

Chapter 9

Shell Bead Sourcing

A Comparison of two Techniques on *Olivella biplicata* Shells and Beads from Western North America

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We compare two methods for tracking the geographic source of *Olivella biplicata* shell beads along the California and Oregon Pacific coast; bulk element composition by inductively coupled plasma-mass spectrometry (ICP-MS) and stable carbon and oxygen isotopes by isotope ratio-mass spectrometry (IR-MS). Both techniques hold some promise for reconstructing prehistoric trading systems, but neither is perfect. Currently, oxygen isotopes can reliably differentiate recent shell beads (post A.D. 1500) derived from points north versus south of Point Conception. We are working to extend the time depth of this technique. Elemental composition will help to divide the northern isotopic zone into finer geographic sections by providing chemical signatures for certain regions, such as Monterey Bay and extreme Northern California. Additional sampling, particularly on prehistoric specimens that are subject to post-depositional chemical alteration, will

CITATION:

Eerkens, J.W., J.S. Rosenthal, H.J. Spero, R. Shiraki, and G.S. Herbert
2007 Shell Bead Sourcing: A Comparison of two Techniques on *Olivella biplicata* Shells and Beads from Western North America. In *Archaeological Chemistry: Analytical Techniques and Archaeological Interpretation*, edited by M.D. Glascock, R.J. Speakman, and R.S. Popelka-Filcoff, pp. 167-193. American Chemical Society, Washington DC.

be necessary to make this technique reliable for sourcing ancient beads. In concert, the two techniques could provide archaeologists with a dependable means for identifying where the shell used to make a bead was originally collected.

Introduction

Marine shell beads are a regular component of the Holocene archaeological record in many areas of the world. Although they rarely outnumber more common artifacts, such as flaked stone and ceramics, they are sufficiently ubiquitous to have been the subject of considerable archaeological research. Such studies focused on both the symbolic aspects of beads (e.g., wealth display) and the reconstruction of prehistoric trade and/or exchange systems.

Despite the potential to track the spatial movement of marine shell beads, archaeometric attempts at sourcing have been minimal. We are aware of only three other groups that have taken this approach including a neutron activation analysis (NAA) of *Busycon* sp. shells and artifacts in the American Southeast (1), the use of strontium isotopes as a measure of geologic age of fossil shells in Southwest Europe (2), and the use of oxygen isotope ratios to source *Spondylus* sp. beads in Central Europe (3).

These geochemical studies notwithstanding, the most common method to trace the geographic origin of marine-shell artifacts is to identify the shellfish species out of which the beads were fashioned, and then determine the geographic distribution of that species (e.g., 4, 5, 6). While informative in some cases, there are several potential problems and drawbacks to this approach. First, it is necessary to establish that the modern geographic distribution of a species is consonant with the prehistoric distribution at the time the bead was made. This can be difficult if archaeological and/or palaeontological research along a coastline has been minimal or if variations in Holocene climate have modified regional environmental conditions across millennial timescales. Second, if the shell has been heavily modified through abrasion or other reduction processes it is not always possible to identify the exact species. This can be particularly troublesome when there are several similar species within a genera that have different geographic distributions. Third, if a shellfish species is found across an expansive length of coastline, the geographic accuracy of bead sourcing will be poor. Frequently shells can only be sourced to oceans (e.g., the Atlantic coast), which limits the spatial resolution of data to archaeological questions about the exchange and consumption of marine shell beads.

Sourcing *Olivella* Beads in California and the Great Basin

Building on the geochemical sourcing methods first attempted over 35 years ago, we have been exploring stable isotopic and elemental analytical techniques for sourcing marine shell beads in California. We have focused our efforts on beads manufactured from the shells of the “purple olive snail” (*Olivella biplicata*), by far the most common species exploited for bead-making material in the region. *Olivella biplicata* is endemic to the Pacific coast from Vancouver Island to the northern Baja peninsula. Shells of this species have been turned into beads since the earliest Holocene (9,000–10,000 years before present; ybp) (7–11), and are regularly recovered at prehistoric sites across the west, where they are found as far inland as eastern Nevada, Utah and Arizona (5, 6, 12, 13). The earliest shell beads from this region are simple spire-ground *Olivella* with little to no additional modification (7–8, 11). By the middle Holocene (ca. 5000 ybp), rectangular to oval-shaped beads cut from the body whorl of *Olivella* were traded over a broad region (13–15), providing the foundation for a manufacturing industry and exchange network that developed through the late Holocene and culminated in the monetized systems of exchange reported ethnographically (12, 13, 16–23).

Centers of prehistoric shell bead production are thought to have existed in the Santa Barbara Channel area of southern California, in central California around Monterey Bay, and at Bodega Bay in northern California (12). Despite the ubiquity of *Olivella* shell beads in archaeological sites throughout California and the Great Basin, centers of bead production and exchange outside the Santa Barbara Channel region (e.g., 17, 24, 25) are poorly documented (12, 26). Extensive archaeological research has been conducted along much of the central and northern California coast (e.g., 26–28), particularly at Monterey Bay (29–32) and Bodega Bay (33). Yet, *Olivella* bead manufacturing is only occasionally represented by small quantities of manufacturing waste and an occasional bead blank (12, 26, 31, 34). This tradition appears to have been small-scale and could not account for the tens of thousands of *Olivella* beads recovered from central and northern California archaeological sites (12, 14, 35).

In contrast, sites located on the northern Channel islands produced as much as 150,000 pieces of bead manufacturing refuse and hundreds of production blanks from a single cubic meter of excavation (18, 20, 36, 37). As well, a tradition of specialized bead making tools, including micro-blade drills and anvils, is documented on the northern Channel Islands (16). Nothing comparable to this level and regularity of production is evident at archaeological sites in central and northern California.

Olivella Sourcing

While it is clear that most *Olivella* beads found in the interior of western North America are ultimately derived from the Pacific Coast, this source zone is

over 2000 kilometers long. As a result, a species-based sourcing program is of limited value in the reconstruction of specific exchange networks, and does not allow us to evaluate the indirect evidence suggesting that southern California supplied the vast majority of beads consumed in western North America. Clearly, an alternative method is necessary to test this hypothesis.

To refine potential *Olivella* source zones to more specific sections of the coastline, we have employed two different archaeometric techniques, including determination of elemental composition by inductively coupled plasma-mass spectrometry (ICP-MS) and the use of carbon and oxygen stable isotopes using an isotope ratio-mass spectrometer (IR-MS) (38). Each of these techniques is described below, and the final section evaluates and compares their utility in sourcing *Olivella* shell beads.

Compositional Analysis by ICP-MS

Because *Olivella biplicata* snails grow in tidal environments, it was hypothesized that their shell chemistry might be influenced by nearshore seawater chemistry, which would include dissolved minerals from local shoreline deposits. If geology varied enough along the California coast, certain regions might be bathed by seawater with a chemically distinct composition that would be incorporated into the shells.

