JASRAMRA1c3	1.6	1.6	9.0
	JASRAMRA1c4	1.3	1.9	7.5
	JASRAMRA1c5	1.5	1.3	10.0
Haliotis rufescens (Red abalone)	JASRAMRA2c1	1.5	.9	11.5
	JASRAMRA2c2	1.4	2.3	6.5
	JASRAMRA2c3	.7	1.4	9.5
	JASRAMRA2c4	1.2	1.6	9.0
	JASRAMRA2c5	1.6	1.2	10.0
Mytilus californianus (California mussel)	JASSM172Mc1c1	1.0	.3	13.5
	JASSM172Mc1c2	1.3	.1	14.5
	JASSM172Mc1c3	1.2	.0	15.0
	JASSM172Mc1c4	1.3	.2	14.0
	JASSM172Mc1c5	1.2	.3	14.0
	JASSM172Mc1c6	1.2	.4	13.5
	JASSM172Mc1c7	1.3	.4	13.5
	JASSM172Mc1c8	1.4	.4	13.5
	JASSM172Mc1c9	1.3	.4	13.5
	JASSM172Mc1c10	1.0	-.5	17.5
Mytilus californianus (California mussel)	JASSM172Mc2c1	1.2	.3	14.0
	JASSM172Mc2c2	.5	.4	13.5
	JASSM172Mc2c3	.6	.9	11.5
	JASSM172Mc2c4	.8	.9	11.5
	JASSM172Mc2c5	.5	.6	13.0
Haliotis rufescens (Red abalone)	JASSM172RA1c1	2.4	.8	12.0
	JASSM172RA1c2	2.0	1.2	10.5
	JASSM172RA1c3	1.5	1.7	8.5
	JASSM172RA1c4	2.0	1.5	9.0
	JASSM172RA1c5	1.8	1.0	11.0
Haliotis rufescens (Red abalone)	JASSM172RA2c1	1.1	1.4	9.5
	JASSM172RA2c2	1.3	1.1	11.0
	JASSM172RA2c3	1.7	1.2	10.5
	JASSM172RA2c4	1.4	1.4	9.5
	JASSM172RA2c5	1.8	1.3	10.0

Carbon isotopic values for the California mussels from SMI-172 are tightly clustered, but the oxygen values demonstrate a wide array of temperatures (see Table 1). These values are within the same range as those from both strata of the SRI-191 dataset, suggesting similar SST at both sites. The red abalone values from SMI-172 cluster together closer than those of SRI-191, and are within the upper range of the SRI-191 abalones. Some values overlap with those of the black abalone from SRI-191, suggesting a low intertidal or shallow subtidal origin for this species. Due to the low variability of these values, it is more likely that they represent a deeper origin, however, and that the red abalones were not exposed to surf or open air conditions like their more variable, intertidal counterparts. While it is possible that inhabitants dove to the low intertidal or shallow subtidal zone for red abalones at SMI-172, the overlapping temperatures between these red abalones and the black abalone of SRI-191 may be result of changes in sea surface temperatures (see Glassow 1993; Glassow et al. 1994), lower El Niño frequencies (Kennett 2005), or red abalones entering the lower intertidal zone as a result of overpopulation (Erlandson et al. 2005:15). Additional information from intertidal, non-surf species (such as black abalone) and comparison with the ocean temperature regime for this part of the channel, however, are crucial to further test this assertion.

Discussion and Conclusions

The analysis of stable oxygen isotopes on three shellfish species from SRI-191 and two species from SMI-172 provide useful information concerning ancient SST while demonstrating the utility of stable isotope analyses. Through the analysis of multiple species and the paleotemperatures they infer, we argue that the inhabitants of SRI-191 exploited both the intertidal and shallow subtidal zones during the earlier occupation of the red abalone midden (~6000 cal B.P.). Between this time and the later occupation represented by the mussel and urchin midden (~4300 cal B.P.), a significant shift in subsistence strategies occurred that led to the abandonment of black and red abalones as a major food source (Rick et al. 2006). This change was likely triggered by environmental factors, most notably an increase in SST between the two occupations of the site and possibly increased El Niño frequencies. At SMI-172, the site inhabitants may have dived to the low intertidal or shallow subtidal (probably <5 m) zone for red abalones, although data from black abalones are necessary to confirm this assertion.

The preliminary data listed here demonstrate the importance of using stable isotopes as a standard practice in California archaeology. Paleotemperatures are helpful for determining a host of characteristics, especially environmental developments and changes in human subsistence. Many researchers in this region have conducted isotopic studies (Burton et al. 2002; Glassow et al. 1994; Kennett 1998; 2003, 2005; Koerper and Killingley 1998; Newsome et al. 2004), but intensive, diachronic studies are rare. Stable isotopes can have a variety of uses aside from paleotemperature studies, including salinity (oxygen), diet (carbon), and trophic analyses (nitrogen), each of which are very

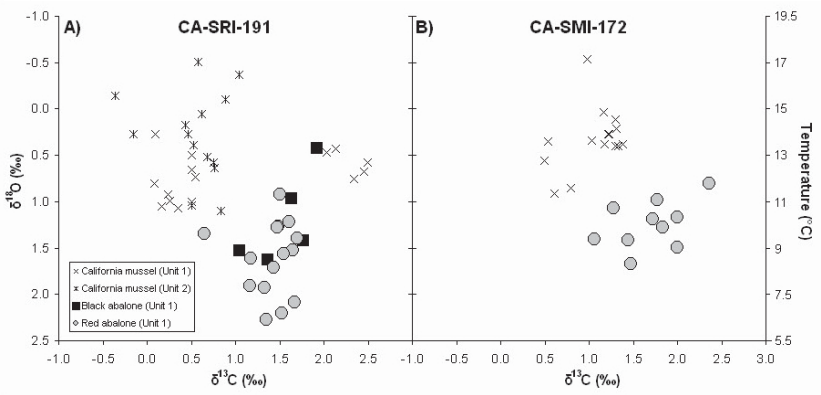

Figure 2: Oxygen and carbon isotopic values obtained from three shellfish species from SRI-191 (a) and two species from SMI-172 (b) as well as inferred temperatures. Note the separation between red abalones and California mussels at both sites, along with the overlap of the black abalone from SRI-191 with red abalone temperatures.

useful for better interpreting the rich and diverse archaeological record of California. Moreover, stable isotope studies have become increasingly less costly over the years, making them an inexpensive analytical tool that can yield large amounts of information. This type of analysis should become a standard practice for archaeologists working in California and beyond and has the potential to dramatically enrich our understanding of the rich human past of the region.

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