THE SOURCE OF EARLY HORIZON *OLIVELLA* BEADS: ISOTOPIC EVIDENCE FROM CCO-548

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Hundreds of thousands of Olivella *beads have been found over the last 100 years of archaeological investigation in central California. Strangely, no bead production sites are known from the region. Whether such sites once existed and were destroyed prior to archaeological investigation, or whether bead production was largely decentralized, is unknown. Lacking direct evidence for bead production, this study turns to geochemical information from conveyed beads in an attempt to track their original source. Our multiproxy approach combines measurements of the carbon, oxygen, and strontium isotope ratios in aragonitic shell. Initial data show promise for bead "sourcing" or provenance analysis. We focus on a small sample of beads from a recently excavated Early Horizon (ca. 4000 B.P.) site on Marsh Creek in the California Delta, CA-CCO-548, as a test case. Results suggest production, not on the Pacific Coast, but in a protected bay or estuary with significant influx of freshwater.*

Beads made out of the purple olive shell, *Olivella biplicata*, are one of the most commonly formed artifact types found in archaeological sites in California. In some areas, such as San Francisco Bay, they are by far the dominant type of shaped artifact found. Indeed, *Olivella* beads, made from a variety of species in this genus, are found archaeologically throughout much of North America (Kozuch 2002; Nelson 1991; Thomas 1988).

In central California, *Olivella* beads have received considerable attention from scholars (e.g., Bennyhoff and Hughes 1987; Chagnon 1970; Gifford 1947; Hartzell 1991; Hughes and Bennyhoff 1986; Milliken and Bennyhoff 1993). Much of this research has been directed at seriating different bead forms and using them to identify different temporal units in the archaeological record, an approach that is still commonly used. For example, recent radiocarbon dating of large numbers of beads has shown that these seriations are generally correct, but has led to some restructuring of the basic chronology (Groza 2002; Milliken et al. 2007; Vellanoweth 2001).

Chronology-building is clearly an important line of research and forms the backbone of much of our analyses. However, considerable anthropological and environmental information remains to be extracted from *Olivella* beads. For example, in southern California, scholars have undertaken considerable research on *Olivella* bead production and spatial distributions (e.g., Arnold 1987, 1991; Arnold and Graesch 2001; Arnold and Munns 1994; Graesch 2004; Erlandson et al. 2005; King 1990;

Pletka 2004). These studies have dramatically changed our understanding of basic Chumash economy, political organization, exchange, and wealth accumulation, among other topics. Moreover, diachronic studies allow archaeologists to track the evolution of various social and political institutions, contributing greatly to general anthropological theory. Thus, the combination of both detailed chronology-building *and* analytical studies on bead production and distribution have yielded great payoffs.

Unlike the Channel Islands region of southern California, there is little evidence from central California for sites where beads were produced in large numbers, and therefore research in central California has lagged considerably. Nevertheless, some central California sites contain small amounts of broken *Olivella* shells, which are occasionally interpreted as the waste from small-scale bead production (e.g., Hartzell 1991) but could also represent broken whole or spire-lopped *Olivella* shells (which were also widely traded). Even if such detritus reflects local bead production, it only represents enough material to produce a few dozen beads in most cases. Abandoned blanks, partially drilled shells, large numbers of drills, and other more direct evidence of bead production are generally lacking. Yet beads must have been produced in great quantities, for many bead types are unique to central California (implying local production) and many hundreds of thousands of beads (likely over a million by quick estimation) have been recovered in archaeological investigations over the last 100 years. Most of these beads have been found in funerary contexts, and many burials contain large quantities of associated *Olivella* beads. For example, one burial at ALA-413 was directly associated with over 30,000 beads (Wiberg 1988).

In order to identify the source of these central California *Olivella* beads, a method is needed for tracking the production and movement of beads across the region. Because significant production sites are lacking, we are exploring alternative geochemical methods in an attempt to localize the provenance of the beads (Eerkens et al. 2005, 2007, 2010). To date, the most promising lines of geochemical fingerprinting analyses include measurements of carbon, oxygen, and strontium isotope ratios. Here we apply those techniques to a small sample of beads (n = 12) from CCO-548, an Early Horizon (ca. 4000-2500 B.P.) site in the California Delta.

