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Big Sites—Short Time: Accumulation Rates in Archaeological Sites

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Large, complex archaeological sites are often characterized by only a handful of radiocarbon dates. This practice encourages indiscriminant dating of sites for the sole purpose of determining age. If a more rigorous dating scheme is employed and accumulation rates are calculated, otherwise invisible aspects of human behaviour become apparent. Issues central to settlement pattern analysis, such as abandonment and reoccupation events, population fluctuations, building activities, and activity areas are more easily identified when accumulation rates are calculated. In this study, accumulation rates are calculated for seven shell midden sites found in the San Juan Islands, Washington. The collections are stored at the Burke Museum of Natural History and Culture, University of Washington, Seattle, Washington. Eighty-two charcoal pieces were selected according to a comprehensive horizontal and vertical sampling regime and radiometrically dated. Accumulation rate calculations suggest that large archaeological sites, like these shell middens, do not always represent continuous human occupation characterized by gradual accumulation of material. Rather, these large complex sites accumulated during short-duration occupations that were repeated infrequently in the same area. This research recommends that numerical accumulation rates be calculated using at least two calculations; the excavation unit accumulation rate and the entire site accumulation rate, and that the excavation unit accumulation rate is the more useful scale for interpreting settlement history. Calculations of these rates focus the multifaceted interaction between human behaviour and natural processes in a way that qualitative guesses cannot.

Keywords: ACCUMULATION RATES, SHELL MIDDEN, RADIOCARBON DATING, SETTLEMENT PATTERN, NORTHWEST COAST, GEOARCHAEOLOGY.

Humans occupy their landscape in a dynamic manner, often altering their spatial organization and subsistence practices in response to changes in climate, technology, population size, and other factors that fluctuate through time. Archaeologists seek to unravel this complex story of human occupation by examining cultural deposits that accumulate sequentially over time. Determining the timeframe of the depositional sequence of cultural deposits, therefore, is intrinsic to any interpretation of past human behaviour on a landscape. An effective technique for analysing that timeframe is to calculate the rate of accumulation for the sequence, which requires the measurement of ages and thicknesses of the cultural deposits. We suggest a method whereby archaeologists can calculate accumulation rates within archaeological sites to better measure the changing use of a landscape through time and to understand stratigraphically complex deposits.

Accumulation rates often support behavioural interpretations of sites, especially studies of settlement pattern. Settlement pattern research has been important in archaeology since the pioneering efforts of Willey and Chang (Billman & Feinman, 1999; Chang, 1968; Vogt & Leventhal, 1983; Willey, 1956). Settlement archaeology was predicated on the assumption that sites were occupied during specific time intervals, which in turn were determined by assuming accumulations rates. This research continues today (e.g., Anderson & Gillam, 2000; Clark & Herdrich, 1993; Ford & Fedick, 1992; Hiscock & Hughes, 2001; McWeeney & Kellogg, 2001; Smyth *et al.*, 1995), as does the researchers' dependence on assumptions concerning accumulation rates.

Archaeologists determine accumulation rates in one of two ways: relatively or absolutely. Relative accumulation rates (e.g. fast versus slow) are based on field observations and are useful for qualitative research

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questions that are focused less on settlement dynamics and more on presence or absence of human occupation and activities occurring at one location. Absolute accumulation rates (e.g. 4·5 mm/yr) are based on quantitative data and are useful for interpreting intensity of human occupation in a certain location and across regions. The absolute method is explored in this study in the context of interpreting stratigraphically complex sites, such as shell middens. The accurate calculation of absolute accumulation rates relies on the depth and age of each sample, and considers factors of precision and accuracy, sample and site sizes, and potential errors.

This report is not the first publication to consider using accumulation rate calculations. Archaeologists concerned with alluvial, rockshelter and cave contexts have reported previously on calculations of accumulation rates (Brown, 1997; Butzer, 1977; Farrand, 1993, 2000; Ferring, 1986; Ferring & Peter, 1987; Fullagar *et al.*, 1996; Gladfelter, 1985; Jerardino, 1995; Parkington, 1988; Waters, 1992), as have archaeologists investigating occupational intensity (Edwards, 1992; Morwood, 1981). Ferring (1986) most thoroughly explained accumulation rates by radiometrically dating cultural material in Holocene alluvial settings of North American. He notes that rapid sedimentation rates result in clear distinctions between archaeological assemblages, and slow sedimentation rates provide no separation of artifacts from different occupations. We have built upon Ferring's example by expanding the discussion to a different depositional context (shell middens) and by considering the consequences of calculating rates at both site and unit scales (the term ''unit'', throughout this paper, refers to a rectangular hole excavated by archaeologists). The calculation methodology, however, is applicable to scholars excavating most types of stratigraphically complex sites.

Several archaeologists have recognized the specific need for shell midden accumulation rate research (Fladmark, 1982; Lyman, 1991; Stein, 1992; Sullivan, 1984), but little work has actually been performed on this front. The research reported here attempts to rectify that gap and focuses on large, complex, late Holocene sites from the North American Northwest Coast.

