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Stable Isotope Provenance Analysis of *Olivella* Shell Beads From the Los Angeles Basin and San Nicolas Island

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ABSTRACT

Production of marine shell beads in island and coastal settings was an important activity in prehistory, with important political and economic ties. Currently, there are few methods to track beads to their locus of production. Examining the spatial distribution of bead types provides one method of doing so. Chemical and stable isotopic methods provide an additional and independent means of testing hypotheses generated by spatial distributions. We use stable oxygen, carbon, and strontium isotope data to reconstruct provenance zones for 18 Olivella biplicata *beads from the Los Angeles Basin and San Nicolas Island, California. We compare the results to isotopic data from modern and radiocarbon-dated whole shells collected along the Pacific Coast. Results indicate that all 18 beads were manufactured from shells growing in open coast locations south*

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of Point Conception. Differences in isotopic composition between bead types suggest that not all were produced in the same location. Some, such as callus beads (K1), have highly variable composition, suggesting production in a range of locations. Others, such as thin lipped (E1), seem to have been produced in more restricted regions.

Keywords Southern California, bead production, *Olivella biplicata*

Tracing the movement of material goods through ancient societies allows archaeologists to examine one facet of interaction and trade between past groups of people. In California, chemical sourcing of lithics, especially obsidian, has been the main way this topic has been approached. However, the continued development of techniques for sourcing other materials, including basalt and ceramics (e.g., Eerkens et al., 2002; Latham et al., 1992; Waechter 2002), offers means to complement obsidian studies in this regard.

In California, shell beads are a visible component of the archaeological record that also inform on ancient interaction (Arnold 1987, 1991; Arnold and Munns 1994; Bennyhoff and Hughes 1987; Fitzgerald et al., 2005; Kennett 2005; King 1990; Vellanoweth 2001). Although it is possible to source shell beads back to geographic regions based on the biogeography of the species they were made from (e.g., Nelson 1991), at least two factors limit the usefulness of such an approach. First, bead production often removes many of the attributes that might allow identification of particular species. Second, even if species can be identified, many shellfish are found across large geographic areas. For example, the purple olive snail (*Olivella biplicata*) so commonly used to produce beads in California, can be found from Baja California all the way to Canada along the Pacific Ocean. Identifying such a large source zone for a bead limits the interpretive potential for reconstructing ancient interaction.

Chemical methods offer one possibility for narrowing the source zone for such beads. Our previous research using oxygen and carbon stable isotope data (Eerkens et al., 2005, 2007) sought to develop such a method for *Olivella* beads. Our approach takes advantage of the fact that ocean temperatures show a north-south gradient along the Pacific Coast, and that these temperatures affect the fractionation of oxygen isotopes in shell carbonate. We build upon that approach to examine possible production sources of beads excavated from southern California archaeological sites.

BACKGROUND AND APPROACH

Figure 1 shows sea-surface temperature (SST) data collected at weather stations along the Pacific coast, from southern California to Washington, showing latitude plotted against average monthly maximums (summer) and minimums (winter), and annual averages (the average of monthly averages), in degrees C. All stations are within 1km of the shore and data are available online (http://shorestation.ucsd.edu).

The figure separates stations from southern California that are south of Point Conception (at 34.5 degrees latitude), from those north of this point. There is slight overlap in the average winter SST in southern California and average summer SST in northern California. However, annual averages do not overlap, and summer SST in southern California (always averaging over 18C) and winter SST in northern California (always averaging under 12.5C) are highly distinctive. These differences are controlled by currents carrying water along the coast. The California Current flows south along the western margin of North America bringing cold North Pacific waters along the coastlines of Washington, Oregon, and northern California. In southern California, the California Current operates only in spring and early summer. During the remainder of the year, the Davidson Counter Current advects warm subtropical water from the south (Bemis

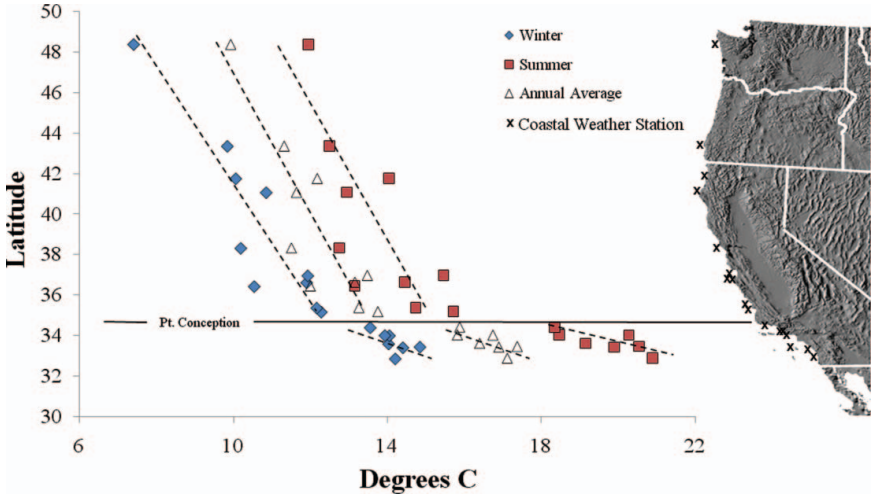

Figure 1. *Latitude vs. average winter, summer, and annual SST along the North American Pacific Coast.*

et al., 2002) into the Santa Barbara Basin. The two currents converge at Point Conception.