CCO-548

The Marsh House site (CCO-548) is located on the northeastern edge of the Diablo Range at approximately 50 m elevation above sea level, adjacent to the California Delta (see Figure 1). The site lies within a broad, open grassland community with scattered oaks on the banks of Marsh Creek, a seasonal stream that originates near the eastern summit of Mount Diablo and flows into the Delta.

The site has been severely impacted by both bank erosion and a housing development. Both the private developer and California State Parks have initiated salvage excavations at the site (Rosenthal et al. 2006; Wiberg and Clark 2004). A range of cultural features, including hearths, fire-cracked rock concentrations, burials, and a house floor, were discovered during this work. At least two discrete occupations are evident: a deeper Middle Holocene occupation dating to about 6500 B.P., and a shallower occupation dating to the Early Horizon, between 3300 and 4500 B.P.

All of the beads in this study derive from the later Early Horizon component. The sample includes beads from both burial and general midden contexts. A total of 12 beads were analyzed, including four spire-lopped and eight rectangular L2/L3 beads (type per Bennyhoff and Hughes 1987). Each bead was sampled multiple times for their $\delta^{13}C$ and $\delta^{18}O$ values (see below). A subsample of these beads was further analyzed for $^{87}Sr/^{86}Sr$.

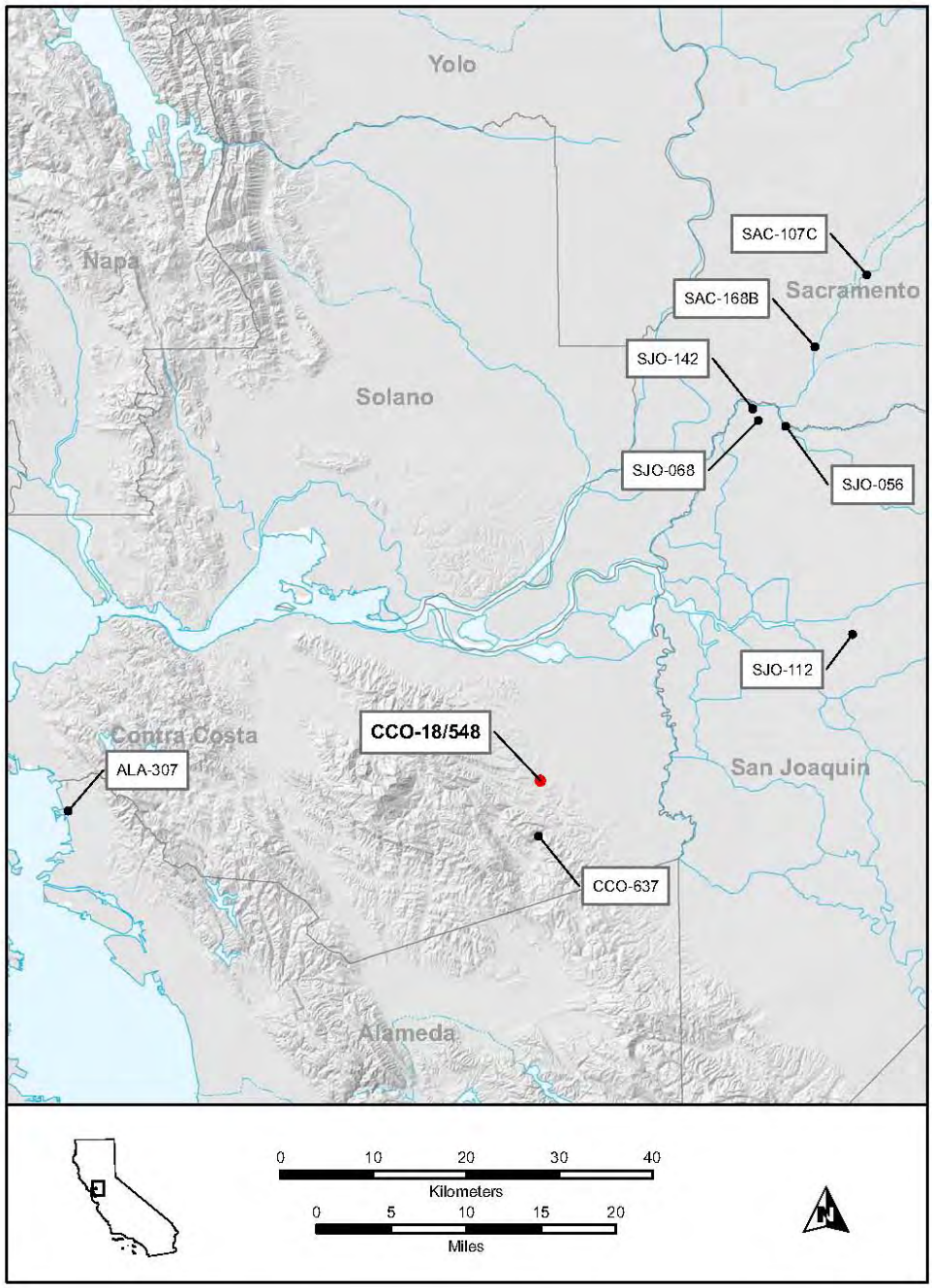

Figure 1: Map showing CCO-548, ALA-307, and geographic features discussed in the text.

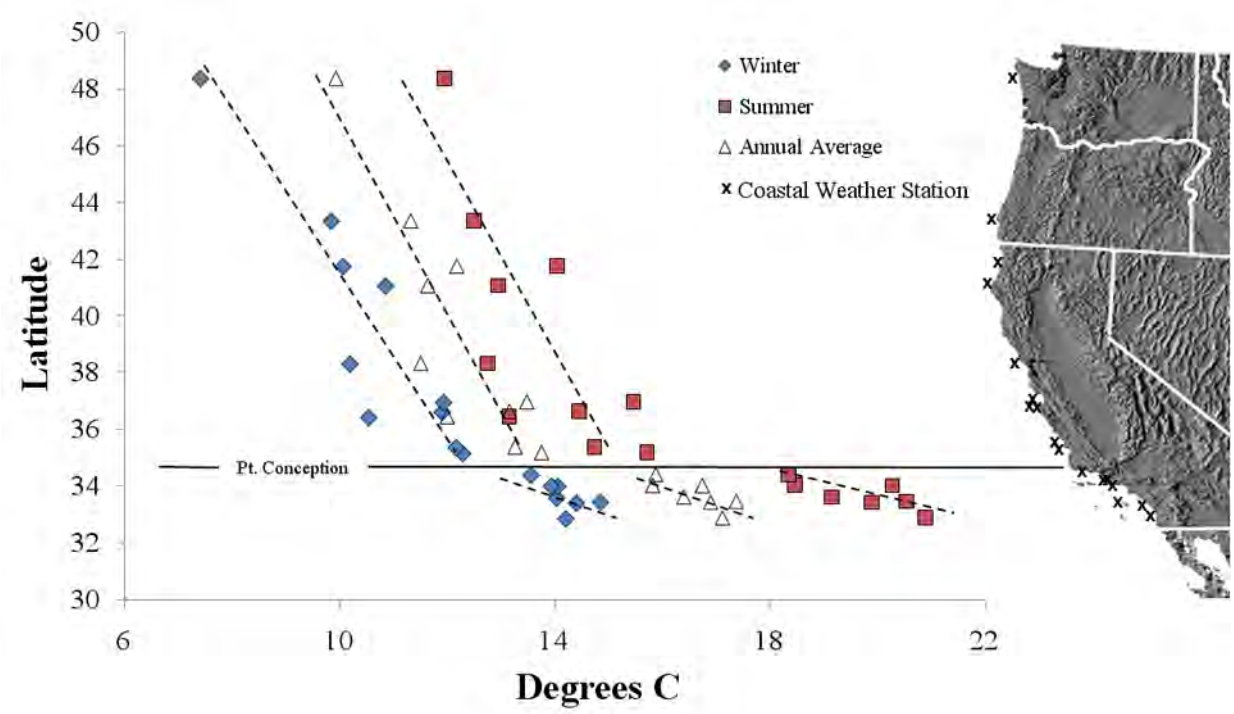

Figure 2. Modern SST temperatures along the Pacific Coast, including average winter, average summer, and average annual SST.

