Bayesian ^{14}C Analysis, Formation Processes, and Accumulation Rates of the Prisoners Harbor Shell Midden and Village Complex, Santa Cruz Island, California

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ABSTRACT

The Prisoners Harbor site (CA-SCRI-240), one of the largest sites on California's Channel Islands and the likely location of the Chumash village *Xaxas*, played a key role in regional models of emergent complexity and culture contact. Despite substantial excavation at the site, published research has focused on the most recent

500 years of the site's occupation, with comparatively little attention given to the 2-3 millennia preceding this. Here we focus on the formation and chronology of CA-SCRI-240 by presenting a Bayesian analysis of 36 radiocarbon dates from throughout the site's occupation. Comparing three suites of radiocarbon dates, we provide a revised chronology for CA-SCRI-240 and examine site formation processes, sediment deposition rates, and the implications our study holds for reconciling older radiometric dates with large analytical errors and higher precision accelerator mass spectrometry dates. Our analysis suggests that the earliest site occupation was 2750 cal BP, roughly 2000 years later than previously presumed. Sedimentation rates vary throughout the 5.7 m sequence. Deposits for the first 1000 years accumulated slowly followed by relative increase in accumulation rates in the uppermost occupation levels dating to historic times. Our study demonstrates the importance of Bayesian analysis for improving radiocarbon chronologies for large, multi-component sites.

Keywords: Maritime hunter-gatherers, Radiocarbon dating, Shell midden, Taphonomy, Coastal archaeology

1. Introduction

Coastal archaeologists have long been interested in understanding the formation and accumulation of shell middens, with such studies having important implications for broader interpretations of site function and human cultural and environmental developments (see Claassen, 1998; Roksandic, et al. 2014; Stein, 1992; Waselkov, 1987). A key component of this research is chronology building, especially the use of radiocarbon (^{14}C) dating, to place site formation and human cultural issues in proper chronological context. In recent years, Bayesian analysis of ^{14}C dates has emerged as an important tool for providing statistical support for the reliability of site chronologies and documenting the presence of outliers or problematic dates (Bayliss and Bronk Ramsey, 2004; Bronk Ramsey, 2009a, 2009b). Bayesian ^{14}C analysis has become a potent tool for researchers working at deeply stratified sites, including shell middens, where ^{14}C dates can be compared to

stratigraphic excavation data (see Culleton et al., 2012, Jazwa et al., 2013; Kennett et al., 2011, 2014).

In this paper, we use Bayesian analysis of radiometric and high-precision AMS ^{14}C dates to evaluate the formation and chronology of the Prisoners Harbor site (CA-SCRI-240) on Santa Cruz Island, California (Fig. 1). The Prisoners Harbor site is the probable location of the Chumash village of *Xaxas* and is one of the most significant sites on the Channel Islands. It has been of scientific interest since at least the 1920s (see Arnold, 1994, 2001; Noah, 2005), producing thousands of artifacts and providing information about Chumash lifeways both before and after contact with Europeans. The site is thought to have been home to island elites, used as a trade hub throughout prehistory, and the location of significant production of chert microliths (see Arnold, 1987). For decades, the site has helped researchers investigate a variety of issues of broad anthropological significance, including emergent sociopolitical complexity, bead manufacture, lithic technologies, subsistence economies, and island settlement patterns (e.g., Arnold, 1983, 1994, 2001; Colten, 1995, 2002; Colten and Arnold, 1998; Kennett, 2005; Noah, 2005; Rick et al., 2005).