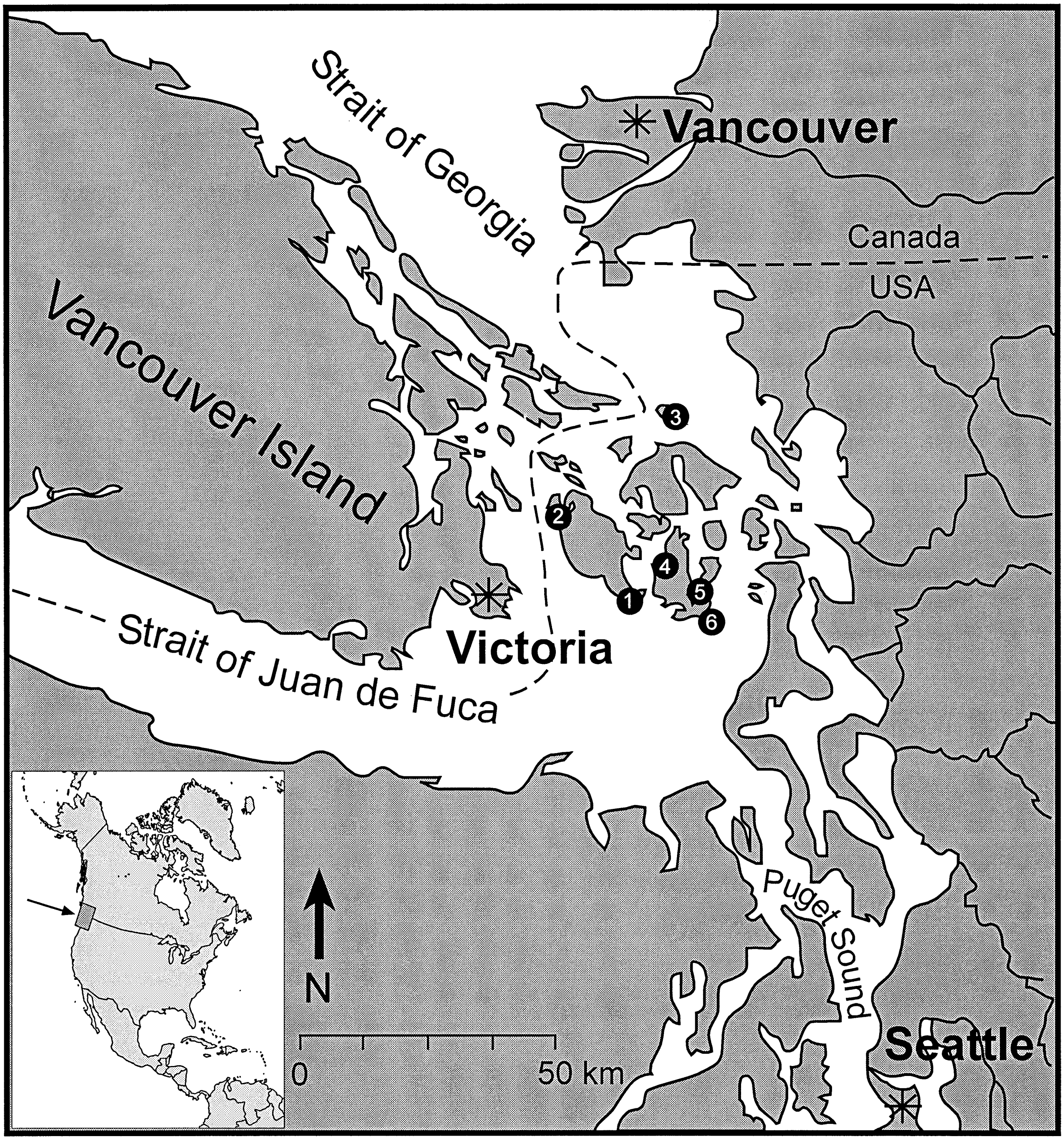
Shell middens have a long history of challenging traditional archaeological methods and interpretations because of their large matrix-to-artifact ratio with the majority of the matrix composed of cultural material (e.g., shell and fire-cracked rock). Researchers who focus on shell middens have developed methods to extract information about diets, palaeoecology, palaeoshorelines, technology, and depositional and post-depositional histories (Ambrose, 1967; Claassen, 1998; Hall & McNiven 1999; Stein, 1992; Waselkov, 1987). Since the 1940s, various scholars on the Northwest Coast have attempted to distill the complex stratigraphy of shell middens into a manageable set of data using various recovery techniques (e.g., in chronological order: King, 1950; Carlson, 1960; Bryan, 1963; Borden, 1970; Mitchell, 1971; Abbott, 1972; Burley, 1980; Stein, 1986, 1992; Coupland, 1991; Coupland *et al.*, 1993; Stucki, 1993; Cannon, 2000; Erlandson & Moss, 2001). Early in that history, methods included using 20 cm arbitrary excavation levels, discarding all but a small sample of shell, and saving only large significantly modified objects. More recently, methods have changed to emphasize: excavating by layers (such as facies) to maximize the extraction of complex stratigraphic information relevant to depositional processes, acquiring more radiometric samples rather than relying only on cultural phases and estimated ages of artifact types, using coring whenever possible, and obtaining statistically significant sample sizes. Accumulation rate calculations fit nicely into the methodological rigor that has become standard in shell midden research, but are seldom-used by researchers in this field.

Our sample of eighty-two dates from shell middens in the San Juan Islands, Washington (Figure 1), furthers the relatively recent understanding of shell midden accumulation dynamics in this area. In the last decade, Northwest Coast archaeologists have begun to move away from equating very deep shell midden sites with long, continuous human occupation. Sites like the West Point site in Seattle, Washington, established that large shell middens can accumulate very rapidly and are often accompanied by a complex history of occupation and abandonment (Larson & Lewarch, 1995). Our results suggest that calculating accumulation rates provides archaeologists with a powerful tool to interpret the past.