To test this hypothesis, we collected 40 modern shells from beaches along the California coast and subjected them to ICP-MS analysis. Shells were generally collected dead as they lay on beaches. Specimens were obtained from five main geographic areas, the Channel Islands off the Santa Barbara coast (n = 3), the mainland region from Santa Barbara (n = 3), central California from north of Pt. Conception to Monterey (n = 11), Monterey and Asilomar (n = 12), and regions north of San Francisco (n = 11). We complemented this sample set with 32 shells from coastal archaeological deposits. All were unmodified whole *Olivella* shells thought to come from local seawaters, rather than representing exotic shells brought in through trade. Due to the availability of various prehistoric collections, the sample of archaeological shells could not exactly duplicate the sample of modern shells. Only three of the regions sampled for modern shells were represented by archaeological ones, including the Channel Islands (n = 12), the mainland between Santa Barbara and Kirk Creek (n = 18), and Monterey Bay (n = 2). Prehistoric shells from north of San Francisco were not available to the authors for analysis at the time this study was conducted. Figure 1 shows the location of the sampling areas.

Each shell was washed on its exterior with filtered water, but was not further cleaned. Two samples were extracted from each shell for compositional analysis, one from the shell wall near the mouth aperture and one from the

callus. Most prehistoric beads were made from these two parts of the shell or consist of whole shells. Figure 2 shows two typical *Olivella* beads (A and B) as well as an unmodified modern shell (C).

Compositional analyses consisted of 50 milligrams of powdered shell, crushed in an agate mortar and pestle and digested in 70% concentrated nitric acid. These liquid samples were diluted with pure water to 5% nitric acid concentration and introduced to the ICP-MS (an Agilent 7500c). Thirty-three elements were measured for each shell sample, ranging from boron to uranium. Four of these (Ga, Rh, Cd and Ce) were generally below the detection limits of the machine for most samples and were not considered further. The remaining 29 elements were of varying utility in the analysis.

Ca was the only element regularly detected above the ppm range. Some elements, such as Na, Mg, K, and Sr, were frequently above 100 ppm, while others, such as Si, Al, B, were generally above 4 ppm but below 100 ppm. The remaining elements were typically measured in the 10 ppb to 100 ppb range. Some of these elements, such as Sr, Mg, and Ba have been examined for their ability to serve as tracers of various environmental factors, such as salinity and temperature (e.g., 39–44). These studies have met with varying degrees of success. In some cases temperature and salinity correlate well with certain elements. However, success varies greatly depending on the species used, environment from which those species derive, and geological age of the samples. Unfortunately, no such study has yet been undertaken on *Olivella biplicata* and it is not clear how well such elements track salinity, temperature, or other environmental and/or biological conditions in this species.

Results

Overall, there was only minor geographic patterning within the chemical data. Among modern shells, notable regional differences were observed among some elements. Figure 3 displays ppb readings for two elements, Cr and Sc, relative to %Ca. There is a clear bimodal distribution along the Y-axis for Cr, separating most Monterey samples. Interestingly, there are three non-Monterey samples within this high Cr group (one from Kirk Creek, one from Piedras Blancas, and one from Santa Cruz Island), hinting that the pattern may not be entirely influenced by geography alone. Furthermore, all three of these samples have one anomalously high Cr reading from the wall of the shell paired with a



Figure 1. Map of region, sampling locations, and places mentioned in text.

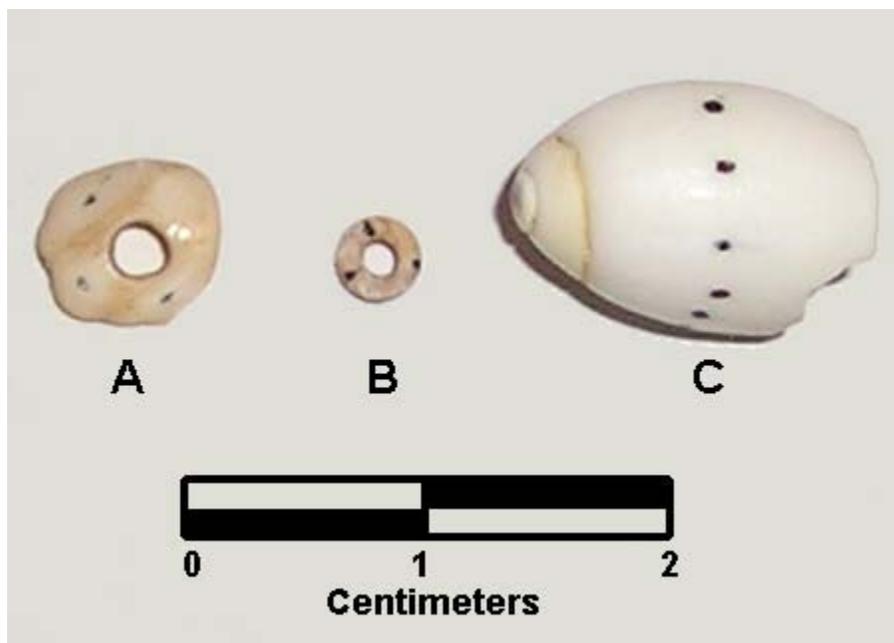


Figure 2. Example of *Olivella* beads (A and B) and modern shell (C)

normal Cr reading from the callus. This suggests, again, that a non-geographic factor may be involved in determining the bimodal distribution in Cr.

Further evidence that the patterns in Cr are not geographically-influenced is given in Figure 4 which plots all prehistoric samples on the same scales for these two ratios. As seen, Cr values are nearly equal for all four regions represented in the prehistoric sample (note that two prehistoric samples had unusually high ppm values for Cr and are not shown on the graph). Moreover, the Cr values of prehistoric shells all fall within the range of modern Monterey shells. Modern Cr contamination in seawater does not seem to be a likely explanation as most modern samples are *depressed* in Cr concentrations relative to prehistoric ones. While post-depositional alteration to shell chemistry is clear in our samples (see below), such a dilution is also not a satisfactory explanation of the observed patterns in Cr. If Cr was increasing relative to other elements over time as a shell was lying with an anthropogenic midden, as would be suggested by the Channel Island, Santa Barbara, and central California samples, such an increase is not evident in the prehistoric Monterey samples, which remain stable near a ratio between 30 and 50. It is unlikely Cr would systematically increase for a diverse set of samples all over California but not for Monterey samples. Our future research will attempt to pinpoint the explanation for the Cr patterns.