Despite significant research at the site, especially by Glassow and Spaulding in the 1970s and by Arnold in the 1990s (see Arnold, 2001), a comprehensive assessment of the site's ^{14}C sequence has never been published. This has created some confusion about the site's antiquity and timespan of occupation. In a review of Channel Islands archaeology, for instance, Rick et al. (2005:202) report that the Late Holocene occupation of the site may have begun around ~ 3210 cal BP, and Kennett

(2005:160-167) similarly suggested an occupation beginning around ~3151 cal BP. Drawing on a single radiometric ^{14}C date obtained in the 1970s, Braje et al. (2011:283) suggested the site occupation may have begun some 5300 years ago. Colten and Arnold (1998: 686-687) describe one of the only attempts to construct a site chronology, conducted by Phillip Walker in the 1990s. He compared reported ^{14}C dates with diagnostic artifacts recovered from the site along with stratigraphic profile drawings to generate a chronology for the upper deposits of the site. This basic chronology encompassed three periods between approximately AD 1000 and 1815. Because of the lack of published research on the site's chronology, questions remain about when human occupation of the site began, how the early occupation of the site compares to later occupations, and how the site's ^{14}C dates can inform site formation.

To resolve these issues, we present an analysis of all ^{14}C dates ($n=36$) from the site, including 21 dates obtained in the 1970s (Taylor, 1975:398-340) and 15 new Accelerator Mass Spectrometry (AMS) high-precision dates from the base of the site deposits to the uppermost deposits during the Historic period. The site includes 50 well-defined strata that provide the stratigraphic details for building the Bayesian radiocarbon model and evaluating the dates obtained in the 1970s and 2010s. Our analysis has implications for chronology building in shell middens and other deeply stratified sites and for reconciling differences between different sets of radiometric and AMS ^{14}C dates often obtained decades apart.

2. Environmental and Cultural Background

2.1. The Northern Channel Islands and the Prisoners Harbor Site

The Northern Channel Islands are located in the Santa Barbara Channel region off the coast of southern California and consist of Anacapa, Santa Cruz, Santa Rosa, and San Miguel islands. The islands are home to highly productive marine ecosystems that contain a variety of shellfish, fish, pinnipeds, seabirds, kelp, and other nearshore and marine resources (see Rick et al., 2005: 173). Freshwater, lithic outcrops, and animal and plant resources vary between islands, with the greatest diversity found on the larger islands of Santa Cruz and Santa Rosa (Jazwa and Perry, 2013b; Rick et al., 2005).

Santa Cruz is the largest island in the chain at 249 km², has the greatest variety of terrestrial resources, and contains the most abundant perennial streams and springs (Jazwa and Perry, 2013a:9; Junak et al., 1995). The island is ~30 km from the mainland and possesses 480 native plant taxa and about a dozen small terrestrial mammals, including the island fox (*Urocyon littoralis*) and island spotted skunk (*Spilogale gracilis amphiala*; Junak et al., 1995; Schoenherr et al., 1999). Santa Cruz Island's interior and coastal environmental diversity helped foster a variety of different human land use strategies and ultimately archaeological site types, including villages with permanent house structures (see Glassow et al., 2010:11.3).

Fig. 1. Map of California's Channel Islands including the location of CA-SCRI-240.

CA-SCRI-240 is located at Prisoners Harbor on northeastern Santa Cruz Island at the mouth of Cañada del Puerto, which extends into the island's large interior valley. Prisoners Harbor is a relatively sheltered anchorage, and a sandy beach is located approximately 50 m beyond the northern edge of the site. A freshwater stream forms a wetland adjacent to the site, but the stream was repositioned in the late 19th century, destroying a large section of the site. D. B. Rogers (1929) could still see portions of the site immediately following stream erosion and he suggested that the site may have originally been 120 m (east-west) x 46 m (north-south). Arnold (1994) noted that in the early 1990s the site measured about 40 x 45 m, having lost about 80 m on its eastern end. Expansion of the wetland was recently part of a major restoration project undertaken by the National Park Service.

CA-SCRI-240 is one of the largest sites on California's Channel Islands, with deposits extending to a depth of ~5.7 m (Fig. 2, see Arnold, 2001). In his 1974 stratigraphic notes, Spaulding distinguishes between two principal stratigraphic units: an upper unit "heavy in shell as opposed to earth and stone" and nearly a meter thick but becoming thinner toward the site margins, and a lower unit with "dark earth as its major component." The matrix of the habitation deposits appears to be sand and silt blown in from the beach located north of the mound. The lowermost deposits contain alluvial deposits from the stream descending to Prisoners Harbor through Cañada del Puerto.