Calculating Accumulation Rates

Geoscientists have determined a way to actually calculate a rate of accumulation using numerical values. One must determine the radiocarbon age and depth below surface of at least two points in the depositional record. The rate of accumulation is calculated by dividing the thickness of the accumulation (in centimetres) by the duration of the accumulation (in years). The *total accumulation* is the difference in depths of the two samples. The *duration of accumulation* is the difference between the mean radiocarbon ages of any two samples. This method assumes a constant rate of sedimentation between the two points.

Figure 2 illustrates this method with a series of hypothetical accumulation rates. Line A represents an extremely gradual rate of sediment accumulation, graphically represented by zero accumulation. Whether it took place 1000 years ago or 100,000 years ago, an archaeological site that receives little sedimentation except from low-density human occupation might approximate this extreme profile. Line C indicates a very rapid rate of accumulation; a relatively large quantity of material deposited over a short period of time. Graphically, this is depicted as an infinite rate. Behaviourally, it represents a single dumping of a large



1 45SJ1, Cattle Point
2 45SJ24, English Camp
3 45SJ105, Fossil Bay
4 45SJ254, Fisherman Bay
5 45SJ278, Mud Bay
6 45SJ280, Watmough Bay

Figure 1. Location of the San Juan Islands, Washington, and archaeological sites mentioned in the text.

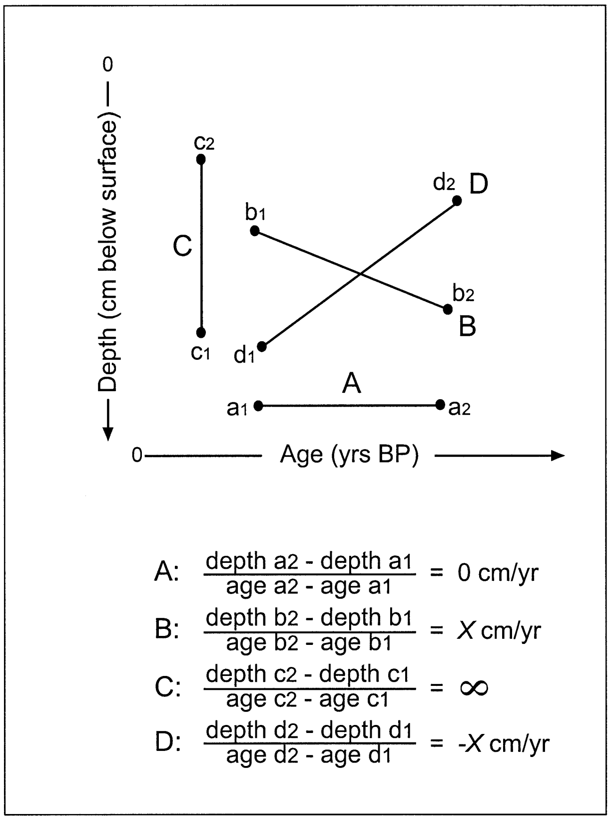


Figure 2. Hypothetical accumulation rates: radiometric age as a function of sample depth. Line A models zero accumulation, Line B models a positive accumulation rate, Line C models an infinite accumulation rate, and Line D models a negative accumulation rate.

amount of material. Sampling can be critical to detect depositional sequences approaching Line C. For example, if only one date is measured at the base of the sequence, then the whole sequence could be misinterpreted as accumulating slowly and continuously from that date to the present. When it actually was deposited in one event, very rapidly. Line B corresponds to an intermediate accumulation rate of X cm/yr and represents one of many possible accumulation rates between zero and infinity. In reality, most sites will display a pattern more like Line B than either A or C. And lastly, Line D signifies a negative accumulation rate ($-X$ cm/yr), or simply, erosion and new deposition. Negative rates of accumulation result from transport agents moving an object whose date of death is older than the age of deposition for the whole unit, signaling some kind of disturbance.

Examples from Northwest Coast Shell Middens

Charcoal samples from six archaeological sites in the San Juan Islands, Washington (Figure 1), were selected from collections owned by the Burke Museum of Natural History and Culture and the National Park Service. The San Juan Islands are located at the convergence of the Strait of Juan de Fuca, Puget Sound, and the Strait of Georgia, at the border between Canada and the United States. These archived collections were chosen because they offered an abundance of datable material, comprehensive field notes, and a geographical distribution throughout the San Juan Islands. The shell middens themselves are located on the shorelines of several different islands and collectively represent several thousand years of late Holocene human occupation. The sites include: 45SJ1 (Cattle Point), 45SJ24 (English Camp, Operation A), 45SJ24 (English Camp, Operation D), 45SJ254 (Fisherman Bay), 45SJ278 (Mud Bay), and 45SJ280 (Watmough Bay). See Table 1 for site-specific excavation information.

Sampling strategy

Single pieces of charcoal were removed from level bags and field specimens with the goal of maximizing horizontal and vertical sampling within each site. The samples consisted of burned segments of branch or twig wood, as identified by palaeoethnobotanist Nancy Stenholm of Botana Labs, Inc. Beta Analytic Inc. performed the radiometric analysis. When combined with Stein's previously submitted English Camp samples (Stein, 1992), 82 radiometric ages were included in this study.