Not only are there distinctions between southern and northern California, but gradual differences exist within these two regions (Figure 1). Overall, temperatures decrease nearly monotonically with increasing latitude. In northern California, temperatures decrease more gradually with increasing latitude. As well, there is greater variation about the regression line, indicating greater effects of local conditions. In southern California, temperature decreases much more rapidly with latitude (but more slowly with longitude), and there is less variation about the line.

Not surprisingly, analyses of oxygen isotope data collected from 25 modern *Olivella biplicata* shells at 17 locations along the California and Oregon coasts (with one additional shell from the Gulf of California) mirror these results. This is because temperature is the primary environmental control on $\delta^{18}O$, and our previous work (Eerkens et al., 2005) showed that *O. biplicata* faithfully records a SST signal in its aragonitic shell. Sequential samples taken along growth lines of shells show seasonal patterns of increasing (spring-summer) and decreasing (winter-spring) oscillations that track seasonal changes in SST. For example, Figure 2 shows $\delta^{18}O$ ($^{18}O/^{16}O$) and $\delta^{13}C$ ($^{13}C/^{12}C$) isotope ratios for a modern *Olivella* shell collected from NAVFAC Beach on San Nicolas Island. The graph shows an oscillating curve where oxygen isotopes temporally lag behind corresponding carbon isotopes, suggesting upwelling (lower $\delta^{13}C$) is closely followed by lower SST (higher $\delta^{18}O$). These patterns are consistent with our knowledge of seasonality in upwelling and SST at these locations. Nearly three years of growth are represented in the 27 sequential samples we analyzed. We deduce that this *Olivella* died sometime during the spring (in the time leading from winter into summer).

Figure 3 shows average oxygen isotope values for the 25 modern shells, plotted against latitude. As in Figure 2, multiple samples were collected per shell (an average of 18), and the figure plots the shell average, as indicated by a symbol, and two standard deviations from this average, as indicated by horizontal bars. Shells from the same collection area and latitude were averaged, producing 17 distinct points in the graph. Because $\delta^{18}O$ is affected by both water temperature and salinity (due to the relationship between salinity and $\delta^{18}O_{seawater}$; see

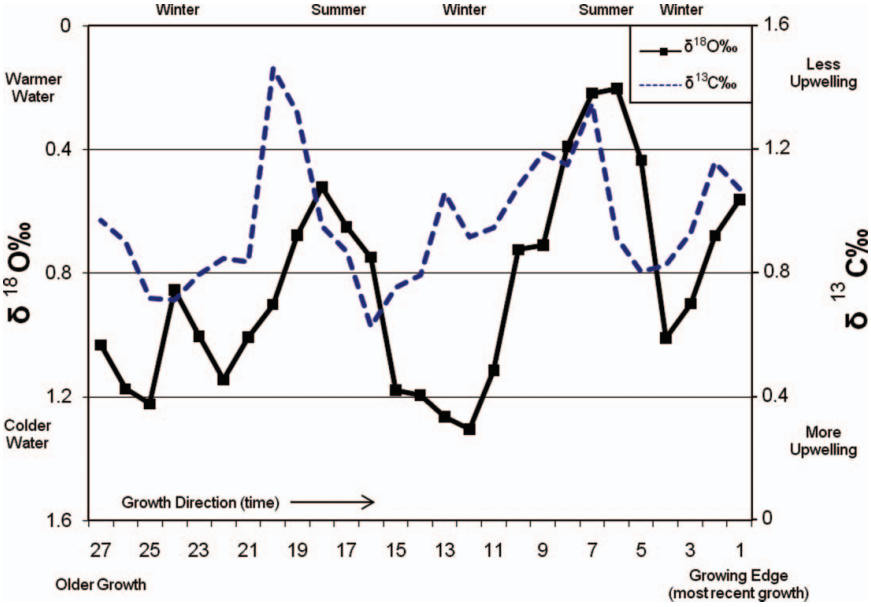

Figure 2. *Sequential sampling of a modern* Olivella biplicata *shell from San Nicolas Island across growth lines, showing seasonal fluctuations in $\delta^{18}O$ and $\delta^{13}C$.*