2.2 Previous Archaeological Research at Prisoners Harbor

Archaeologists have worked at the Prisoners Harbor site since at least the 1920s, and it may have been excavated by antiquarians and looters prior to this (Arnold, 1994). Ronald Olson conducted the first formal excavations at the site in 1927-1928, excavating a 15 x 1 m trench to a depth of 0.3-1.5 m and a total of 316 m³ in just a few days (Arnold, 1994; Hoover, 1971). Rogers worked at the site in 1936, excavating a few human burials, and Woodward of the Natural History Museum of Los Angeles County also excavated a few burials at the site in 1939 (Arnold, 1994). Phil Orr of the Santa Barbara Museum of Natural History visited the site in 1947 and 1950, excavating a 1.5 x 1.5 m pit to a depth of ~3 m in the cemetery, perhaps in areas disturbed by Woodward's excavations (Arnold, 1994). These early excavations lack stratigraphic control and depth information, and none of the radiocarbon samples reported here come from these excavations.

Fig. 2. (A) 1974 photo of CA-SCRI-240 looking southwest. (B) 1974 excavation showing Test Unit 2 north and west profile.

In 1973 Glassow and his team excavated a 50 x 50 cm column sample in the bank of the stream that bisects the site deposits along its eastern edge. At the time, this bank was nearly vertical and only minor trimming and removal of slough near the base of the exposure was necessary to achieve a plumb face. Excavation levels followed natural stratigraphic divisions, with each level being identified by a letter beginning with A at the top of the column (Fig. 4). Double letters designated strata below stratum Z. Because the water table was reached at stratum CC, excavation could not continue below stratum HH because of water inundation. Consequently, the base of the deposits was not reached. Deposits from each stratum were sifted through a 1/8-inch mesh screen, and all material recovered in the screen was retained. Concentrations of charcoal encountered during excavation were collected when encountered during excavation for ^{14}C dating. Because the initial date for Stratum HH appeared to be anomalously early, a new date for this stratum was obtained for this study from a California mussel (*Mytilus californianus*) shell fragment collected from this deposit.

In 1974 Spaulding and his crew excavated two trenches through the mound deposits: Unit 1 was 16 m long and located on the northern flank of the mound and Unit 2 was 14 m long and located on the southern flank. Both trenches extended from the outer margins to the relatively flat top of the mound. The trenches were each 2.5 m wide and divided into three parts that included 75 cm sections on the east and west sides and a 100 cm section between them. Excavations were conducted in 20 cm arbitrary horizontal levels called “cuts,” with depths of each cut given in cm below a master site datum near the center of the site. Each cut was numbered successively beginning at the surface. The bulk of the deposits was removed without screening, although samples of deposits from each cut typically were sifted through 1/4-inch screens and field-sorted, and smaller samples were sifted through 1/8-inch screens and retained for lab sorting. Profile drawings showing the stratification of deposits were drafted for each trench, but strata were not labeled, and it is apparent that the cuts bisected sloping strata. Concentrations of charcoal encountered during excavation were collected when encountered and labeled according to unit and cut; however, horizontal position within a cut usually was not recorded. Consequently, the stratigraphic relationship among dates is unknown.

Spaulding had not reached sterile deposits in either of the two trenches he and his team excavated. In 1976, before the trenches were backfilled, Glassow and his team excavated a 1 x 1 m unit at the base of Spaulding’s Unit 2 (Fig. 5). The deposits were excavated by natural stratigraphy, with thicker deposits divided into arbitrary 20 cm levels. All depth information was recorded relative to the base of

Spaulding's Unit 2. Because excavation began at depths near the water table with moist deposits, all materials were water-screened in the field through 1/4-inch-mesh. The water table was reached at approximately 50 cm, requiring a sump hole to be dug adjacent to the unit from which water was removed with a submersible sump pump. The flow of water into the unit below the water table, as well as the dampness of the deposits, meant that divisions between strata during excavation were not as precise as was the case above. Sterile deposits ultimately were encountered at 180 cm below the base of Spaulding's Unit 2, or 566 cm below Spaulding's master datum. After completion of the unit excavation, a 25 x 25 cm column sample was excavated, with deposits from each stratigraphic level being water-screened through 1/8-inch mesh. Radiocarbon dates were obtained from individual shells selected from different levels of the column sample.