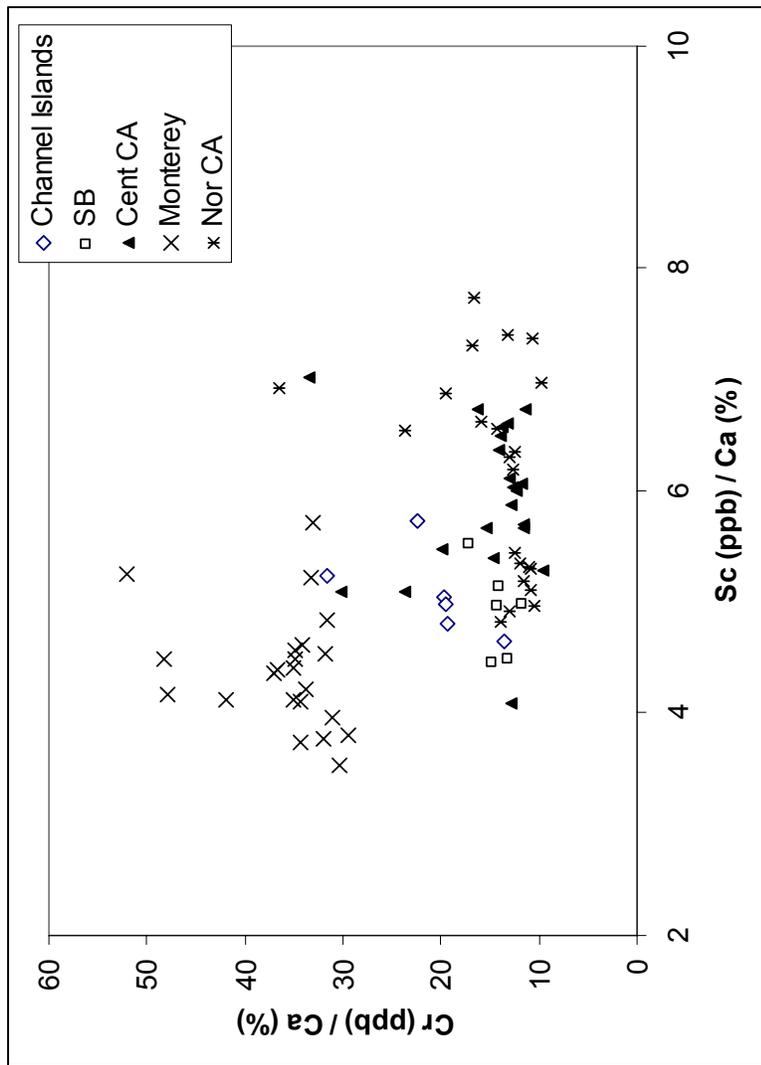


Figure 3. Plot of Cr vs. Sc for modern Olivella shells.

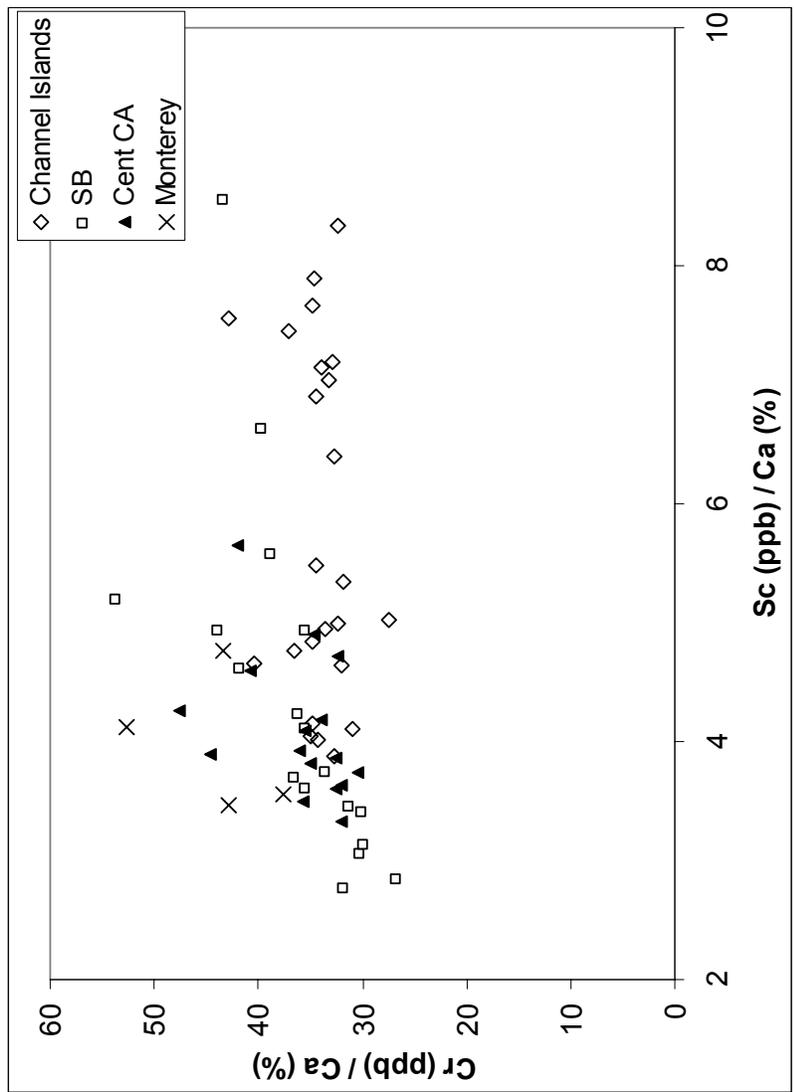


Figure 4. Plot of Cr vs.Sc for prehistoric *Olivella* shells (scale identical to Figure 2).

Although far less pronounced, patterns in Sc are more promising as geographical signatures. As seen in Figures 3 and 4, Monterey samples, both prehistoric and modern, tend to be slightly depressed in Sc while Santa Barbara and Channel Island samples tend to be elevated. Central California samples are more variable in Sc. More promising in this regards are Al, Sr and Zr concentrations. Shown in Figure 5 are Al (ppm) and Zr (ppb) as ratios of %Ca (note that both are on a logarithmic scale to facilitate display). Monterey samples fall on the upper right hand side of the scatter of points while Channel Islands samples fall on the left and central and northern California samples are intermediate. Prehistoric samples, shown in Figure 6, follow some of these same patterns though variability seems to have increased for some of these regional samples.

Other elements are even less discriminatory geographically, though they occasionally serve to distinguish one particular sampling location within a region where more than one shell was collected. For example, shells from Devereaux Beach in Santa Barbara were frequently higher in heavy metals and rare earth elements than other shells from this region.

The most obvious pattern among all the data concerned the difference between prehistoric and modern samples. A number of elements show either systematic increases or decreases in ppm concentrations between the modern and prehistoric shells. For example, Figure 7 plots Na and Ba as ratios of % Ca. Relative to prehistoric samples, modern ones are systematically enriched in Na and depleted in Ba. Other elements that show such systematic changes include Ti, V, Mn, As, and Cd, where prehistoric samples tend to be enriched in these elements. Enrichment of some elements in prehistoric samples is likely the product of leaching of other elements over time (such as Na), thereby increasing the relative proportion of the former.

Even Ca, the element we used to normalize all our other measures, may be subject to post-depositional alteration. Moreover, such alteration may vary depending on local environmental conditions. Such a factor may account for some of the overlap or blurring we see between regional elemental signatures in our prehistoric samples. Without knowing exactly how much change may have taken place in Ca concentrations in different burial conditions, it is difficult in such sourcing studies to account for this possibility.

In sum, the ICP-MS analyses suggest that *Olivella* shells are subject to fairly significant post-depositional alteration as shells are exposed to midden soils over hundreds to thousands of years. While discouraging, it does not preclude the application of elemental compositional studies for shell-bead sourcing. Some elements, such as Sc, Zr, and Al, among others not discussed in detail here, remain fairly constant when taken as ratios against Ca. It is these elements that should be the subject of provenance analyses and that we will target in future research with *Olivella* shell.