Table 1. Archaeological site information for San Juan Island sites included in this study

Site name	Site no.	Excavator	Year excavated	Island	Excavation intervals	Topo map	References
Cattle Point	45SJ1	Arden King	1946	San Juan	13·2 cm (6 in)	Figure 3	King, 1950
English Camp, Op A	45SJ24	Julie Stein	1983–91	San Juan	3-pt provenience	Figure 4	Stein, 1992, 2000
English Camp, Op D	45SJ24	Julie Stein	1983–91	San Juan	3-pt provenience	Figure 5	Stein, 1992, 2000
Fossil Bay	45SJ105	Robert Kidd	1955–56	Sucia	20 cm	Figure 6	Kidd, 1971
Fisherman Bay	45SJ254	David Munsell	1967–68	Lopez	3-pt provenience	N/A	Field notebooks, Burke Museum, Accn. 1997-115
Mud Bay	45SJ278	David Munsell	1968	Lopez	20 cm	Figure 7	Field notebooks, Burke Museum, Accn. 1996-121
Watmough Bay	45SJ280	David Munsell	1968	Lopez	20 cm	Figure 8	Field notebooks, Burke Museum, Accn. 1996-11

While shells and bones are ubiquitous in these archaeological sites, they were not selected for radiometric analysis. The problems associated with shell involving local marine reservoir effects in the Puget Sound/Gulf of Georgia region are being investigated using paired charcoal and shell from many of the sites mentioned in this report (Deo *et al.*, manuscript submitted). Recent research in California indicates that reservoir age corrections for radiocarbon-dated shell vary not only by region, but also through time (Kennett *et al.*, 1997; Ingram, 1998). Such temporal variations are a relatively recent discovery and are most likely based on differences in deep ocean upwelling between regions. Since late Holocene fluctuations in Gulf of Georgia reservoir ages are not yet documented, shell dates are considered a less reliable source of chronometric data. Bone in these shell middens is primarily fish, bird, and mammal, all of which can lack sufficient collagen to date conventionally. The expense of AMS dating was minimized by selecting charcoal over bone.

Data

The radiocarbon dates are displayed in Table 2, arranged by site and sample number. Many samples were too small to undergo conventional analysis and were therefore selected for extended counting (EC) or Accelerator-Mass Spectrometry (AMS) dating, as noted. All dates discussed in this text are 2σ calibrated results.

Accumulation rates were computed on two different scales: entire site and individual excavation units. Calculation of the *site accumulation rates* (Table 3) entailed plotting all samples from an entire site, according to each sample's mean 2σ calibrated radiocarbon age and mean depth of sample (see Table 2 and Figures 3–8 for results). A regression equation describes the most parsimonious relationship between samples, and a correlation coefficient (R^2) describes the degree of fit. The slope of the equation represents the accumulation rate (in cm/yr). The *unit accumulation rates* were calculated in the same manner (Table 3), with the difference of using only samples within a given excavation unit. If a unit contained only one dated sample, a unit accumulation rate could not be calculated.

Although the shell middens in our study are not alluvial deposits, we also performed the pairwise calculation recommended by Ferring (1986) for comparison purposes (in Table 3, see "accumulation rate by pair"). The results show wildly fluctuating accumulation rates within many units. For instance, in 45SJ1, Unit 100–105N, 530–535W, the pairwise accumulation rates are 13·45 cm/100 yr, −65·31 cm/100 yr, and 2·49 cm/100 yr. The rates do not provide a clear pattern of deposition over time, but instead provide insight into specific deposition rates between layers. This is valuable for determining one layer's accumulation rates, but as the table shows the fluctuations are great and appropriate for only questions asked at the scale of layer. If the research questions require a scale larger than layer, then excavation unit accumulation rates, or site accumulation rates, are more useful.

The correlation coefficient R^2 is indicative not necessarily of the accumulation dynamics present at the current site, but may be a function of the variety of scales over which the value was calculated and the sample size used in the calculation. A low R^2, when calculated from the entire site (all excavation units), indicates that there are variable accumulation rates throughout the depositional sequence. This rate may be a result of different intensities of use for different parts of the site, or may be a function of fluctuating periods of sediment accumulation. On the other hand, a low R^2, when calculated from individual excavation units, indicates a non-uniform accumulation of materials between stratigraphic layers but allows correlation from excavation unit to unit. The calculation of R^2 using two samples will result in a correlation coefficient equal to "1·0", and is meaningless because of its predictable correlation. Therefore, a sample should be greater than two to provide conclusive results.

45SJ1, Cattle Point

Calculations show an overall site accumulation rate of 0·66 cm/100 yr and an R^2 of 0·01 (see Table 3 and Figure 3). The accumulation rate of this site approaches line A in Figure 2 and therefore reflects a very slow accumulation. There is relatively low correlation (0·01), compared to other rate calculations in this study. This pattern, however, is expected since great horizontal distances exist between units.

The individual unit accumulation rates (Figure 3) are greater than the site rate, and are probably more accurate in light of their higher correlation coefficients. Unit 105–110N, 15–20W, exhibits a 21·58 cm/100 yr rate, with a R^2 of 1·00, since only two samples were dated. Unit 100–105N, 530–535W, accumulated at a rate of 6·56 cm/100 yr and had a R^2 of 0·66. The relatively high correlation and inclusion of four samples lends confidence to the accuracy of the Unit 100–105N, 530–535W rate. The horizontal distances of hundreds of metres between excavation units is probably the cause for the individual unit accumulation rates to be more meaningful than the overall site accumulation rate. These widely spaced areas were considered together because they were recorded in 1946 as one site and only small amounts of charcoal are available in this old collection.