BACKGROUND AND APPROACH

Figure 2 shows sea-surface temperature (SST) data from weather stations along the Pacific coast (within 1 km of shore), from southern California to Washington. Latitude is plotted against average monthly maximums (summer) and minimums (winter), and annual averages (the average of monthly averages), in degrees C. These data points are available online (http://shorestation.ucsd.edu).

The figure shows that stations south of Point Conception (at 34.5º latitude) have significantly warmer SST than localities to the north. There is slight overlap between 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 18º C) and winter SST in northern California (always averaging under 12.5º C) are distinctive. These differences are controlled by the northern California current, which derives its source water from the north Pacific, and the subtropical Davidson countercurrent which brings warm waters into southern California from the Baja California, Mexico region (Bemis et al. 2002). Furthermore, gradual differences exist within northern and southern California respectively. Average SST decreases nearly monotonically with increasing latitude more gradually in northern California than in southern California.

Shell oxygen isotopic composition, expressed as $^{18}O/^{16}O$ ratios or the $\delta^{18}O$ value, which is the normalized isotopic ratio relative to the international standard, V-PDB (Vienna-Pee Dee Belemnite), is primarily affected by two factors: the $\delta^{18}O$ of seawater ($\delta^{18}O_{sw}$), which covaries linearly with salinity, and water temperature. Because $\delta^{18}O_{sw}$ is relatively constant along the Pacific Coast, temperature becomes the primary factor affecting $\delta^{18}O$ along the open coast (for additional discussion see Kirby et al. 1998; Krantz et al. 1987; Schmidt et al. 1999; Spero and Lea 1996; Wefer and Berger 1991). This correlation allows us to geographically source shell beads based on $\delta^{18}O$ values. Previously, Eerkens et

al. (2005) provided a proof-of-concept demonstration of this technique using the $\delta^{18}O$ from modern *Olivella biplicata* shells collected along the Pacific Coast.

Rather than conducting only one oxygen isotopic measurement on each bead, we sampled each specimen at multiple points along the parallel growth rings to obtain more complete seasonal information. Sampling along multiple bands provides a greater chance of capturing a distinctive season of growth, for example, summer in southern California, which is particularly warm, or winter in northern California, which is distinctively cold. As well, we collected information on shell $\delta^{13}C$ (the $^{13}C/^{12}C$ ratio relative to PDB), which often reflects changes in the $\delta^{13}C$ of dissolved inorganic carbon (DIC) in the ocean due to differences in upwelling conditions.

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 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 percent 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. Precision of these analyses was 0.05 per thousand and 0.08 per thousand ($\pm 1\sigma$) for $\delta^{13}C$ and $\delta^{18}O$ respectively, based on repeat analyses of an in-house calcite standard.

RESULTS

Figure 3 plots $\delta^{13}C$ against $\delta^{18}O$ for the 12 beads analyzed from CCO-548. Squares in the graph represent samples taken from rectangular L-series beads, while circles represent samples taken from spire-lopped beads. Again, each bead was sampled at multiple points along the growth lines, and colors are used to denote samples from particular beads. Also plotted, for comparison, is one rectangular Early Horizon bead (type L2) from ALA-307, the West Berkeley Shellmound (represented as open squares; Wallace and Lathrap 1975). Dotted ellipses represent the range of isotopic values obtained from modern *Olivella* samples from southern and northern California (south and north of Point Conception, respectively), while the solid ellipse represents the range of values from *Olivella* beads collected from the Los Angeles Basin and San Nicolas Island (see Eerkens et al. 2010).

The figure highlights several interesting patterns. First, the isotopic distributions of spire-lopped and rectangular wall beads (L2/L3) largely overlap. This suggests that the geographic origins of the shells used to make these bead types also overlap. In other words, we cannot say that spire-lopped and rectangular beads were produced in different regions. As well, the Early Horizon bead from ALA-307 falls within the same range, suggesting it too was produced in the same general vicinity.