From 1990 to 1997, Arnold led excavations at Prisoners Harbor focusing on the upper deposits dated to the late prehistoric and historic periods. Arnold's crews excavated 13 1 x 1 m units more or less in a block in an undisturbed area of the site. Dense deposits of faunal remains and lithic and shell artifacts dominated the Late and Historic deposits, with fine-mesh screen (1/8-inch and smaller) yielding thousands of beads, microliths, and other small artifacts (see Arnold, 1994, 2001; Noah, 2005). Five new AMS ^{14}C dates were obtained from samples collected during Arnold's excavations, and these dates form the basis for establishing an absolute chronology of the terminal site deposits (Fig. 3).

3. Materials and Methods

3.1 Provenience and samples for radiocarbon dating

We obtained 16 new AMS ^{14}C dates from CA-SCRI-240 for this study from bulk shell samples from specific excavated levels because samples collected from sidewalls were not available. Ten ^{14}C dates were obtained from Glassow's test unit excavated at the base of Spaulding's Trench 2. The samples were obtained from the column sample excavated in the test unit for nearly every 20 cm level from the top of the unit at 384 cm to the bottom at 566 cm below the surface (Fig. 5). All of these samples were well-preserved California mussel shells selected by Rick from collections housed at the University of California, Santa Barbara.

Because the test unit samples did not include the uppermost site deposits, we obtained five ^{14}C dates from materials in the site deposits excavated by Arnold (2001). These samples all come from Unit 4N17W between 60 to 15 cm deep (Fig 3). These radiocarbon samples are from a terminal Late Period possible house floor, non-floor contexts, and an early Historic floor and possible feasting contexts. All five samples were obtained from collections housed at the Cotsen Institute of Archaeology, University of California, Los Angeles.

Glassow obtained a date from a single marine shell from level HH of his 50 x 50 cm column sample (Fig. 4). A previous date on charcoal from level HH was obtained by UCR to ~5300 cal BP. We obtained a new date because there had long been questions about the reliability of this earlier UCR date.

All shell samples submitted for AMS dating were oversized fragments that crossed over multiple shell growth bands to reduce any potential intrashell variability (see Culleton, et al. 2006). The samples from Glassow's test unit were

sent to the National Ocean Sciences AMS Facility at the Woods Hole Oceanographic Institution. The samples from Unit 4N17W and level HH were sent to the DirectAMS laboratory in Bothell, Washington. Details of the AMS procedures are available at <http://whoi.edu/nosams> and <http://directams.net>, respectively.

3.2 Bayesian Modeling and Calibration for CA-SCRI-240

Bayesian statistics are increasingly applied to archaeological contexts for modeling chronometric data because they have the ability to incorporate stratigraphic information, historic records, or diagnostic artifacts of known ages as part of the modeling process (see Aldenderfer, 2005). Three types of probabilities are commonly used in archaeological application of Bayesian analyses for ^{14}C sequences, including the *prior*, *likelihood*, and *posterior*. *Prior* is information or observations that are inferred before any data are collected or processed. *Likelihood* is information obtained “from the absolute dates as measured from a ^{14}C probability function” (see Allen and Morrison, 2013:4569). The *posterior* is the probability outcomes expressed as the *highest posterior density region* based on the relationship between the *prior* and *likelihood* (Buck and Millard, 2004). A benefit of a Bayesian framework is that this analysis will also identify problematic dates with poor agreement indices (A) below the index threshold of 60% (see Bronk Ramsey, 2000).

We used Oxcal’s 4.2 Bayesian framework to calibrate ^{14}C determinations and generate ^{14}C sequences for modeled chronologies (Bronk Ramsey, 1995, 2001, 2009a, 2014). Radiocarbon determinations sampled from CA-SCRI-240 were separated into three groups (RS₁, RS₂, and RS₃) and run as independent ^{14}C series

(RS_a). These groupings were based on where in the site these dates came from and by excavator. Because material collection and excavation methods varied by excavator and unit, ¹⁴C series were grouped first by excavation unit and then identified by researcher (Table 1).