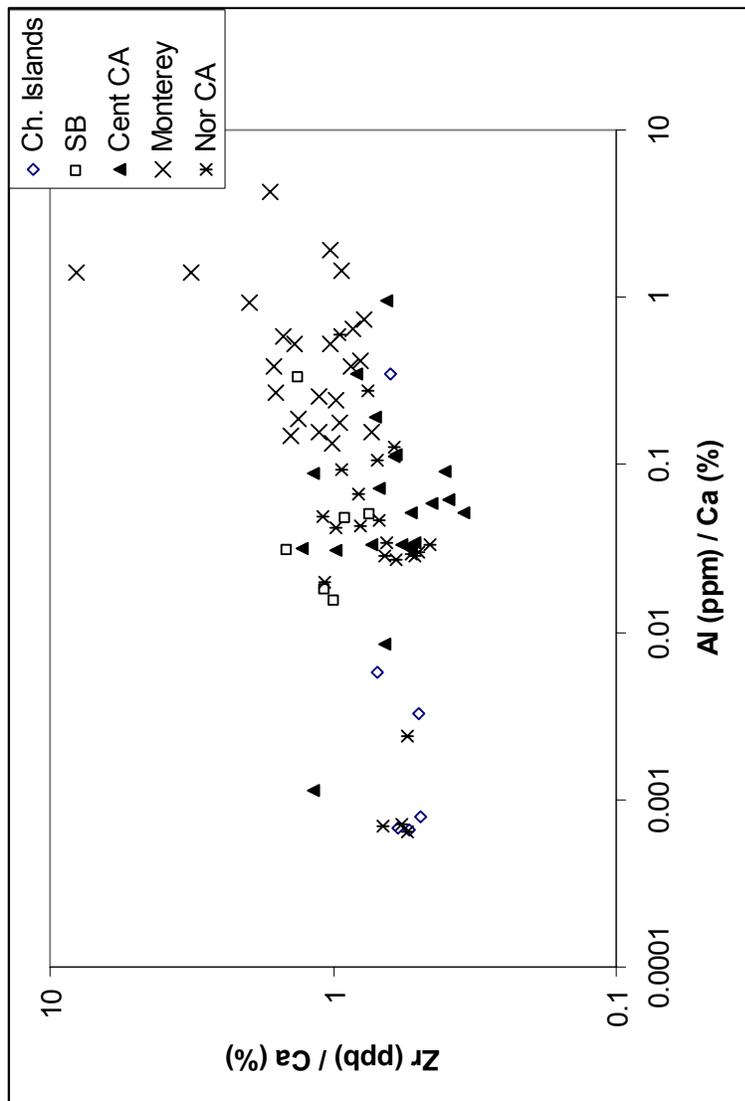


Figure 5. Zr and Al values for modern shell samples

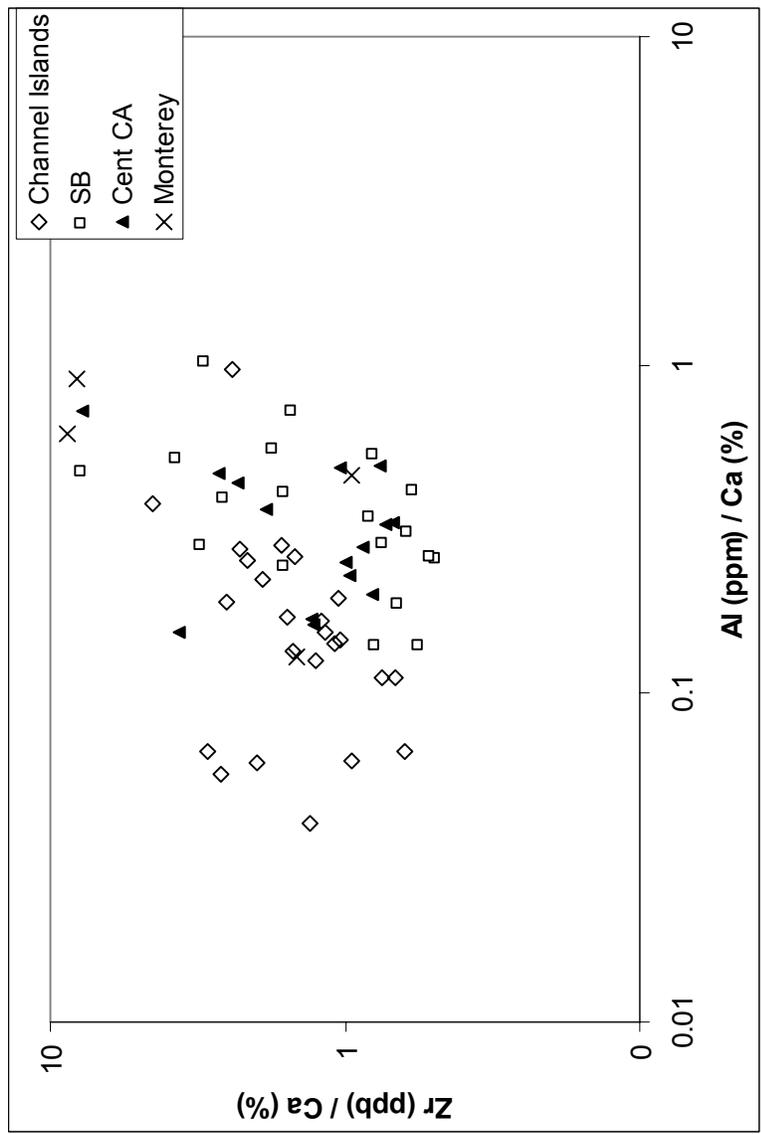


Figure 6. Zr and Al values for prehistoric samples (note that the scale of the X-axis is slightly different than in Figure 4).

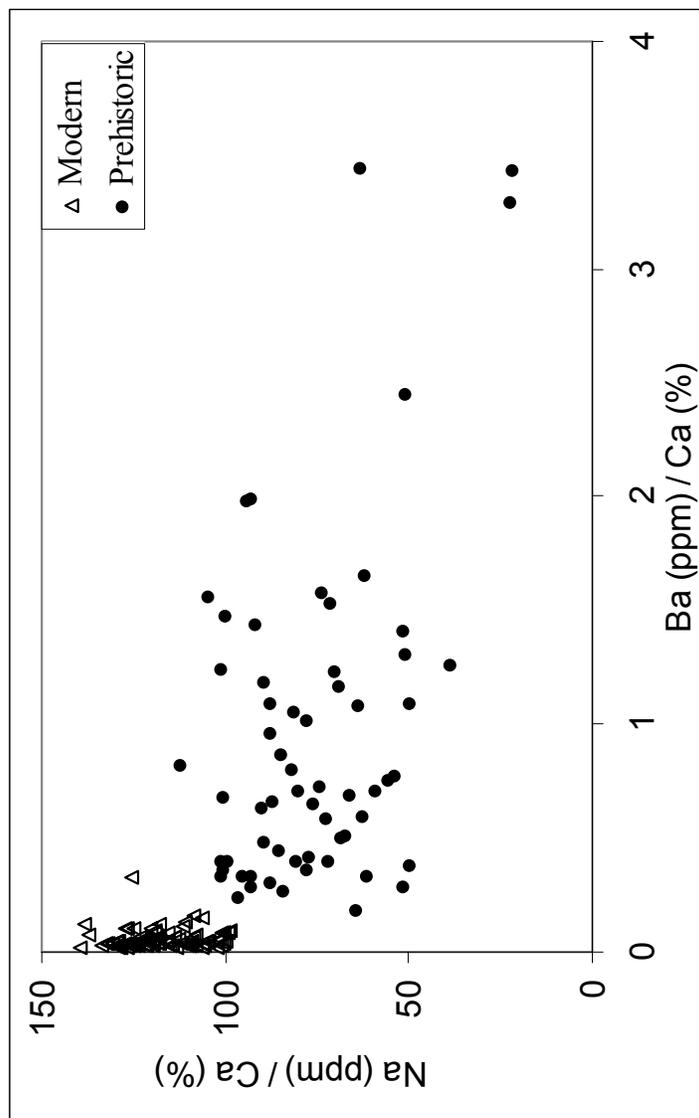


Figure 7. Plot of Na and Ba showing difference between prehistoric and modern shells.