Second, and more surprising, the majority of data from these beads do not fall into the isotopic range of modern *Olivella biplicata* shells from beaches north of Point Conception (below, we refer to areas north of this point collectively as "northern California"). With the exception of one spire-lopped sample (SB5), each bead displays at least one, and usually several (or all), data points that fall outside the range for modern samples from northern California. Given that all these beads were found at sites in northern California, we had expected a different pattern.

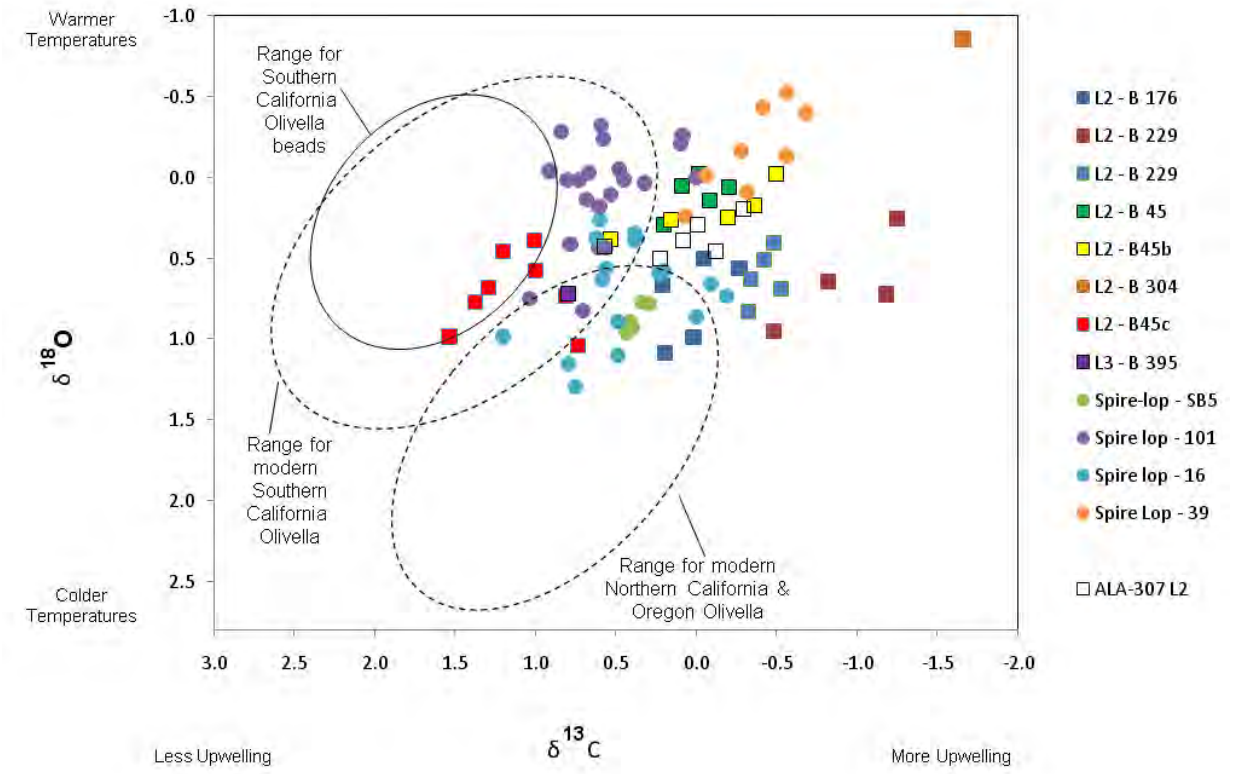

Figure 3. $\delta^{13}C$ and $\delta^{18}O$ for samples from 12 beads from CCO-548.

While these data do not fall within the northern California range of modern shells, the majority of the data are also quite different from data obtained from modern shells collected along southern California beaches. With the exception of one spire-lopped (101) and one rectangular bead (B45c), all beads are shifted towards lower $\delta^{13}C$ values, although the range of $\delta^{18}O$ values is similar to that of the southern California ellipse. Thus, the CCO-548 beads tend to fall outside the range of *any* modern *Olivella* samples we have analyzed to date.