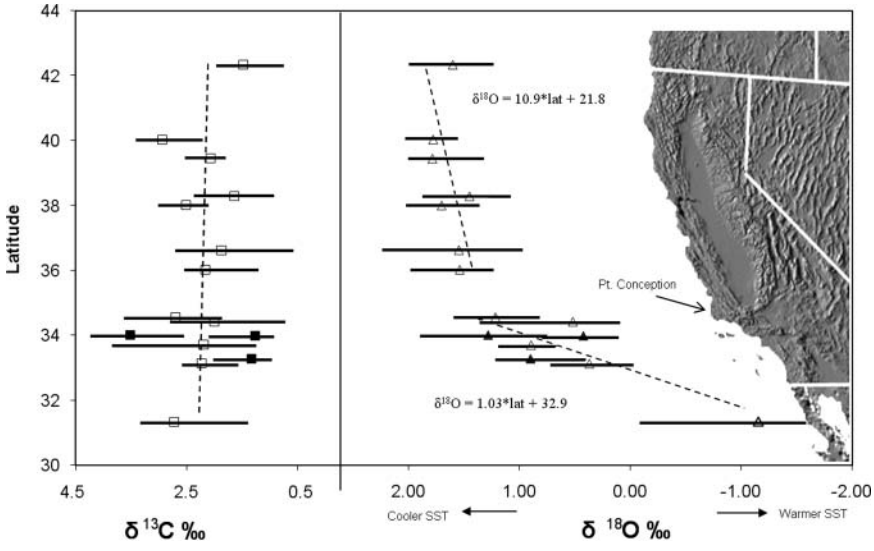

Figure 3. *$\delta^{13}C$ and $\delta^{18}O$ in modern* Olivella *shells plotted against latitude. Squares and triangles indicate medians, for carbon and oxygen respectively, and horizontal bars show .1 and .9 percentiles. Filled-in symbols indicate Channel Island samples. Dashed lines are regressions through latitudinal means.*

Schmidt et al., 1999), there is slightly greater variation in these shell data than that seen in Figure 1. However, the distinctions between southern and northern California are clearly maintained, and a gradual increase in $\delta^{18}O$ with latitude is visible. Also shown in Figure 3 are average $\delta^{13}C$ isotope data, which show little change with latitude along the California Coast.

Methods and Sample: C and O Isotopes

Eighteen shell beads recovered from three archaeological sites in Southern California were analyzed for their oxygen and carbon isotope values in an attempt to determine their regional source. Two of these sites are in the Ballona wetlands of the Los Angeles Basin, CA-LAN-62 (n = 10 beads) and CA-LAN-211 (n = 3 beads) (for more information see Altschul et al., 2003). The third is on San Nicolas Island CA-SNI-39 (n = 5 beads; for more information see Fagan et al., 2006). The beads represent a range of standard types (n = 5) as defined by Bennyhoff and Hughes (1987).

Rather than take a single isotopic measurement per bead, we sampled each specimen at multiple points along the growth rings to obtain complete seasonal information in order to more completely interpret the isotope data. For example, sampling along multiple bands allows us to examine the covariance in oxygen-carbon isotope patterns (e.g., whether both geochemical signals increased, both decreased, or one increased and one decreased). It also provides a greater chance of capturing a distinctive season of growth, for example, summer in southern California, which is particularly warm, and winter in northern California, which is distinctively cold.

Powdered carbonate samples were drilled from the shell surface in shallow grooves (<0.3 mm deep) which ran parallel to the growth lines using a 0.5 mm bit attached to a hand-held drill. Powdered carbonate samples ranged from 50 to 80 μg in weight. For whole shells, sampling began at the *Olivella* shell lip (most recent growth) and continued until we reached the parietal callus (earlier growth), and included at least one complete whorl revolution. The linear distance between samples ranged from 1.0 mm to 2.0 mm. The analysis of beads required determining the axis of growth, orienting the artifacts in the same way as complete shells, and making sure to sample consecutive growth bands. The number of isotopic samples depended largely on the size of the bead and the number of growth bands present.

Samples for isotopic analysis were processed in the stable isotope laboratory at UC Davis on a Micromass Optima isotope ratio mass spectrometer (IRMS). Prior to analysis on the IRMS, powdered aragonite samples were gently heated at 75°C in vacuo for 30 minutes to remove adsorbed water and subsequently reacted in 105% orthophosphoric acid at 90°C using an ISOCARB automated common acid bath system. The resulting CO_2 was then purified through a series of cryotraps and introduced into the IRMS through a dual inlet system.

Stable isotopic ratios are presented as the per mil (parts per thousand ‰) deviation from the Vienna-Standard Mean Ocean Water (V-SMOW) or Pee Dee Belemnite (PDB) standard. External precision for $\delta^{18}O$ and $\delta^{13}C$ values is ± 0.09 and ± 0.07 (one standard deviation), respectively, based on multiple (N = 138) analyses of the calcite standards NBS-19 and UCD-SM92. The precision for $\delta^{18}O$ is equivalent to a 2σ temperature uncertainty of ± 0.75°C when oxygen isotope data are converted to sea surface temperature.

Our data on 10 radiocarbon-dated and three modern whole shells from southern California archaeological sites and beaches (primarily northern Channel Islands) suggest that the isotopic composition of surface seawater has not changed markedly over the last 1,100 years (data given in Table 1). This suggests that interpretation of the isotopic values from modern shells should be similar to that of prehistoric shells. Figure 4 shows the distribution of oxygen and carbon isotope data by age for the dated shells.