Furthermore, shell compositional studies may be informative for more micro-scale sourcing. While some elements may discriminate large-scale geographic regions (e.g., the California coast south of Point Conception), others could be indicative of micro-habitats (e.g., individual beaches influenced by certain drainages). We did not collect and sample *Olivella* shells at a spatial scale to properly test this possibility, however some data we collected support this notion. For example, in cases where we sampled multiple shells from particular beaches, the chemical composition of these shells were frequently more alike than other shells from the broader geographic region we studied. One potential problem with such an approach to sourcing is that there may not be enough variation between different beaches to individually characterize each. Thus, shells from a beach in northern California may have similar chemical signatures for certain elements to a beach in southern California.

O and C Stable Isotopes

The second approach we have taken to sourcing *Olivella* shells is to exploit differences in oxygen and carbon isotope ratios (38). Oxygen isotopes have been particularly useful in this regard due to sea-surface water temperature gradients that exist along the California coast. The oxygen isotope value ($\delta^{18}\text{O}$) of biogenic carbonates such as aragonite depend primarily on two factors; the proportion of ^{18}O and ^{16}O in seawater ($\delta^{18}\text{O}_{\text{sw}}$) which varies as a function of evaporation, precipitation and continental runoff (e.g., salinity), and the calcification temperature in which the organism precipitated its shell (45–50). In this study, we focused on the contribution of sea surface temperature, which is a significant factor contributing to oxygen isotopic variability in *Olivella* shells in California.

Along the California coast, two currents influence sea surface temperatures (51). The California Current flows southward along the western margin of North America bringing cold, nutrient-rich waters from subpolar latitudes. During spring and early summer, these currents flow along much of the California coast. However, during summer through late fall, the Davidson Counter-Current flows northward from subtropical latitudes, where it transports warmer, nutrient-depleted, waters along the southern California coast. These two currents meet near Point Conception (see Figure 1). As a result, *Olivella* shells growing south of this point record low $\delta^{18}\text{O}$ values during most of the year, while those shells north of this region record high $\delta^{18}\text{O}$ during the entire year. The only departure from this pattern occurs during El Niño Southern Oscillation (ENSO) events, which bring large amounts of precipitation, especially to Northern California, significantly affecting the salinity of near-shore waters. This influx of freshwater brings Northern California oxygen isotope values in *Olivella* shells within the range of Southern California shells.

Fortunately, such events usually last less than two months and are infrequent, on average once every five to seven years. As a result, ENSO events notwithstanding, we can source modern shells with high confidence to either Southern or Northern California (38).

A second geochemical tracer is shell $\delta^{13}\text{C}$ ($^{13}\text{C}/^{12}\text{C}$). In mollusks, shell $\delta^{13}\text{C}$ records may be influenced by metabolic rate, and reproductive condition, although the processes by which this influence occurs are less well understood (52–57). More important is the source of shell $\delta^{13}\text{C}$ variation that is related to shifts in the $\delta^{13}\text{C}$ of dissolved inorganic carbon (ΣCO_2) in seawater. This environmental parameter is ultimately controlled by the balance between photosynthesis and respiration in the water column. In surface waters, phytoplankton preferentially remove $^{12}\text{CO}_2$ during photosynthesis, thereby increasing $\delta^{13}\text{C}$ of ΣCO_2 . Organic matter sinking below the photic zone is then metabolized by consumer organisms, thereby releasing ^{13}C -depleted CO_2 back into the water column. When these ^{13}C -depleted waters return to the surface during seasonal upwelling events, the shell $\delta^{13}\text{C}$ records the ambient decrease in $\delta^{13}\text{C}$ of ΣCO_2 (e.g., 49, 58, 59). In California, upwelling occurs most intensively between April and July (60, 61). Thus, shell $\delta^{13}\text{C}$ values may be distinctive of certain regions of the California coast that experience more intensive upwelling than others. In combination with $\delta^{18}\text{O}$, this information could be used to isotopically fingerprint shells.

These geochemical tracers have been successfully applied to studies of the shells of a variety of marine organisms including bivalve and gastropod mollusks, ostracods, forams, brachiopods and solitary corals (47, 54, 57, 58). In the case of mollusk shells, for example, serial microsampling around the spiral whorls from earliest to oldest growth revealed sinusoidal variations in isotope ratios, which result from shell deposition in a seasonal environment (47, 50, 62–64). Our previous work showed this to be true of *Olivella* shells as well, where $\delta^{18}\text{O}$ levels fluctuate from warm summer temperatures to cold spring and winter temperatures (38).

Samples for isotopic analysis were processed at UC Davis on a Micromass Optima isotope ratio mass spectrometer (IRMS). 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. Sampling began at the *Olivella* shell lip (most recent growth) and continued until the parietal callus was reached (earlier growth), including at least one whole whorl revolution. The analysis of beads required determining the axis of growth and orienting the artifacts in the same way as complete shells. The linear distance between samples ranged from 0.5 mm to 2.5 mm depending on the size of the shell or bead and how intensively it was sampled.

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

Table I. Beads Analyzed and Range of Isotopic Values Recorded.