Table 1. All ¹⁴C dates from CA-SCRI-240 organized by radiocarbon series and then by cmbs.

¹⁴ C Series	Lab #	Provenience	Depth (cmbs)	Material	14C	Error±	Cal BP 2σ
RS1:JA1	DAMS-3989	Unit 4N17W	15-20	<i>Mytilus californianus</i>	936	23	410-265
RS1:JA2	DAMS-3990	Unit 4N17W	30-35	<i>Haliotis cracherodii</i>	736	21	230-historic
RS1:JA3	DAMS-3991	Unit 4N17W	35-40	<i>H. cracherodii</i>	938	27	415-260
RS1:JA4	DAMS-3992	Unit 4N17W	45-50	<i>H. cracherodii</i>	850	20	290-135
RS1:JA5	DAMS-3993	Unit 4N17W	55-60	<i>H. cracherodii</i>	705	21	135-historic
RS2:MG1	UCR-0156	50x50 m Level A2	31-46	Charcoal	960	150	1240-660
RS2:MG2*	UCR-0157	50x50 m Level E	106-116	Charcoal	1650	150	1890-1295
RS2:MG3*	UCR-0128	50x50 m Level I	153-167	<i>M. californianus</i>	1445	100	930-550
RS2:MG4	UCLA-1892	50x50 m Level I	153-167	<i>M. californianus</i>	1600	80	1060-700
RS2:MG5	UCR-0127	50x50 m Level L	215-231	Charcoal	980	100	1170-690
RS2:MG6	UCLA-1891	50x50 m Level L	215-231	Charcoal	1160	80	1260-935
RS2:MG7	UCR-0158	50x50 m Level O	264-267	Charcoal	1735	150	1990-1340
RS2:MG8*	UCR-0167	50x50 m Level S	319-333	Charcoal	2190	150	2700-1830
RS2:MG9*	UCR-0159	50x50 m Level X	364-386	Charcoal	1795	150	2100-1385
RS2:MG10	UCR-0166	50x50 m Level AA	402-408	Charcoal	2290	125	2710-2010
RS2:MG11	UCR-0165	50x50 m Level DD	424-447	Charcoal	2825	150	2670-1890
RS2:MG12*	DAMS-4221	50x50 m Level HH	479-487	<i>M. californianus</i>	2706	22	2200-1980
RS2:MG13	UCR-0164	50x50 m Level HH	479-487	Charcoal	4430	150	5570-4630
RS3:AS1	UCR-0472	Unit 2:cut 10	103-110	Charcoal	525	100	675-320
RS3:AS2	UCR-0469	Unit 2:cut 6	115-124	Charcoal	1065	110	1260-760
RS3:AS3	UCR-0470	Unit 1:cut 27	170-190	Charcoal	1055	115	1255-740
RS3:AS4	UCR-0468	Unit 2:cut 13c	220-206	Charcoal	1015	110	1180-710
RS3:AS5	UCR-0471	Unit 2:cut 18	300-320	Charcoal	1100	100	1260-800
RS3:AS6	UCR-0473	Unit 2:cut 19	320-340	Charcoal	1240	100	1320-960
RS3:TR1	OS-82466	1x1 m pit, col.	384-404	<i>M. californianus</i>	2240	25	1630-1415
RS3:TR2	OS-82467	1x1 m pit, col.	404-432	<i>M. californianus</i>	2210	25	1595-1400
RS3:TR3	OS-82468	1x1 m pit, col.	442-463	<i>M. californianus</i>	2520	25	1970-1770
RS3:TR4	OS-82469	1x1 m pit, col.	469-481	<i>M. californianus</i>	2460	25	1880-1700
RS3:TR5	OS-82470	1x1 m pit, col.	487-494	<i>M. californianus</i>	2600	25	2060-1860
RS3:TR6	OS-82497	1x1 m pit, col.	494-506	<i>M. californianus</i>	2600	25	2060-1860
RS3:TR7	OS-82498	1x1 m pit, col.	506-514	<i>M. californianus</i>	2620	25	2090-1880
RS3:TR8	OS-82499	1x1 m pit, col.	533-541	<i>M. californianus</i>	2640	25	2110-1910
RS3:TR9	OS-82500	1x1 m pit, col.	541-551	<i>M. californianus</i>	2640	30	2115-1900