45SJ24, Operation A, English Camp

English Camp, excavated recently, was considered as two separate areas within one site. Originally recorded in 1948, the two areas were excavated at different times

Table 2. Radiometric data for San Juan Island archaeological sites

Sample IDs	Beta Analytic number	Material*	Measured C-14 age (BP)	C13/C12 Ratio**	Conventional C-14 age (BP)	Intercepts of radiocarbon age with calibration curve (AD)	1-Sigma calibrated results (AD)	2-Sigma calibrated results (AD)	Depth (cm except where noted)	Unit
Cattle Point, 45-SJ-1										
00102	123523	Charcoal/AMS	1220 ± 50	− 23·5‰	1240 ± 50	785	705–875	675–895	2·0–2·5 ft	105–110N, 15–20W West Bluff
00104	123525	Charcoal/EC	1540 ± 100	− 25·0‰**	1540 ± 100	550	420–635	330–675	4·0–4·5 ft	105–110N, 15–20W West Bluff
00105	123526	Charcoal/AMS	1240 ± 40	− 26·1‰	1220 ± 40	800	775–880	695–895	1·5–2·0 ft	100–105N, 530–535W West Bluff
00106	123527	Charcoal/AMS	1610 ± 40	− 23·4‰	1630 ± 40	425	405–450	370–540	3·0–3·5 ft	100–105N, 530–535W West Bluff
00108	123529	Charcoal/AMS	1500 ± 40	− 22·2‰	1540 ± 40	550	465–475, 515–590	430–620	4·5–5·0 ft	100–105N, 530–535W West Bluff
00110	123531	Charcoal/AMS	2530 ± 40	− 22·2‰	2570 ± 40	790 BC	800–775 BC	810–760 BC, 670–550 BC	5·5–6·0 ft	100–105N, 530–535W West Bluff
00111	123532	Charcoal/AMS	2490 ± 50	− 22·8‰	2530 ± 50	775 BC	790–755 BC, 685–540 BC	805–485 BC, 465–425 BC	1·5–2·0 ft	375–380N, 460–465E East Bluff
00112	123533	Charcoal/AMS	2510 ± 40	− 26·1‰	2490 ± 40	760 BC, 670 BC, 550 BC	775–515 BC	790–415 BC	1·5–2·0 ft	370–375N, 465–470E East Bluff
English Camp, 45-SJ-24—Operation A										
294,270fF#18	N/A	Charcoal	680 ± 135	N/A	N/A	1283	1230–1410	1030–1450	57	294/270 facies 1F
310,300fB1#9	N/A	Charcoal	535 ± 80	N/A	N/A	1408	1308–1356	1280–1480	24	310/300 facies 1B 01
310,300fB1#1	N/A	Charcoal	670 ± 70	N/A	N/A	1285	1270–1317, 1346–1389	1230–1410	18	310/300 facies 1B 02
310,300fC#7	N/A	Charcoal	885 ± 65	N/A	N/A	1164	1034–1225	1010–1270	36	310/300 facies 1C
310,300fN#25	N/A	Charcoal	1070 ± 80	N/A	N/A	980	888–1021	780–1060, 1078–1125, 1136–1156	54	310/300 facies 1N
310,300fR3#4	N/A	Charcoal	1585 ± 70	N/A	N/A	438	401–552	263–285, 330–610	106	310/300 facies 1R 03
310,302fD1#1	N/A	Charcoal	1150 ± 90	N/A	N/A	889	776–986	670–1030	48	310/302 facies 1D 01
310,302fD2#6	N/A	Charcoal	1250 ± 70	N/A	N/A	772	673–880	650–900, 902–953	47	310/302 facies 1D 02
310,302fE1#1	N/A	Charcoal	1690 ± 60	N/A	N/A	348, 367, 371	253–305, 314–416	220–450	34	310/302 facies 1E
310,304fB1#1	N/A	Charcoal	160 ± 60	N/A	N/A	1679, 1743, 1802, 1938, 1955	1660–1886	1640–1955	35	310/304 facies 1B
310,304f2#26	N/A	Charcoal	355 ± 50	N/A	N/A	1489	1911–1955, 1456–1635	1440–1650	90	310/304 facies #2
310,304fD1#5	N/A	Charcoal	370 ± 70	N/A	N/A	1480	1442–1636	1420–1660	43	310/304 facies 1D
310,304fD3#6	N/A	Charcoal	450 ± 50	N/A	N/A	1440	1422–1461	1400–1510	78	310/304 facies 1D 03
1983#3	N/A	Charcoal	580 ± 70	N/A	N/A	1328, 1333, 1395	1289–1418	1270–1440	104	310/306
1983#4	N/A	Charcoal	630 ± 55	N/A	N/A	1300, 1365, 1374	1282–1397	1270–1410	135	310/306
QL-4153	N/A	Charcoal	430 ± 40	N/A	N/A	1441	1430–1468	1415–1516, 1599–1617	32	306/300 facies 1F
QL-4154	N/A	Charcoal	810 ± 80	N/A	N/A	1223	1158–1278	1020–1300, 1374–1378	52	306/300 facies 1L