| <i>Bead Type</i> | <i>Site</i> | <i>Approx. Date</i> | <i>Number Samples Taken</i> | $\delta^{18}O$ <i>Range</i> | $\delta^{13}C$ <i>Range</i> |
|------------------|-------------|---------------------|-----------------------------|--------------------------------|--------------------------------|
| G1 | INY-3806 | A.D. 850 | 2 | [0.79,0.62] | [1.90,1.74] |
| G1 | INY-3806 | A.D. 850 | 2 | [0.83,-0.16] | [2.30,1.91] |
| G2a | INY-3806 | A.D. 850 | 3 | [0.63,0.34] | [2.05, 1.82] |
| G2b | INY-5207 | A.D. 1700 | 4 | [0.40,-0.51] | [2.16,1.36] |
| K1 | INY-5207 | A.D. 1700 | 2 | [0.76,0.42] | [2.67,2.33] |
| A2a | INY-5207 | A.D. 1700 | 8 | [0.17,-0.49] | [1.87,1.55] |
| H1b | YOL-69 | A.D. 1810 | 8 | [0.67,-0.27] | [1.74,1.27] |
| H1b | YOL-69 | historic | 9 | [0.62,0.11] | [0.91,0.20] |
| H1b | YOL-69 | A.D. 1870 | 3 | [-0.05,-0.74] | [2.57,2.45] |
| H1b | SCL-30 | A.D. 1825 | 3 | [0.40,0.16] | [1.53,1.60] |
| F2a | SCL-732 | 1518 B.P. | 6 | [1.63,1.09] | [0.55,0.28] |
| F2a | CCO-269 | 1518 B.P. | 10 | [0.99,0.17] | [1.30,-0.09] |
| F2a | ALA-413 | 1512 B.P. | 3 | [1.32,0.34] | [0.87,0.45] |
| F2a | ALA-329 | 1512 B.P. | 1 | [-0.04,-0.04] | [0.61,0.61] |
| F2a | SOL-355 | 1323 B.P. | 3 | [1.28,0.64] | [1.25,1.11] |
| F2b | CCO-269 | 1531 B.P. | 9 | [1.42,0.96] | [0.87,0.31] |
| F2b | CCO-269 | 1399 B.P. | 4 | [1.15,0.67] | [0.59,0.03] |
| F2b | ALA-413 | 1483 B.P. | 3 | [0.73,0.00] | [0.77,0.67] |
| F3a | ALA-413 | 1496 B.P. | 5 | [1.46,0.85] | [1.36,0.77] |
| F3a | ALA-329 | 981 B.P. | 5 | [1.05,0.75] | [0.94,0.53] |
| F3a | ALA-46 | 874 B.P. | 4 | [1.65,0.43] | [1.18,0.22] |
| F3a | ALA-46 | 955 B.P. | 10 | [0.85,0.18] | [0.66,0.31] |
| F3a | ALA-329 | 1075 B.P. | 3 | [0.65,0.33] | [0.49,0.35] |
| F3a | ALA-329 | 1075 B.P. | 5 | [1.19,0.38] | [0.85,0.18] |
| F3a | ALA-329 | 966 B.P. | 5 | [1.05,0.39] | [0.93,0.36] |
| F3b | ALA-343 | 1247 B.P. | 2 | [1.09,0.55] | [1.10,0.94] |
| F3b | ALA-343 | 551 B.P. | 5 | [0.81,0.38] | [1.21,0.20] |
| F3b | ALA-343 | 1180 B.P. | 3 | [0.46,0.41] | [0.53,0.10] |
| G2a | ALA-413 | 1426 B.P. | 1 | [-3.26,-3.26] | [-7.18,-7.18] |
| G2a | COL-247 | 2159 B.P. | 2 | [0.20,-0.15] | [1.43,0.53] |

| | | | | | |
|-----|---------|-----------|----|---------------|---------------|
| G2b | ALA-413 | 1531 B.P. | 8 | [0.67,0.25] | [1.88,1.28] |
| G2b | ALA-413 | 1496 B.P. | 4 | [1.40,1.13] | [1.10,0.92] |
| G2b | ALA-413 | 1451 B.P. | 4 | [1.15,0.42] | [2.13,1.37] |
| G2b | ALA-413 | 1518 B.P. | 10 | [0.76,0.33] | [1.20,0.74] |
| G2b | ALA-413 | 1562 B.P. | 1 | [0.61,0.61] | [0.77,0.77] |
| G2b | SCL-732 | 1806 B.P. | 6 | [-0.83,-3.63] | [-1.94,-4.92] |
| G2b | SCL-732 | 1871 B.P. | 5 | [0.51,0.19] | [0.42,-0.37] |
| M1a | ALA-42 | 910 B.P. | 3 | [0.70,0.39] | [0.73,0.32] |
| M1a | ALA-42 | 899 B.P. | 4 | [0.87,0.47] | [0.81,0.52] |
| M1a | ALA-42 | 891 B.P. | 3 | [0.44,0.14] | [0.94,0.44] |
| M1a | ALA-42 | 899 B.P. | 5 | [1.00,0.70] | [0.77,0.64] |
| M1a | ALA-329 | 764 B.P. | 6 | [1.40,0.94] | [1.85,1.08] |
| M1a | ALA-329 | 685 B.P. | 8 | [1.10,0.52] | [1.36,0.18] |
| M1a | ALA-42 | 854 B.P. | 2 | [1.42,1.03] | [1.60,1.44] |
| M1a | ALA-42 | 926 B.P. | 6 | [1.10,0.67] | [1.52,1.04] |
| M1a | ALA-329 | 619 B.P. | 2 | [-0.90,-1.40] | [-3.22,-3.69] |
| M2a | YOL-187 | 548 B.P. | 2 | [1.09,1.00] | [0.18,0.03] |
| M2a | ALA-42 | 493 B.P. | 1 | [0.40,0.40] | [0.95,0.95] |

Note: Type according to Bennyhoff and Hughes (1987).

subsequently reacted in 105% orthophosphoric acid at 90°C using an ISOCARB automated common acid bath system. The resulting CO₂ was purified through a series of cryotrap and introduced into the IRMS through a dual inlet system. Repeated analyses of standards showed that external precision for δ¹⁸O and δ¹³C values was ± 0.09 and ± 0.07 respectively (one standard deviation).

Results

We collected 20 modern *Olivella* shell samples from along the California coast to test our hypothesis that δ¹⁸O values vary from southern to northern California as predicted. Each shell was microsampled along growth rings for O and C isotopes, with an average of 15 samples per shell. Figure 8 shows the results of these analyses. As predicted, shells from northern and southern California largely differentiate themselves on oxygen isotopes, shown on the y-

axis and expressed as the ratio of ^{18}O to ^{16}O relative to an international standard and multiplied by 1000 ($\delta^{18}\text{O} = R_{\text{sample}}/R_{\text{standard}} - 1] \times 1000$) in “per mil” units or parts per thousand. There is some overlap in the central part of the plot, between $\delta^{18}\text{O}$ values of 0.6 to 1.7 per mil, correlating to either ENSO events in Northern California, or overlap of summer water temperatures in Northern California and winter temperatures in Southern California. Shells from Santa Cruz Island stray slightly from this pattern, displaying slightly higher $\delta^{18}\text{O}$ values than predicted. We also measured $\delta^{13}\text{C}$ values to see if this tracer could provide further separation between these regions. Although the Santa Cruz Island samples were also slightly elevated for carbon isotopes, samples were not noticeably different for Northern vs. Southern California. Ellipses in the graph do not represent 95% confidence intervals, but merely subjective “zones” where the majority of samples from particular geographic regions fall.

To date we have analyzed 48 *Olivella* beads from two regions, the San Francisco Bay and Sacramento/San Joaquin Delta area in Northern California (n = 42), hereafter referred to simply as the Delta, and Owens Valley in southeastern California (n = 6). Most of the beads from the Delta region have been independently dated by AMS (65). Owens Valley beads comprise three types, saucers (G1/G2), callus cup (K1), and spire-lopped (A2). Delta beads comprise four types following the typology defined by Bennyhoff and Hughes (12), including historic needle-drilled (H1b), saucers (G2), saddles (F2/F3), and sequins (M1/M2). We reported on 10 of these beads in an earlier publication, including all six Owens Valley beads and the four historic H1b beads from the Delta (38). All ten had oxygen isotopic signatures that were consistent with a southern California source (i.e., at least one isotopic reading lower than 0.6; in fact, most had *maximum* readings equal or less than 0.6).

Prior to the current analyses we had predicted that most of the remaining 38 prehistoric Delta *Olivella* beads would be made from shells procured in northern California. This was based purely on an economic model that minimizes transport distance. In other words, the closest source (by foot) of *Olivella* shell to Owens Valley is southern California, while the closest source of *Olivella* in the Delta region is the coast immediately north and south of San Francisco Bay. Moreover, saddle (F2/F3) and sequin (M1/M2) beads are found exclusively in central and northern California (12, 13), again implying a more northern source. On the other hand H1b and G2 beads are found all over California. Results of the carbon and oxygen isotopic analyses are presented in Table II.