Our interpretation of little or no major change in minimum and maximum SST may be seen by some as a contrast to conclusions drawn by Kennett et al. (2007) of increasing SST over the last 800 years of prehistory. Figure 4 includes the Holocene *Globigerina*

Table 1. **Radiocarbon-dated prehistoric *Olivella biplicata* shells from southern California collected in shell middens and associated isotopic measures.**

Site	$\delta^{18}O$ ‰ Avg [max, min]	$\delta^{13}C$ ‰ Avg [max, min]	Calibrated Year AD	Uncalibrated Radiocarbon Age BP		University of Arizona #
SCRI-694	0.56 [1.00, 0.14]	1.55 [1.82, 1.06]	1632	899	±32	AA73442
SCRI-328	0.77 [1.15, 0.09]	1.77 [2.07, 1.54]	1625	906	±37	AA73439
SCRI-694	0.91 [2.02, 0.31]	2.04 [2.53, 1.37]	1597	937	±38	AA73440
SBA-210	1.16 [1.60, 0.65]	1.58 [2.15, 1.08]	1573	967	±32	AA73449
SCRI-240	0.92 [1.18, 0.44]	1.46 [2.07, 1.14]	1436	1132	±32	AA73445
SCRI-240	0.71 [1.30, 0.08]	1.26 [1.96, 0.94]	1408	1167	±32	AA73444
SCRI-240	0.86 [1.41, −0.35]	1.38 [2.00, 0.63]	1405	1172	±34	AA73443
SCRI-694	1.11 [1.25, 0.85]	2.30 [2.45, 2.18]	1399	1179	±32	AA73441
SBA-46	0.46 [1.25, 0.03]	0.98 [1.83, 0.53]	844	1784	±45	AA73448
SBA-2425	1.18 [1.34, 0.99]	1.12 [1.65, 0.71]	n/a	31250	±420	AA73450

*Due to Pleistocene age, sample not used in analyses below.

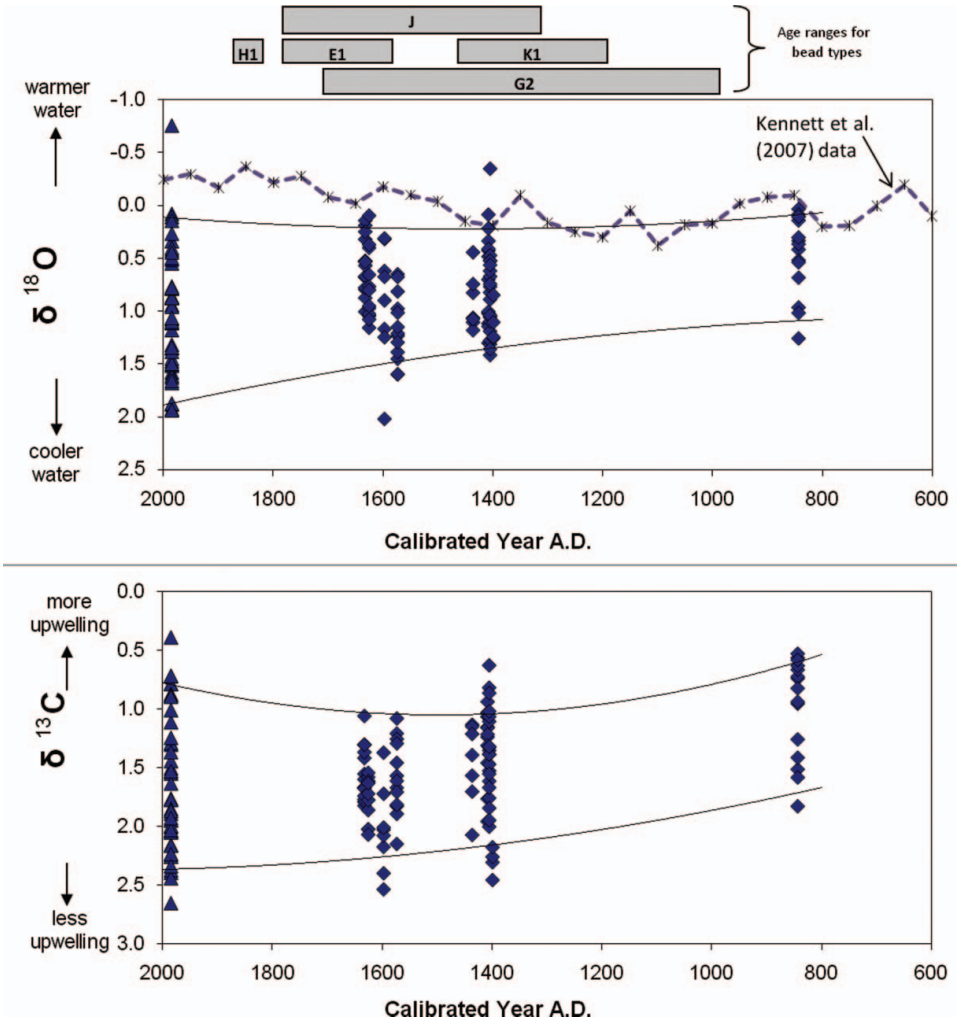

Figure 4. *Isotopic data from 4 modern and 9 prehistoric whole* Olivella *shells from southern California, sorted by age. Solid lines depict 95% confidence intervals around isotopic measurements. Also shown are age ranges for bead types (after Bennyhoff and Hughes 1987) and data extracted from Kennett et al. (2007:354).*