Table 2. Continued

Sample IDs	Beta Analytic number	Material*	Measured C-14 age (BP)	C13/C12 Ratio**	Conventional C-14 age (BP)	Intercepts of radiocarbon age with calibration curve (AD)	1-Sigma calibrated results (AD)	2-Sigma calibrated results (AD)	Depth (cm except where noted)	Unit
English Camp, 45-SJ-24—Operation A *continued*										
QL-4155	N/A	Charcoal	1000 ± 40	N/A	N/A	1004, 1008, 1019	992–1031, 1144–1146	979–1071, 1084–1127, 1137–1154	74	306/300 facies 1W
QL-4156	N/A	Charcoal	830 ± 70	N/A	N/A	1215	1075–1077, 1131–1136, 1155–1263	1020–1280	77	306/300 facies 2E
QL-4157	N/A	Charcoal	900 ± 40	N/A	N/A	1133, 1136, 1156	1035–1142, 1148–1193, 1202–1206	1021–1223	55	306/302 facies 1M
English Camp, 45-SJ-24—Operation D										
105B7	N/A	Charcoal/EC	1470 ± 90	− 25·0‰**	1470 ± 90	615	535–660	415–705	85	105/365 1B 7
105O1	N/A	Charcoal/EC	1710 ± 70	− 25·0‰**	1710 ± 70	370	245–420	160–530	103	105/365 1O 1
105T1C	N/A	Charcoal/EC	1400 ± 90	− 25·0‰**	1400 ± 90	650	600–690	465–475, 515–800	176	105/365 1T 1
111P1	N/A	Charcoal	1760 ± 80	− 25·0‰**	1760 ± 80	260	210–395	90–440	59	111/349 1P 1
111W1	N/A	Charcoal	1460 ± 70	− 25·0‰**	1460 ± 70	620	555–655	440–685	67	111/349 1W 1
111EE2	N/A	Charcoal/EC	1940 ± 110	− 25·0‰**	1940 ± 110	75	40 BC–AD 220	185 BC–AD 350	159	111/349 2E 2
123A5	N/A	Charcoal/EC	850 ± 90	− 25·0‰**	850 ± 90	1215	1045–1105, 1115–1275	1010–1300	56	123/347 1A 5
123I1	N/A	Charcoal	1370 ± 80	− 25·0‰**	1370 ± 80	665	630–705	555–855	92	123/347 1I 1
130C1	N/A	Charcoal	1180 ± 70	− 25·0‰**	1180 ± 70	880	780–970	685–1005	39	130/352 1C 1
130H1	N/A	Charcoal	1230 ± 60	− 25·0‰**	1230 ± 60	790	705–885	670–970	78	130/352 1H 1
130K1	N/A	Charcoal	1300 ± 50	− 25·0‰**	1300 ± 50	695	670–780	650–865	92	130/352 1K 1
TABC1	N/A	Charcoal	1480 ± 80	− 25·0‰**	1480 ± 80	605	535–650	420–685	55	TAB 1C 1
TABD2	N/A	Charcoal	1430 ± 70	− 25·0‰**	1430 ± 70	640	590–665	530–705	88	TAB 1D 2
TAB003	N/A	Charcoal	1600 ± 60	− 25·0‰**	1600 ± 60	440	410–550	350–605	163	TAB oo 3
TAB004	N/A	Charcoal	1460 ± 50	− 25·0‰**	1460 ± 50	620	575–650	535–665	168	TAB oo 4
TAB007	N/A	Charcoal	1740 ± 60	− 23·2‰	1770 ± 60	250	220–370	120–415	192	TAB oo 7
TCD002	N/A	Charcoal	1470 ± 70	− 25·0‰**	1470 ± 70	615	550–650	435–680	111	TCD oo 2
TEF0073	N/A	Charcoal/EC	1430 ± 50	− 22·7‰	1470 ± 50	615	560–645	530–665	190	TEF oo 73
TEF0077	N/A	Charcoal	1300 ± 80	− 25·0‰**	1300 ± 80	695	660–800	620–895	184	TEF oo 77
TGHB3	N/A	Charcoal	1800 ± 70	− 25·0‰**	1800 ± 70	240	135–340	75–410	138	TGH 1B 3
TGH008	N/A	Charcoal	1170 ± 70	− 25·0‰**	1170 ± 70	885	785–975	690–1010	209	TGH oo 8
TGH009	N/A	Charcoal/EC	1410 ± 80	− 25·0‰**	1410 ± 80	650	600–680	530–780	123	TGH oo 9
Fossil Bay, 45-SJ-105										
10501	119295	Charcoal/EC	470 ± 90	− 25·0‰**	470 ± 90	1435	1410–1485	1305–1645	20–40	2·5N, 5E
10502	119296	Charcoal/EC	1950 ± 100	− 25·0‰**	1950 ± 100	70	40 BC–AD 160	180 BC–AD 265, AD 290–320	60–80	2·5N, 5E
10504	119297	Charcoal/AMS	1860 ± 50	− 23·1‰	1890 ± 50	120	75–210	25–245	100–120	2·5N, 5E
10506	119298	Charcoal	880 ± 50	− 25·0‰**	880 ± 50	1180	1055–1090, 1150–1225	1030–1265	30–40	7·5N, 7·5E