Contrary to our predictions, none of the 42 Delta beads display an oxygen isotopic signature consistent with modern shells from northern California (i.e., at least one $\delta^{18}\text{O}$ reading greater than 1.7). Instead, the majority of the beads (n = 29; 69%) have oxygen isotopic signatures indicative of a warm water source (i.e., at least one reading less than $\delta^{18}\text{O} = 0.6$). All but two of these fall within the range of southern California modern shells. Three shells have $\delta^{18}\text{O}$ values

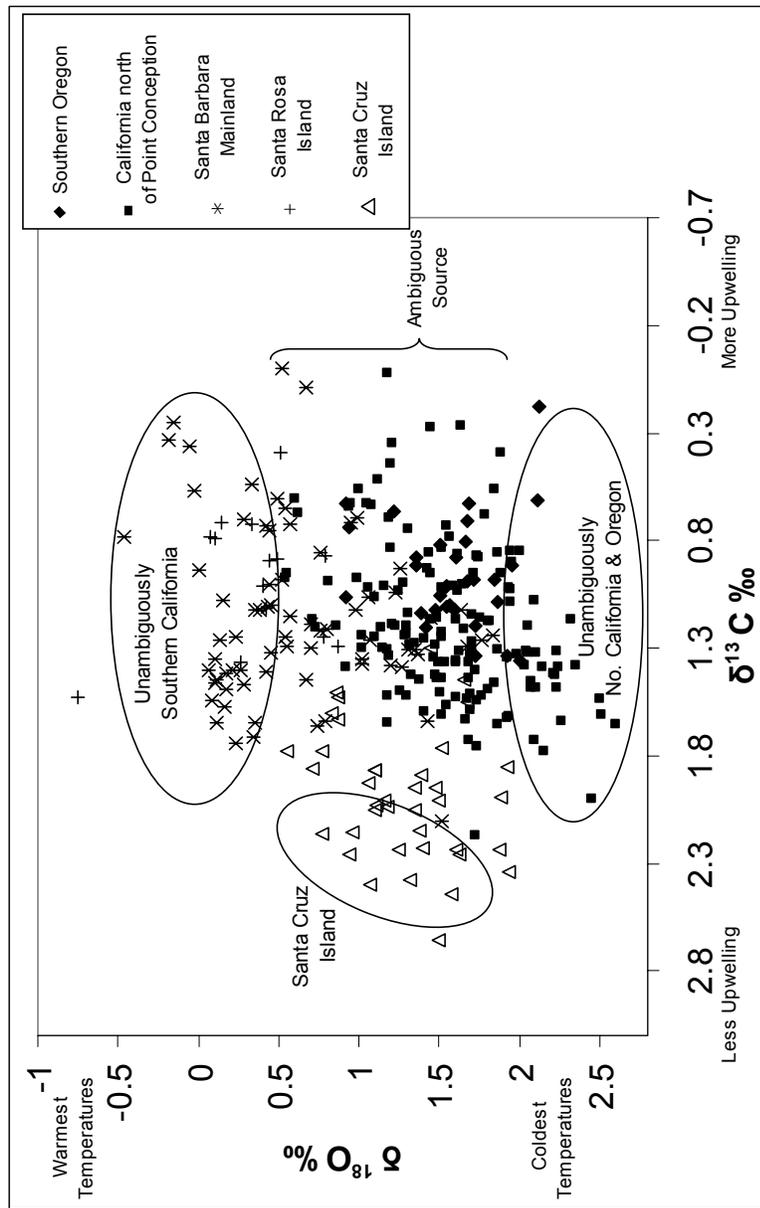


Figure 8. Distribution of Carbon and Oxygen isotope ratios for modern shells.

that are far lower than any values we recorded or predicted for modern shells from southern California (38), suggesting a possible source far south of California, perhaps in the Gulf of California, or brackish waters such as in the San Francisco Bay. We are unaware of *Olivella* shells growing in the bay, but our rough calculations suggest that if they did, the lower salinity values in the bay would lead to $\delta^{18}\text{O}$ similar to those found on these anomalous beads. However, highly unusual $\delta^{13}\text{C}$ values for these shells support the notion they do not come from southern (or northern) California.

The remaining 13 beads (31%) display signatures that are more ambiguous with regard to source. These shells show neither unambiguously northern or southern California isotopic values (i.e., all $\delta^{18}\text{O}$ readings are between 0.6 and 1.7). These beads fall in the middle of Figure 8 where the two regional ellipses overlap.

This is a result we found difficult to accept. We would have expected at least *some* of these beads to return oxygen isotopic signatures consistent with the colder waters of northern California. There is some tendency for bead types that we strongly suspect were produced in northern California (F2/F3 and M1/M2 types), to have more ambiguous signatures rather than unambiguously southern California ones. Such a pattern suggests that these beads have slightly lower $\delta^{18}\text{O}$ values (indeed, average $\delta^{18}\text{O}$ values by type shows this to be true). However, this pattern is far from strong. Thus, while 11 of 29 (38%) F2/F3 and M1/M2 beads have ambiguous signatures, only 2 of 13 (15%) G2 and H1 beads do. Table II shows these results.

Table II. Results of Oxygen Isotope Sourcing for Historic and Prehistoric Delta Beads Based on Modern Shell Data

| <i>Type/Source</i> | <i>F2/F3</i> | <i>M1/M2</i> | <i>G2</i> | <i>H1</i> | <i>Total</i> |
|--------------------|--------------|--------------|-----------|-----------|--------------|
| SoCal Signature | 12 | 5 | 5 | 4 | 26 |
| Other warm water | 0 | 1 | 2 | 0 | 3 |
| NorCal Signature | 0 | 0 | 0 | 0 | 0 |
| Ambiguous | 6 | 5 | 2 | 0 | 13 |
| Total | 18 | 11 | 9 | 4 | 42 |

Although our analyses are still in progress, two possible explanations for the isotopic data seem likely at this point. The first is that the majority, if not all, of these beads were in fact produced from shells collected in southern California. If true, this would imply that F2/F3 and M1/M2 beads, which have a geographical distribution limited to central and northern California, were either produced by southern California bead makers exclusively for northern California consumption, or made by central/northern California bead makers

who traded for or directly procured unmodified whole *Olivella* shells from southern California.

Neither of these options is particularly attractive. First, if they were really produced in southern California, we would expect at least some blanks, or broken or lost F2/F3 and M1/M2 beads to show up in archaeological sites. To our knowledge, this is not the case (see also King 1990:32). Second, if they are southern California shells that were reduced into beads in central and northern California, we would expect to see greater evidence for *Olivella* bead manufacturing in archaeological sites in this region. Though some production is evident (e.g., 34), the scale of such production does not appear to be large enough to account for the tens of thousands of F2/F3 and M1/M2 beads found in archaeological sites.