bulloides δ^{18}O dataset from Kennett et al. (2007), on which they base their SST reconstructions. As shown in the figure, the two data sets do not track one another. This difference is most easily explained by considering ecological and geochemical differences between the planktonic foraminifera, *G. bulloides*, and the gastropod *O. biplecta*. First, *G. bulloides* displays a very strong oxygen isotope offset from predicted equilibrium that is not seen in *Olivella* (Bemis et al., 1998). The result of this *G. bulloides* fractionation is to yield computed temperatures that are 3–4C warmer than temperatures from *Olivella* (Bemis et al., 2002). Second, the data from *G. bulloides* represent a flux-weighted average of the annual signal of this organism. Because *G. bulloides* has a lifespan

of approximately two weeks (Spero and Lea 1996) and is most abundant during the upwelling months of May and June (Sautter and Thunell 1991), the signal presented by Kennett et al. (2007) reflects an increase in temperature during these upwelling months rather than the whole year. In contrast, our *Olivella* data record an annual temperature range from which we cannot extract such a mid-year temperature shift. In short, the two studies are not incompatible but record different aspects of paleo-SST.

Methods and Sample: Sr Isotopes

We sampled a subset of control shells (n = 10) and beads (n = 4) for strontium isotope ratios ($^{87}Sr/^{86}Sr$). Control samples consist of paired modern and radiocarbon-dated prehistoric *Olivella biplicata* shells from along the California Coast. Sr isotope analysis facilitates the evaluation of the growing conditions of a shell, in particular, as a proxy for paleosalinity in coastal environments near estuarine systems (Ingram and Sloan 1992). Northeast Pacific seawater has a salinity of 33 to 35 per mil, and has had a constant $^{87}Sr/^{86}Sr$ ratio of 0.7092 over the last 400,000 years (Capo and DePaolo 1990; Ingram and DePaolo 1993). River water, on the other hand, contains dissolved Sr that has been weathered from metamorphic rocks in the mountain ranges that feed the rivers. In the Sacramento-San Joaquin River watershed of Northern California, for example, dissolved Sr is more radiogenic than seawater with a $^{87}Sr/^{86}Sr$ ratio between 0.7048 and 0.7077 (Ingram and Weber 1999). Thus, shifts in $^{87}Sr/^{86}Sr$ in *Olivella biplicata* carbonate from values near 0.7092 indicate growth under more estuarine conditions (Bryant et al., 1995).

Shell material (~0.1 grams of powder) was treated with 15% hydrogen peroxide (H_2O_2) to remove organic material (i.e., soil particles). Samples were centrifuged and H_2O_2 supernatant was removed from samples. Samples were then rinsed in water, dried down to a solid, and dissolved in 2 N Hydrochloric Acid (HCl). All samples dissolved completely (i.e., no residual solids remained). Samples were dried down again, to evaporate HCl, and brought up in 800 microliters (μL) 8 N Nitric Acid (HNO_3) and centrifuged. The supernatant was then loaded onto ion exchange columns containing Eichrom Sr Spec resin. Rubidium and most other elements were eluted in 2 mL 3 N HNO_3 whereas Sr was collected in 2.8 mL of 0.5 N HNO_3. Sr fractions were dried down to completeness and were reloaded onto the columns a second time (in 8 N HNO_3) to ensure complete purification of Sr from Rb. All acids were distilled to ensure their purity.

Sr isotope ratios were determined by *Nu Plasma* MC-ICP-MS (multi-collector inductively coupled plasma mass spectrometer) at the UC Davis Interdisciplinary Center for Plasma Mass Spectrometry (icpms.ucdavis.edu). Since the Nu Plasma arrived in November 2003, the mean $^{87}Sr/^{86}Sr$ value for the SRM987 standard has been 0.710229 ± .000050 (2 σ; n = 78). Isotope analyses were mass-fractionation corrected to $^{86}Sr/^{88}Sr = 0.1194$. $^{87}Sr/^{86}Sr$ isotope measurements for the samples were normalized to an accepted value of 0.710248 for the SRM987 standard. The total procedural blank for Sr was <800 pg (<0.8 ng).

RESULTS

Table 2 gives information on the 18 beads included in the current study, along with the number of isotopic analyses conducted on each bead, average, maximum, and minimum $\delta^{13}C$ and $\delta^{18}O$ values, as well as Sr isotope ratios, when available. Figure 5 plots the bead data against ellipses from modern and prehistoric *Olivella* shells collected from north and south of Point Conception. The resulting bead data do not suggest any differences in the isotopic composition of beads collected from San Nicolas Island and the Ballona wetlands on the California mainland. The data for the majority of beads are most consistent with a collection and presumably production area somewhere between Los Angeles and Orange counties. However, as seen in Figure 3, there is much overlap in shell isotope composition for all locations south of Point Conception. Thus, it is not possible to rule out production in the Santa Barbara (north of