RS3:TR10	OS-82501	1x1 m pit, col.	551-566	<i>M. californianus</i>	2740	30	2280-2020
RS3:MG14	UCR-0602	1x1 m pit, col.	551-566	Mollusk shell	2570	110	2250-1670
RS3:MG15	UCR-0601	1x1 m pit col.	551-566	Charcoal	2575	120	2920-2350

*outliers as identified through outlier analyses.

Series RS₁ includes five AMS ¹⁴C determinations collected from stratigraphic depths between 15 and 60 centimeters below surface (cmbs) from Unit 4N17W. Because of several reversals in the depth sequence, which extended above house features and possible living floors, these dates were organized into a single *phase* within a sequence (see Culleton et al., 2012:1577). RS₂ and RS₃ were each run as *sequences* with the dates ordered based on depth from deepest to shallowest. Series RS₂ includes 13 ¹⁴C samples collected from an extended 50 x 50 cm column sample that consists of almost 50 strata between 487 and 31 cmbs. This series includes the 1970s University of California, Riverside (UCR) radiometric ¹⁴C dates. Series RS₃ consists of seven ¹⁴C dates obtained during the 1970s and 10 new AMS dates, all recovered from Unit 1. The 1970s dates include the upper levels of the unit trench between 340 and 103 cmbs, while the new reported dates include a sequence between 551 and 384 cmbs. The remaining two UCR dates were collected from the deepest strata, between 566 and 551 cmbs.

All ¹⁴C dates were adjusted using the Intcal13 or Marine13 datasets for terrestrial and marine samples, respectively (see Reimer et al., 2013). Marine samples were further adjusted using a ΔR of 261 ± 21 based on dating of *Olivella* and *Mytilus* (see Jazwa et al. 2012; Thakar 2014). Researchers working on California's Channel Islands have used a variety of different ΔR values, including 225 ± 35 and 261 ± 21 (see Kennett et al. 1997; Jazwa et al. 2012). Kennett et al. (2013) and

Thakar (2014) recently used different ΔR values through time based on calculations made on marine planktonic foraminiferal carbonate and paired organics presented by Hendy et al. (2013). However, the specifics of the calculations and corrections have not been published. While using different ΔR values will undoubtedly impact the results, the 261 ± 21 value is currently the best correction to use for this study, but future refinements in ΔR will undoubtedly improve chronologies for Prisoners Harbor and the broader Channel Islands.

Because there were reversals in the RS₂ series, we conducted outlier analyses using the default model provided by Bronk Ramsey (2009b:6) where: “Outlier_Model (“SSimple”, N(0,2), 0, “s”)” (see supplemental materials). Identified outliers were removed from the ¹⁴C series (see Table 1). For each Bayesian analysis, we report the agreement indices for modeled (A_m), overall (A_o), and minimum and maximum posterior ranges (2α) based on the earliest and latest radiocarbon date in each series and likelihood for each RS series including model schematics and probability ranges (see supplemental materials).

4. Results

The combined results for all three series suggest that there is a 95% probability that CA-SCRI-240 was occupied between 2750 and 145 cal BP. There is considerable overlap in modeled ages between all ¹⁴C series. This suggests some degree of continuity between occupation sequences at different locations within the site despite differences between excavation methods.

For RS₁, our analyses of all five ¹⁴C determinations produced agreement indices $A_m=102.6\%$ and $A_o=94.2\%$. Despite two reversals in these Unit 4N17W deposits, which suggest disturbed or redeposited materials, these strata were treated as a phase that we believe is associated with the house features. The 95% probability distribution range for this phase is between 405 and 0 cal BP (Fig. 3). The group (phase) sequence of ¹⁴C dates shows the two house features (RS₁:JA3 and RS₁:JA5) modeled between 230 and 0 cal BP, while the midden layer (RS₁:JA4) dates between 305 and 145 cal BP, and the abalone layer (RS₁:JA2) falls within 235 and 0 cal BP. Reversals in some of the dates from this unit, however, demonstrate that there is mixing within these deposits discussed in greater detail below.