The second possibility is that prehistoric oxygen isotope signatures for different regions of the coast differ from modern values. Specifically, if water temperatures in northern California had been about 2–3° C warmer than at present when the prehistoric beads were produced (ca. 500–2000 cal B.P.), the northern California ellipse in Figure 8 would be shifted up by approximately 0.4–0.6 ‰ (an increase of ~0.2‰ in $\delta^{18}\text{O}$ equates to ~1C reduction in temperature and vice versa). As a result, we would obtain the “ambiguous” isotopic data discussed above even though the beads were produced in northern California.

There are conflicting data on whether northern California sea surface temperatures (SST) were consistently 2–3° C colder from 500–1600 cal B.P. This spans the period when most of our F, M, and G beads were made. Some studies suggest a 1–2 degree SST increase between 700–1300 cal B.P., with a decrease from modern between 500 and 700 cal B.P. (66). Such a change could explain a large fraction of the seemingly anomalous data we have collected from our beads. On the other hand, some researchers suggest approximately 1 degree cooler SST, on average, between 700 and 2000 cal B.P., with a slight *increase* between 500 and 700 cal B.P. (67). These studies are in slightly different areas, the former based on extreme northern California and near San Francisco Bay, the latter along the Big Sur coast. Information from southern California indicates temperatures there were approximately 1–3 degrees colder between 500 and 1500 cal B.P. (37). Yet as discussed earlier, southern California sea surface temperatures are influenced by a different set of oceanic currents than northern California and it is far from clear that the two are necessarily correlated. In any case, there are no clear patterns evident for all of northern California, and indeed, SST may have varied over time and space.

The preceding discussion is an issue we will address in greater detail in the near future. For example, we are in the process of sampling additional prehistoric whole *Olivella* shells from coastal sites in northern California for oxygen and carbon isotopes. At present, we have data on two whole *Olivella*

shells collected from archaeological sites near Kirk Creek in northern California. These shells were AMS dated to 1180 and 1755 cal B.P. Both shells display isotopic data wholly consistent with modern samples from that region (e.g., $\delta^{18}\text{O}$ readings greater than 1.6), indicating no change in SST. As part of our study, we plan to radiocarbon date the shells to develop a more detailed prehistoric record of sea surface temperature change along the northern California coast over the last 2000 years. Such a program should give us more confidence in sourcing ancient *Olivella* beads, allowing us to extend the time depth over which we can apply this technique.

Discussion

We have applied two distinct techniques, analysis of bulk chemical composition and the ratios of oxygen and carbon stable isotopes, in an effort to determine source provenance of *Olivella* shell beads in Western North America. These techniques produce varying degrees of success.

In our experience, bulk chemical composition holds only minor promise for sourcing specimens where source location is completely unknown. This is due to several complicating factors. Unfortunately, the concentration of most elements in a shell is quite low, limiting the number of variables available for discriminating between possible source zones. For many elements there seems to be high inter-shell variability collected from the same region, suggesting that biological and environmental factors are different for individual snails and have strong influences on shell chemistry. Furthermore, the chemical composition of a shell is quite dynamic following deposition as the aragonite interacts with the soil. Many elements become enriched in prehistoric shells, either due to replacement of existing minerals within the shell, or due to leaching out of other elements (thereby increasing relative concentration of existing ones). Although it may be possible to sample the interior of shells to minimize the effects of such post-depositional alteration and/or only analyze for elements that are more stable within the shell, it will be difficult to control for factors such as depositional environment and the amount of time a shell has been subject to leaching.

Furthermore, even among modern shell specimens there are only a few elements that seem to systematically characterize macro-regions of the California coast. Due to leaching and other issues discussed above, these patterns are less pronounced for prehistoric specimens (though still slightly evident). Thus, our hope that a single or small number of elements would unambiguously allow us to source shells to particular sections of the coast did not prove to be true. Together, these complications make it difficult for us to both define “source zones” based on bulk shell chemistry as well as to assign unknowns to any potential source zones.

Yet we are not without hope for future applications of bulk chemical analyses. More thorough chemical cleaning of the shell to remove inorganic components may reduce some of the variability among shells collected from a region, allowing us to better define potential source zones and assign unknown beads to these source zones.

Moreover, if a general source location is already known or suspected for a shell bead, bulk composition analysis may hold the potential to discriminate between micro-scale environments. For example, shells growing near certain rivers with peculiar geological watersheds within Southern California may have unique chemical composition relative to other rivers within that macro-region. If a bead was then suspected of having been produced in Southern California, bulk chemical composition might rule out or support production near that particular river. Our sampling strategy did not allow us to test this notion, but it is something we hope to investigate in the future.

At present, we believe oxygen and carbon isotopes hold greater promise for sourcing *Olivella* beads. We believe it is now possible to accurately determine the geographic origin of recent (latest prehistoric and historic) beads. We are working to extend this technique to more ancient contexts. Ultimately, such an approach would require knowing the approximate age of a bead before being able to infer geographic source based on the isotopic profile. This is not a problem for *Olivella* beads in California where a detailed chronology has been established (e.g., 12), but may be more problematical for other bead and pendant types that are poorly dated.

Although the source zones established by stable isotope analysis are quite large, effectively discriminating only between regions north vs. south of Point Conception, such information is still of great anthropological significance in California archaeology. Much has been made archaeologically of the importance of prehistoric bead production, particularly on the Channel Islands off the southern California coast. Bead producers on these islands are thought to have supplied most or all of California with *Olivella* beads. The use of oxygen and carbon isotopes facilitates the testing of this hypothesis. While we are still hesitant to assign the majority of the Delta beads we analyzed to a southern California source, the available evidence clearly does not rule out such a scenario. In future work, we will subject a sample of these beads to ICP-MS analysis in hopes of generating additional data that might inform on geographic provenance.

Conclusions

It is clear that shell-bead sourcing using chemical means is still in its infancy. If shell-bead sourcing is to play a more important role in archaeological

studies we will have to better identify criterion that will discriminate among shellfish species growing in different areas. A major hurdle in this respect is the dynamic nature of oceanic environments from which many shellfish species draw their chemical makeup, both temporally and spatially. Oceanic currents distribute the same body of seawater over large areas, exposing shellfish to many of the same conditions. Furthermore, seasonal, inter-annual, and even millennial variations in seawater conditions introduce variability that reduces the geographic accuracy of our source assignments. Moreover, shellfish are dynamic organisms which alter their chemistry depending on local conditions, unlike obsidian and ceramics. These factors still make shell bead sourcing a difficult undertaking.

Combining both bulk elemental composition with C and O stable isotope analysis would provide some degree of cross-checking on shell bead analyses. This is something we will pursue in future research. Indeed, in the future, we expect archaeologists to turn to other techniques to generate complementary data for sourcing shell beads. For example, we believe a useful approach will be the analysis of isotopic ratios of other elements, such as strontium, neodymium, and lead, among others. As our analytical techniques become more accurate and precise, it will be easier to analyze the ratios of rare isotopes that could prove useful in provenance analysis.

Acknowledgements

Funding for this project was provided by the Wenner-Gren Foundation for Anthropological Research (grant #7370) and the National Science Foundation (#0504615). We thank Iain Freckleton, Rowan Gard, Pamela Reynolds, Michelle Gras, and Dave Winter for assistance with sample preparation and mass spectrometry. We further thank Doug Kennett, Michael Glassow, Randy Groza, Linda Hylkema, Mark Hylkema, Randy Milliken, Dustin McKenzie, Allika Ruby, Greg White, and Randy Wiberg for providing us access to shells and beads.

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