Table 2. **Beads included in the current analyses, corresponding O, C, and Sr isotopic data.**

Site	Bead Type	Catalog #	Depth (cm)	# Isotopic Analyses	$\delta^{18}O$ ‰ Avg [max, min]	$\delta^{13}C$ ‰ Avg [max, min]	$^{87}Sr/^{86}Sr$
LAN-62	H1b	15189	60–70	7	0.58 [1.15, 0.26]	1.94 [2.10, 1.76]	
LAN-62	G2	15195	110–120	6	0.54 [0.86, 023]	1.55 [1.80, 1.25]	
LAN-62	G2	15200	90–100	10	0.68 [1.03, 0.35]	2.14 [2.51, 1.94]	
LAN-62	K1	15243	100–110	7	0.31 [0.96, −0.01]	1.90 [2.08, 1.72]	.709129
LAN-62	E1b	11950	190–200	6	0.51 [0.71, 0.29]	1.78 [2.27, 1.50]	
LAN-62	G2	15235	100–110	10	0.61 [1.02, 0.20]	1.65 [2.08, 1.40]	.709159
LAN-62	E1b	15620	130–140	4	0.87 [1.09, 0.75]	1.51 [1.66, 1.42]	
LAN-62	K1	303D8	70–80	5	0.32 [0.52, 0.21]	1.86 [2.07, 1.56]	
LAN-62	K1	2925A	Surface	6	0.58 [0.85, 0.23]	1.62 [1.77, 1.38]	
LAN-62	K1	1ACB7	90–100	5	−0.16 [0.10, −0.32]	1.96 [2.24, 1.69]	
LAN-211	H1b	21216	60–70	5	0.35 [0.90, −0.13]	2.11 [2.34, 1.68]	
LAN-211	E1b	21190	80–90	6	0.79 [1.24, 0.28]	1.49 [1.94, 1.32]	.709205
LAN-211	H1b	17485	30–40	6	0.43 [0.83, 0.19]	1.83 [1.99, 1.73]	
SNI-39	J	2501	40–50	7	0.69 [1.01, 0.37]	1.80 [2.06, 1.51]	
SNI-39	E1a	2053	Surface	5	0.73 [0.86, 0.62]	1.55 [1.67, 1.47]	
SNI-39	K1	2529	50–60	5	−0.69 [−0.62, −0.82]	1.04 [1.06, 1.03]	
SNI-39	K1	2530	50–60	2	0.69 [0.82, 0.57]	2.19 [2.23, 2.15]	.709140
SNI-39	E1a	2533	50–60	6	0.78 [0.98, 0.47]	2.19 [2.34, 1.92]	

Errors on all Sr ratios are +/− 0.00005.

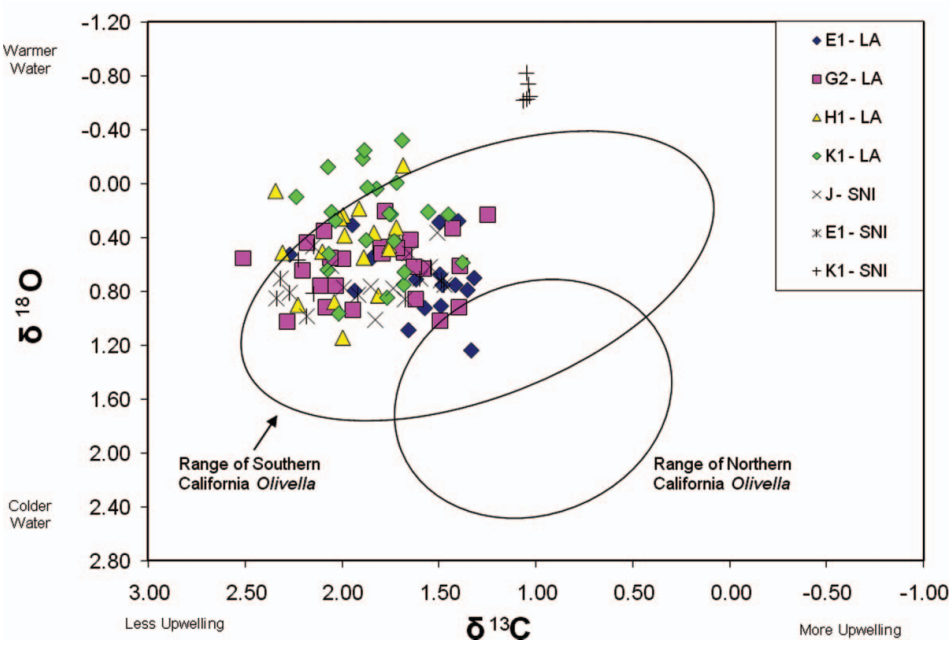

Figure 5. *C and O isotopes for beads from Los Angeles (LA) and San Nicolas Island (SNI). Each point represents an isotopic measurement; multiple readings per bead represented.*

Los Angeles) or San Diego (south of Orange) regions. Significantly, none of the beads displays an isotopic composition consistent with a northern California source.