Fig. 3. Unit 4N17W stratigraphic profile and modeled ¹⁴C results for CA-SCRI-240.

For RS₂, initial outlier analysis of all 13 ¹⁴C determinations yielded four ¹⁴C determinations as outliers (RS₂:2, 3, 8, 9 and 12). Removing these outliers, the remaining ¹⁴C determinations were analyzed in a sequence ordered by depth and yielded agreement indices of $A_m=111.3\%$ and $A_o=110\%$ and modeled ages between 2610 and 660 cal BP (Fig. 4). The youngest probability range distribution (95%)

from zone A₂, 46 to 31 cmbs, was between 955 and 660 cal BP (RS₂:MG1:), while the lowest zone, HH, located between 487 and 479 cmbs produced a modeled ¹⁴C age between 2610 and 2010 cal BP (RS₂:MG12).

Fig. 4. Stratigraphic profile and modeled ¹⁴C results for 50x50 column sample.

Agreement indices for RS₃ series were A_m=71.9% and A_o=87.7%, with 95% probability ranges for the modeled ages between 2750 and 450 cal BP (Fig. 5). This series is from Unit 2, in which the upper sequence (RS₃:AS) consists of UCR dates from 340 to 103 cmbs and the remaining dates include new AMS dates from 566 to 384 cmbs. Based on the modeled ages, there is a 95% probability that this 463 cm of deposition spans 2200 years, with the upper levels of the site ranging between 1340 and 450 cal BP. The lower levels produced a modeled ¹⁴C age between 2750 and 1405 cal BP. The range for the date sampled in the deepest strata between 566 and 551 cmbs ranged from 2750 to 2010 cal BP (RS₃:TR:10, RS₃:MG 14, 15). These dates

are consistent with the ^{14}C dates in the lowest deposits from RS₂ (447 cmbs) of 2610 cal BP.

Fig. 5: 1x1 meter SE/SW profile for the lower strata layers and modeled radiocarbon series for CA-SCRI-240.

5. Discussion

Our analysis of the three suites of ^{14}C dates and resulting modeled chronologies suggests that CA-SCRI-240 was occupied between approximately 2750 into historic times. Historic period artifacts (glass, needle-drilled beads, etc.) and ethnohistoric data also support the radiocarbon chronology extending into the early 19th century (see Arnold 2001). All three ^{14}C series present overlapping chronological sequences, including general continuity in minimum and maximum

ranges for each sequence. The uppermost strata at the site (RS₁) produced modeled ages between 405 and 0 cal BP. ¹⁴C dates from the deepest deposits ranged between 2750 and 2010 cal BP. Our modeled results for the 566 to 541 cmbs deposits demonstrate that the earliest occupation of the site occurred some 2000 years later than previously indicated by an erroneous ¹⁴C date obtained in the 1970s (UCR-1064).

Five ¹⁴C dates suggest that there is a 95% probability that the uppermost portion of the site was occupied intensively from 405 to 0 cal BP (or AD 1548-1950). Arnold and UCLA crews have conducted an intensive investigation of a buried house feature and associated deposits dating to the later pre-contact era and the first few decades of the Historic era (AD 1769-1819). Dating of these deposits has been assisted by time-sensitive glass and metal objects, proportions of needle-drilled Olivella disc beads and ratios of Olivella wall and callus beads (Arnold and Graesch, 2001). When the radiocarbon dates are placed in the context of these time-sensitive artifacts, these uppermost deposits likely date from ~400 to 130 cal BP, suggesting Protohistoric and Historic period occupations. The distribution of the ¹⁴C dates from these deposits (Unit 4N17W) by depth and the modeled ¹⁴C ages demonstrates that there was some minor stratigraphic mixing in the uppermost strata [0-15 cm]. This could be from human activities, including house construction, repair and other daily activities, as well as more recent land use disturbances, possible backfill from the 1920s excavation, or looting. In general, this stratigraphic mixing is relatively limited. Considering the general size of the site and depth of the deposits, there are

no other dramatic reversals in the radiocarbon sequence, especially the new series of AMS dates from Glassow's test unit that make up the RS₃ series.