Continued on next page

Table 2. Continued

Sample IDs	Beta Analytic number	Material*	Measured C-14 age (BP)	C13/C12 Ratio**	Conventional C-14 age (BP)	Intercepts of radiocarbon age with calibration curve (AD)	1-Sigma calibrated results (AD)	2-Sigma calibrated results (AD)	Depth (cm except where noted)	Unit
Fossil Bay, 45-SJ-105 *continued*										
10507	119299	Charcoal	930 ± 60	− 25·0‰**	930 ± 60	1055, 1090, 1150	1025–1195	1000–1245	40–60	7·5N, 7·5E
10508	119300	Charcoal/AMS	1810 ± 50	− 22·0‰	1860 ± 50	145	100–235	65–260	60–80	7·5N, 7·5E
10509	119301	Charcoal	360 ± 50	− 25·0‰**	360 ± 50	1505, 1595, 1620	1460–1640	1440–1655	100–120	7·5N, 7·5E
10510	119302	Charcoal/EC	850 ± 70	− 25·0‰**	850 ± 70	1215	1065–1075, 1155–1265	1025–1290	20–40	2·5N0, 2·5N, 2·5W
10511	119303	Charcoal/AMS	670 ± 40	− 24·2‰	690 ± 40	1295	1285–1305	1270–1325, 1340–1390	40–60	2·5N0, 2·5N, 2·5W
10513	119304	Charcoal/AMS	850 ± 50	− 25·4‰	850 ± 50	1215	1170–1250	1040–1275	100–120	2·5N0, 2·5N, 2·5W
10514	119305	Charcoal/AMS	1010 ± 60	− 24·1‰	1030 ± 60	1010	980–1035	890–1165	120–140	2·5N0, 2·5N, 2·5W
10516	119306	Charcoal/EC	1010 ± 70	− 25·0‰**	1010 ± 70	1020	985–1045, 1105–1115	890–1195	160–180	2·5N0, 2·5N, 2·5W
Fisherman's Bay, 45-SJ-254										
25401	119307	Charcoal/AMS	510 ± 50	− 23·4‰	530 ± 50	1420	1400–1435	1310–1355, 1385–1450	8 in	Pit A
25402	119308	Charcoal/AMS	1410 ± 40	− 22·4‰	1450 ± 40	630	600–650	555–665	22 in	Pit A
25403	119309	Charcoal/AMS	1310 ± 40	− 25·4‰	1310 ± 40	690	670–770	655–790	26 in	Pit A
Mud Bay, 45-SJ-278										
27801	123534	Charcoal/AMS	1270 ± 50	− 27·6‰	1230 ± 50	790	720–735, 760–880	680–905, 920–950	80–100	3N, 2W
27803	119310	Charcoal/AMS	1210 ± 50	− 26·6‰	1190 ± 50	875	785–895	705–980	80–100	15N, 2W
27804	119311	Charcoal/AMS	1580 ± 50	− 26·7‰	1560 ± 50	535	435–575	410–620	100–120	15N, 2W
27805	119312	Charcoal/EC	3190 ± 110	− 25·0‰**	3190 ± 110	1435 BC	1535–1380 BC, 1335–1330 BC	1690–1170 BC	160–180	15N, 2W
27806	119313	Charcoal	1090 ± 70	− 25·0‰**	1090 ± 70	980	885–1015	790–1040	60–80	21N, 2W
27809	11914	Charcoal/AMS	1210 ± 60	− 23·2‰	1240 ± 60	785	695–880	665–960	120–140	21N, 2W
27810	123535	Charcoal/AMS	1770 ± 40	− 26·2‰	1750 ± 40	265, 290, 320	245–370	220–405	210	54N, 0E
27811	119315	Charcoal/EC	690 ± 90	− 25·0‰**	690 ± 90	1295	1265–1395	1195–1425	80–100	66N, 0E
Watmough Bay, 45-SJ-280										
28001	119316	Charcoal	2340 ± 50	− 23·6‰	2360 ± 50	400 BC	415–385 BC	525–370 BC	60–80	12S, 0E
28007	119317	Charcoal	1350 ± 100	− 25·0‰**	1350 ± 100	670	630–780	540–890	60–80	0N, 24W
28008	119318	Charcoal	1560 ± 50	− 25·0‰**	1560 ± 50	535	435–575	410–620	80–100	0N, 24W
28009	119319	Charcoal	1560 ± 50	− 24·0‰	1580 ± 50	465, 475, 515	425–555	395–605	100–120	0N, 24W
28010	119320	Charcoal	120 ± 50	− 24·5‰	120 ± 50	1700, 1720, 1820, 1855, 1860, 1920	1680–1755, 1805–1940	1665–1950	40–60	1N, 9W
28012	119321	Charcoal	2180 ± 50	− 23·5‰	2200 ± 50	330 BC, 205 BC	365–180 BC	380–100 BC	120–140	1N, 9W
28013	119322	Charcoal	2070 ± 40	− 23·4‰	2090 ± 40	75 BC	165–40 BC	190 BC–AD 5	153	1N, 9W
28014	119323	Charcoal	2130 ± 50	− 26·1‰	2110 ± 50	115 BC	185–45 BC	345–310 BC, 210 BC–AD 5	160–180	1N, 9W
28015	119324	Charcoal	2620 ± 40	− 23·8‰	2640 ± 40	805 BC	820–795 BC	835–785 BC	160–180	9N, 3W

*Charcoal samples submitted for: AMS=accelerator mass spectrometry, EC=extended counting. **Where C13/C12 could not be measured, a constant of − 25.0‰ was assumed.