Several interesting patterns are worth noting in this dataset. First, except for a single K1 (callus cup) from San Nicolas Island, the isotope samples from the Los Angeles Basin and San Nicolas Island beads cluster tightly in the upper and left side of Figure 5, overlapping with data obtained from modern and late prehistoric whole *Olivella biplicata* shells from southern California (see also Figure 3). This suggests that the majority of the shells from which the beads were produced inhabited the "local" southern California region when they were alive. By extension, we presume the beads were produced in this region as well.

The unusual K1 bead from San Nicolas is demarcated by five data points in the very upper-center part of Figure 5. This bead displays δ^{18}O values between −0.8‰ and −0.6‰, approximately 0.4 to 0.6 ‰ lower (more negative) than the next closest K1 bead. Converting the δ^{18}O data to temperature (~0.2‰/°C) yields SST at least 2–3C warmer than the next K1 and over 6C warmer than the average of all other K1 beads. There are several potential explanations. First, it is possible this shell was collected from a location far south of the Southern California Bight, where water temperatures are warmer on average. Given typical SST conditions, we estimate a location well into Mexico in Baja California (ca. 27–31 degrees latitude based on the regression line in Figure 3).

Second, it is possible the snail grew in Southern California, but during a period of elevated SST, for example during an El Niño Southern Oscillation (ENSO) event. We find this explanation less appealing. The elevated temperatures along the coast during ENSO events typically last only a few weeks to months. Our sampling of multiple growth rings (n = 5) on the shell, all of which are unique, would imply an extended ENSO event during which the shell continuously

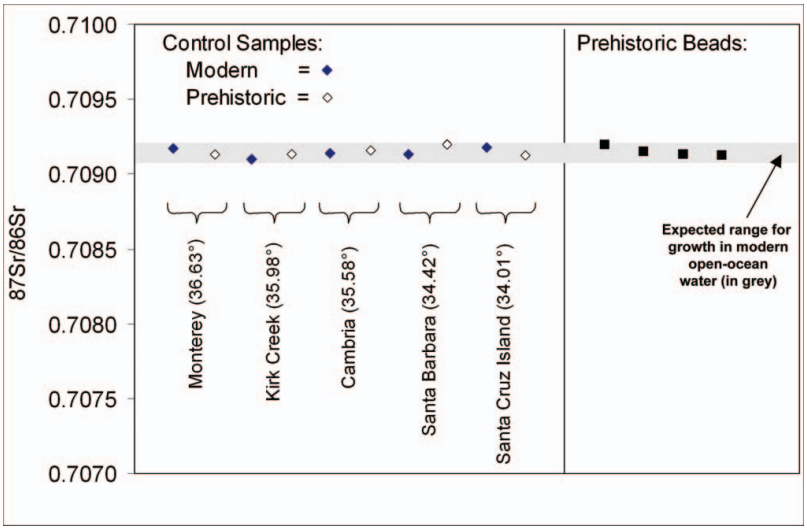

Figure 6. *$^{87}Sr/^{86}Sr$ isotope ratios for 10 control samples and five beads.*

grew. We cannot say exactly how long because we do not know the size and age of the original shell (age, size, and growth rate are related), but given our sampling of modern shells, we estimate these readings would require at least 3–4 months of elevated SST. Moreover, our data from modern and prehistoric whole shells from Southern California Bight do not record any ENSO events with SST as low as that indicated by this K1 bead.

Third, it is possible that the low $\delta^{18}O$ readings reflect growth in Southern California, but under slightly lower salinity conditions. This reasoning is extremely unlikely for several reasons. First, the ecology of *Olivella biplicata* which favors open coast and bay locations does not inhabit low-salinity environments (Edwards 1968, 1969; Stohler 1969). Second, outside of Goleta Slough, there are no large estuaries that exist along this stretch of the Pacific Coast that receive significant influxes of freshwater (i.e., enough to change salinity conditions). However, even for Goleta Slough, changes in salinity are probably brief and unlikely to be captured in sequential growth rings on a shell. Third, although we intend to describe the results in greater detail in a future paper and expand the sample size, the Sr isotope data on four of the 18 beads are consistent with collection from an open ocean (i.e., non-estuarine and fully saline) location. Figure 6 shows the Sr isotope data for these four beads relative to 10 control samples (5 modern and 5 prehistoric *Olivella* shells collected from open ocean locations along the California Coast). As shown, the control samples from along the coast are extremely consistent and fall, as expected, within the range of $^{87}Sr/^{86}Sr$ readings for the open ocean (.7092). Likewise, the beads all fall within the same range, suggesting they too grew under open-ocean and fully saline conditions. Unfortunately, we do not yet have Sr data for the anomalous K1 bead, but there is nothing in the data so far to indicate anything other than collection in open-ocean conditions.