Based on our study, 566 cm of deposition occurred during 2700 years, consisting of over 50 clearly defined strata, the majority of which contain evidence of human occupation. Comparing the Prisoners Harbor site stratigraphy with the modeled ¹⁴C ages suggests that sediment accumulation rates varied through time. The five ¹⁴C dates from RS₁ in the uppermost 60 to 15 cmbs of the site show deposition over a modeled 410 year period, at an average of 0.3 cm per year. In the RS₂ series between 167 and 31 cmbs include 12 strata (A₂ to I₂) and modeled ranges between 1010 and 659 cal BP, with an average deposition rate of 0.4 cm per year. From 267 to 153 cmbs, including seven strata (Strata O through I), we see the slowest average deposition rate in the sequence, from 1970 to 745 cal BP or 0.09 cm per year over 1225 years. For the RS₃ series, the uppermost 27 strata, between 340 and 103 cmbs, spanned 1340 to 450 cal BP, 840 years of deposition and on average 0.27 cm per year. For the lowest sequence of RS₃, between 561 and 384 cmbs, modeled ages are between 2750 and 1405 cal BP, averaging 0.13 cm of deposition per year. The change in deposition rates for the three suites of modeled ¹⁴C dates fall between 0.09 and 0.4 cm per year, with the faster accumulation in middle and upper portions of the sequence and slower deposition in the lower middle and lowest strata. It is important to note that not all of the deposition at CA-SCRI-240 is cultural, with windblown sand and silt also contributing to the site depositional history, especially in the deeper, lower-density deposits.

Beyond the Prisoners Harbor site, a few nearby sites have also recently been dated and help put the CA-SCRI-240 occupation into broader context. Located on a ridge overlooking CA-SCRI-240, a small, disturbed shell midden at CA-SCRI-254 produced a 1 sigma age range of 2835-2745 cal BP, or roughly several hundred years before the initial occupation of CA-SCRI-240 (Rick et al. 2014). Similarly two, other small shell middens on a terrace to the west of the site and towards Pelican Harbor (CA-SCRI-897 and CA-SCRI-899), produced 1 sigma calibrated age ranges of 3370-3255 cal BP and 3415-3310 cal BP, respectively. Additional dating of other sites in the vicinity will undoubtedly enhance our understanding of the general chronology and intensity of human settlement in this portion of the Channel Islands, but for now the area was clearly occupied throughout the Late Holocene from at least 3400 cal BP to the 19th century.

6. Conclusion

For almost a century, the Prisoners Harbor shell midden and village complex has been the subject of archaeological research, but until now, the site chronology has been based on radiometric ¹⁴C dates from the 1970s with relatively large analytical errors and some stratigraphic reversals. Our refined chronology for CA-SCRI-240, culling radiometric ¹⁴C dates following basic chronological hygiene principles (removing dates with large analytical errors, poor or unknown provenience, spurious results, etc.) and focusing on new high-precision AMS ¹⁴C dating, indicates that the earliest occupation started at 2750 cal BP. Despite several possible outliers from the radiometric ¹⁴C series, many of these dates provided

comparative utility and demonstrated continuity between stratigraphic levels from all three ^{14}C series.

Our research adds to a growing body of work that demonstrates the importance of high-precision AMS ^{14}C dates and Bayesian statistical analysis (e.g., Allen and Morrison 2013. Culleton et al. 2012; Kennett et al. 2014). This framework allows researchers to reinterpret existing cultural chronologies for archaeological sites and build useful models of site formation and ultimately prehistoric human behavioral and environmental change. Additional reassessment of existing ^{14}C dates in concert with new AMS ^{14}C dates and stratigraphic information, like our work at Prisoners Harbor, is an important direction for research at other Channel Islands and coastal archaeological sites around the world.

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