Overall, the bead data reflect a greater influence of upwelling or coastal estuarine conditions due to the reduced $\delta^{13}C$ values and either warm waters which are similar to those of southern California, or cooler waters with reduced salinity (= lower $\delta^{18}O_{sw}$). The latter scenario would be possible if the shells used to produce these beads were collected from a brackish-water locality such as within a protected bay or estuary. Although the central California coastline has few river estuaries north of Point Conception, northern California contains several such bays, including San Francisco Bay, Tomales Bay, and others.

To test this hypothesis, we analyzed three beads for their strontium isotopic composition ($^{87}Sr/^{86}Sr$). Strontium readily substitutes for calcium within the shell matrix, and shells do not discriminate between the isotopes of strontium. Thus, the $^{87}Sr/^{86}Sr$ in a shell reflects the chemical composition of the water in which they grew. Importantly, the $^{87}Sr/^{86}Sr$ of the ocean is uniform around the Earth with a ratio of 0.7092, and has not changed on the short timescale of the Holocene. However, the $^{87}Sr/^{86}Sr$ of river-derived strontium can deviate significantly from oceanic $^{87}Sr/^{86}Sr$, so that a freshwater contribution to coastal or estuarine systems can change this ratio. In northern California, where the eroding terrain is not enriched in radiogenic ^{87}Sr, stream runoff is more enriched in ^{86}Sr than the adjacent ocean and can lower the $^{87}Sr/^{86}Sr$ ratio. For example, freshwater input into San Francisco Bay averages about 0.7065 (Ingram and DePaolo 1993).

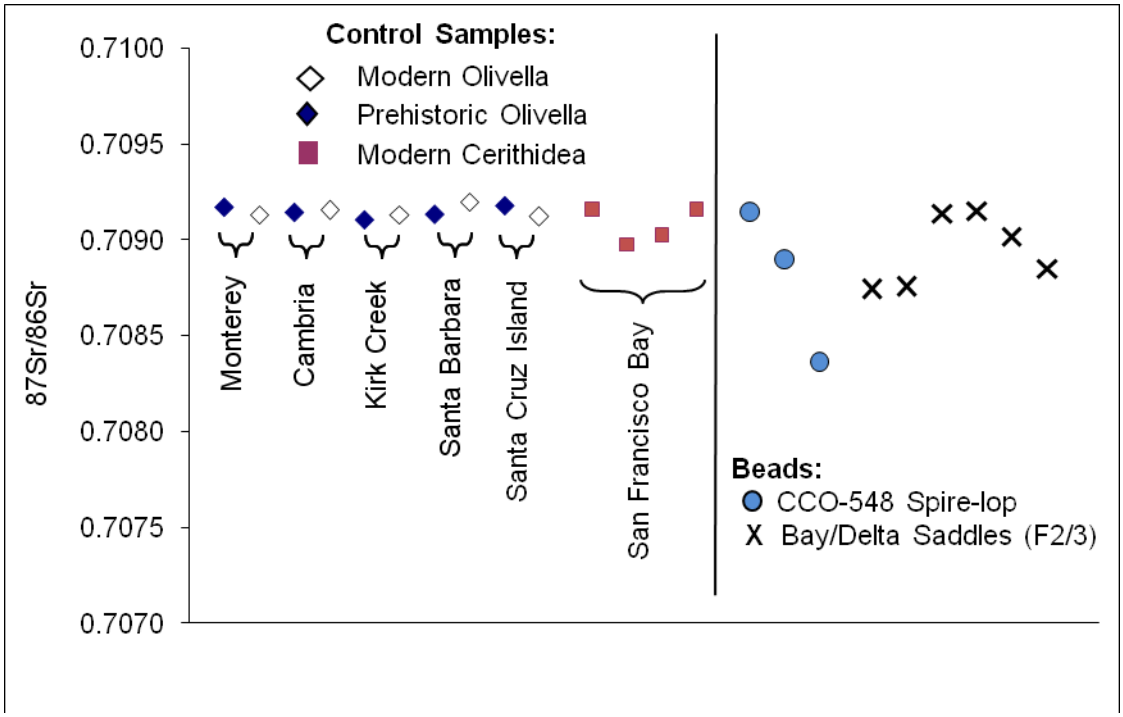

Figure 4. $^{87}Sr/^{86}Sr$ of control and CCO-548 and other northern California beads.