A second interesting pattern in Figure 5 concerns variation in the isotopic range of different bead types. For example, G2 (n = 3 beads; 26 measurements), E1 (n = 5 beads; 27 measurements), and J (n = 1 bead; 7 measurements) beads have slightly higher oxygen isotope values, averaging 0.6‰, 0.7‰, and 0.6‰ $\delta^{18}O$ respectively. By contrast, K1 (n = 6 beads; 30 readings)

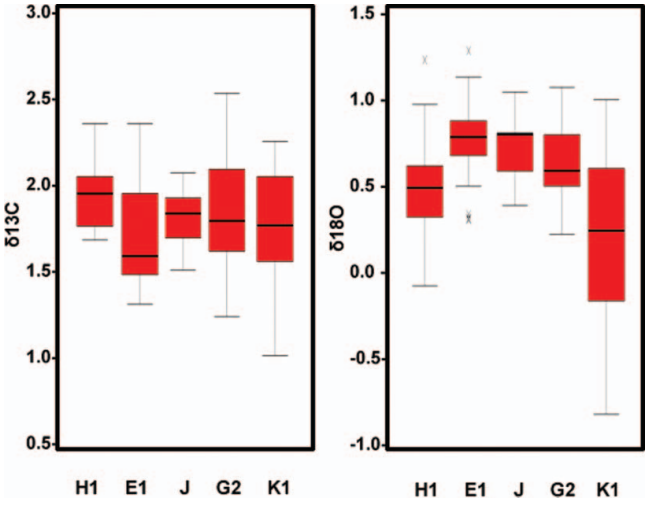

Figure 7. *Boxplot of oxygen and carbon isotopes by bead type.*

average 0.1‰ (0.3‰ without the anomalous bead mentioned above), and H1 beads (n = 3; 18 readings) average 0.5‰. Figure 7 shows boxplots for the five bead types we analyzed. While the sample size for each type is not large the differences may indicate alternative source zones and production localities. Alternatively, because there is a temporal component to many of these types, isotopic differences may indicate stability in the locus of shell collection and bead manufacture, but changes in SST conditions over time. Because we did not see obvious changes in SST over time in our radiocarbon-dated shells (see Figure 4), and because there is much temporal overlap in the bead types themselves, we tend to favor the former explanation, that is, different locations of bead manufacture as the primary cause of variation in isotopic composition of bead type. If so, this suggests that production centers with slightly different SST conditions may have produced beads in slightly different ways (e.g., one production locus in a certain area tends to produce beads of a certain style, while another locus in another region produces them slightly differently). These differences in methods or styles of bead production, expressed as bead "types," may be responsible for the variation seen in Figure 7. An interesting follow-up to this hypothesis would be to 1) increase the sample size to see if the basic pattern holds, and to 2) date individual beads and analyze C and O isotopes to track consistency within and the evolution of bead types over time.

A third pattern concerns the degree of variation in oxygen isotopic composition within bead types. Certain bead types, particularly K1, show a great deal of variation, suggesting the shells to produce them were collected across a relatively large source zone. Others, such as E1, show significantly less variation, suggesting they were collected and produced in a much more restricted area. On the other hand, variance in carbon isotope ratios is more constant across types. This was expected given the generally similar ratios observed in our control samples collected along the entire California Coast (as shown in Figure 3).

DISCUSSION AND CONCLUSIONS

Olivella bead production has a long prehistory in California (Erlandson et al., 2005; Fitzgerald et al., 2005; Vellanoweth 2001). Over 20 years ago, Bennyhoff and Hughes (1987) proposed different source zones

for the production of certain types, and distinctive conveyance systems for the movement of beads from the coast to inland locations. Their hypothesized production zones were based on careful examination of bead morphology relative to spatial distributions of beads. Archaeometric analyses allow the possibility of testing these notions using independent data. To date, our analyses largely confirm their hypotheses, but add important details to our knowledge of *Olivella* production and conveyance.

Eighteen *Olivella* beads collected from archaeological sites in the Los Angeles Basin and San Nicolas Island appear to have been produced from shells growing south of Point Conception. The majority are consistent with a production location in or near Los Angeles County (including Santa Catalina and San Nicolas Islands), though production as far north as Santa Barbara and as far south as San Diego cannot be ruled out given observed variation in ancient and modern SST. At least one bead appears to have been produced south of the California-Mexico border, suggesting the transport of prehistoric beads (or less likely, raw shell material) over long distances. None of the beads in this study appear to have been produced in regions north of Point Conception.

At the same time, variation between bead types suggests different source zones for different bead forms. In other words, particular areas may have produced certain forms or types of beads. Some, especially callus-cut (K1), seem to have been produced in a broad range of locations along the Pacific, from southern California to Mexico, while others, such as thin-lipped (E1), appear to be much more restricted to the Los Angeles to Santa Barbara Coast. Additional research on bead detritus from potential production centers is needed to link bead types with particular locations.

In sum, C, O, and Sr isotopic data shed new light on ancient and historic bead production and conveyance in California. Although some of the basic patterns were predicted by Bennyhoff and Hughes (1987) long ago, others are cast in a new light with new data. Still other patterns were surprising and not predicted by existing data. We plan to continue investigating isotopic patterns in beads by adding different regions of California to our growing database. As well, we hope that additional testing, for example using strontium isotopes and/or chemical composition (e.g., Eerkens et al., 2007), will help narrow the source ranges to more specific geographic areas for the beads we have already analyzed.

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