Figure 4 shows 10 control samples collected along the coast, paired prehistoric and modern specimens, collected from five geographic locations between southern and northern California. These are plotted as diamonds in the figure, and all yielded an expected $^{87}Sr/^{86}Sr$ ratio of 0.7092. This supports our primary hypothesis that the $^{87}Sr/^{86}Sr$ ratio in *Olivella* locks in ambient water Sr chemistry, and has remained constant during the Holocene. We were unable to locate *Olivella* specimens from San Francisco Bay, but did collect and measure the $^{87}Sr/^{86}Sr$ ratios in four modern specimens of *Cerithidea californica* (California hornsnail). These were collected from the southern part of the Bay in brackish water locations. Two of the samples yielded $^{87}Sr/^{86}Sr$ ratios with an oceanic signature (or only slightly brackish water), while the other two yielded slightly lower ratios at 0.7090, suggesting exposure to significant amounts of terrestrial Sr.

The right side of Figure 4 shows $^{87}Sr/^{86}Sr$ for three of the spire-lopped beads from CCO-548, and for comparison, six saddle beads (F2 and F3 series; Middle Horizon, ca. 2500-900 B.P.) from archaeological sites in the Bay and Delta regions. As seen, one of the CCO-548 beads (101) yields an $^{87}Sr/^{86}Sr$ signature consistent with open oceanic conditions. This bead occurs in the upper center part of the graph in Figure 3, and had $\delta^{13}C$ and $\delta^{18}O$ values that were most like southern California shells and beads. The other two CCO-548 spire-lopped beads have Sr isotopic data unlike ocean water. Likewise, four of the six saddle beads suggest the shells used to make them grew in waters with significant inputs of fresh water. Beads analyzed from southern California (Eerkens et al. 2010) display $^{87}Sr/^{86}Sr$ ratios of 0.7092, indicative of growth under open oceanic conditions.

DISCUSSION AND CONCLUSIONS

Based on the combined C, O, and Sr isotope data, we believe that the unusual O and C values in the Early Horizon beads are due to the collection of *Olivella* shells from waters with significant inputs of fresh water. Thus, contrary to our initial assumptions, salinity may play a more important role in C, and especially O, isotopic composition in northern California than we had originally estimated. $^{87}Sr/^{86}Sr$

isotope analyses provide us with a method to estimate and correct for such salinity effects. Our future research will focus on such adjustments.

Although we have not yet pinpointed the exact geographic origin of the artifacts, what is clear is that the Early Horizon beads we have analyzed from the Bay and Delta are relatively consistent with one another. Outside of one spire-lopped and one rectangular L2 bead that have geochemical fingerprints that suggest they could come from southern California, we believe the remaining shells were collected from a northern California locality. Strontium isotope analyses indicate that this location is in a more enclosed bay or estuary with significant influx of fresh water. San Francisco Bay and Tomales Bay are obvious candidates. Although *Olivella biplicata* are known to inhabit Tomales Bay (Mueller 1990), our initial explorations along the shores were unable to locate either modern or ancient *Olivella* shells. Likewise, we have been unable to locate modern *Olivella* shells along the shores of San Francisco Bay, and are not aware of significant quantities of this species from shell middens, though they are occasionally mentioned as minor constituents of such sites (e.g., Nelson 1910:376).

In conclusion, our provenance research with shell beads is ongoing. It appears that the majority of Early Horizon beads derive from northern California locations, apparently not along the coast, but primarily in a bay or estuarine location. While we have answered some questions, many more unexpected questions arose during the data-collection phase. In the future we plan to continue sampling modern shells from different geographic regions and types of shell beads from different time periods. As well, we aim to explore the potential of other isotopes in differentiating the geographic source of beads.

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