Table 3. Calculated accumulation rates for sites mentioned in text. Accumulation rates by overall site were calculated using all dated samples from that site (“accumulation rate by site”) and are noted in the shaded rows. Accumulation rates by individual units were calculated using all samples from one unit (“accumulation rate by unit”). Accumulation rates were also calculated between each sample pair (“accumulation rate by sample pair”). R^2 represents the correlation coefficient of the regression equation

Site	Unit	Number of samples	Sample IDs	Accumulation rate by pair (cm/100 yr)	Accumulation rate by site and unit (cm/100 yr)	R^2
45SJ1	All	8			0·66 (site)	0·01
45SJ1	105–110N, 15–20W	2	00102	21·58	21·58	1·00
			00104			
45SJ1	100–105N, 530–535W	4	00105	13·45	6·56	0·66
			00106	− 65·31		
			00108	2·49		
			00110			
45SJ1	375–380N, 460–465E	1	00111	N/A	N/A	N/A
45SJ1	370–375N, 465–470E	1	00112	N/A	N/A	N/A
45SJ24—Op A	All	20			0·64 (site)	0·01
45SJ24—Op A	294, 270	1	294,270fF#18	N/A	N/A	N/A
45SJ24—Op A	310, 300	5	310,300fB1#1	− 10·00	8·68	0·98
			310,300fB1#9	5·00		
			310,300fC#7	21·39		
			310,300fN#25	7·60		
			310,300fR3#4			
45SJ24—Op A	310,302	3	310,302fD1#1	80·00	− 2·62	1·00
			310,302fD2#6	− 2·52		
			310,302fE1#1			
45SJ24—Op A	310, 304	4	310,304fB1#1	3·11	12·31	0·47
			310,304fD1#5	41·18		
			310,304fD3#6	− 13·33		
			310,304f2#26			
45SJ24—Op A	310, 306	2	1983#3	206·67	206·67	1·00
			1983#4			
45SJ24—Op A	306, 300	4	QL-4153	7·44	10·28	0·93
			QL-4154	12·50		
			QL-4155	− 5·17		
			QL-4156			
45SJ24—Op A	306, 302	1	QL-4157	N/A	N/A	N/A
45SJ24—Op D	All	22			5·36 (site)	0·06
45SJ24—Op D	105, 365	3	105B7	8·37	− 13·22	0·12
			105O1	− 33·37		
			105T1C			
45SJ24—Op D	111, 349	3	111P1	− 2·69	17·04	0·55
			111W1	19·17		
			111EE2			
45SJ24—Op D	123, 347	2	123A5	8·00	8·00	1·00
			123I1			
45SJ24—Op D	130, 352	3	130C1	156·00	53·23	0·76
			130H1	22·40		
			130K1			
45SJ24—Op D	TAB	5	TABC1	− 50·77	25·01	0·37
			TABD2	53·57		
			TAB003	− 4·08		
			TAB004	7·22		
			TAB007			
45SJ24—Op D	TCD	1	TCD002	N/A	N/A	N/A
45SJ24—Op D	TEF	2	TEF0073	3·75	3·75	1·00
			TEF0077			
45SJ24—Op D	TGH	3	TGHB3	3·64	− 9·31	0·39
			TGH008	− 11·69		
			TGH009			
45SJ105	All	12			1·22 (site)	0·02

Continued on next page

Table 3. Continued

Site	Unit	Number of samples	Sample IDs	Accumulation rate by pair (cm/100 yr)	Accumulation rate by site and unit (cm/100 yr)	R^2
45SJ105	2·5N, 5E	3	10501	3·07	4·61	0·77
			10502	103·23		
			10504			
45SJ105	7·5N, 7·5E	4	10506	60·00	− 1·37	0·06
			10507	2·08		
			10508	− 2·89		
			10509			
45SJ105	2·5N0, 2·5N, 2·5W	5	10510	− 11·51	35·04	0·55
			10511	34·53		
			10513	15·38		
			10514	− 266·67		
			10516			
45SJ254	All	3			5·46 (site)	0·88
45SJ254	Pit A	3	25401	4·65	5·46	0·88
			25402	− 9·03		
			25403			
45SJ278	All	8			3·58 (site)	0·40
45SJ278	3N, 2W	1	27801	N/A	N/A	N/A
45SJ278	15N, 2W	3	27803	6·11	3·37	0·99
			27804	3·08		
			27805			
45SJ278	21N, 2W	2	27806	58·54	58·54	1·00
			27809			
45SJ278	54N, 0E	1	27810	N/A	N/A	N/A
45SJ278	66N, 0E	1	27811	N/A	N/A	N/A
45SJ280	All	9			4·14 (site)	0·51
45SJ280	12S, 0E	1	28001	N/A	N/A	N/A
45SJ280	0N, 24W	3	28007	10·00	14·92	0·80
			28008	133·33		
			28009			
45SJ280	1N, 9W	4	28010	3·91	5·03	0·89
			28012	− 15·59		
			28013	13·88		
			28014			
45SJ280	9N, 3W	1	28015	N/A	N/A	N/A

using different strategies and large numbers of dates for each area were measured. For this study they are compared separately.

The all unit site accumulation rate of English Camp Operation A (Table 3, Figure 4) is relatively low (0·64 cm/100 yr) and is accompanied by a weak correlation coefficient. The site rate approximates the Line A model in Figure 2, or a slow accumulation.

Higher rates and much stronger correlations are apparent when individual unit accumulation rates are calculated, with the exception of Unit 310,302 (Figure 4). The high individual unit rates range from 10·28 to 206·67 cm/100 yr, reflecting the Line B accumulation model (Figure 2). These rates, coupled with their strong correlations, suggest that this site accumulated under an intermediate to rapid scheme. The rapid accumulation of Unit 310,306, however, is represented by only two samples and may be a function of inadequate sample size. The exception, Unit 310,302, is interesting in that it reflects a negative accumulation rate similar to the Line D model in Figure 2. Evidence of erosion in the form of a large pit is clear in the profile of the unit (see photograph of pit profile in Stein, 1996, Figure 19). Older charcoal was deposited over younger charcoal as pit fill.

45SJ24, Operation D, English Camp

An all unit site rate for English Camp Operation D of 5·36 cm/100 yr is represented by a weak correlation of

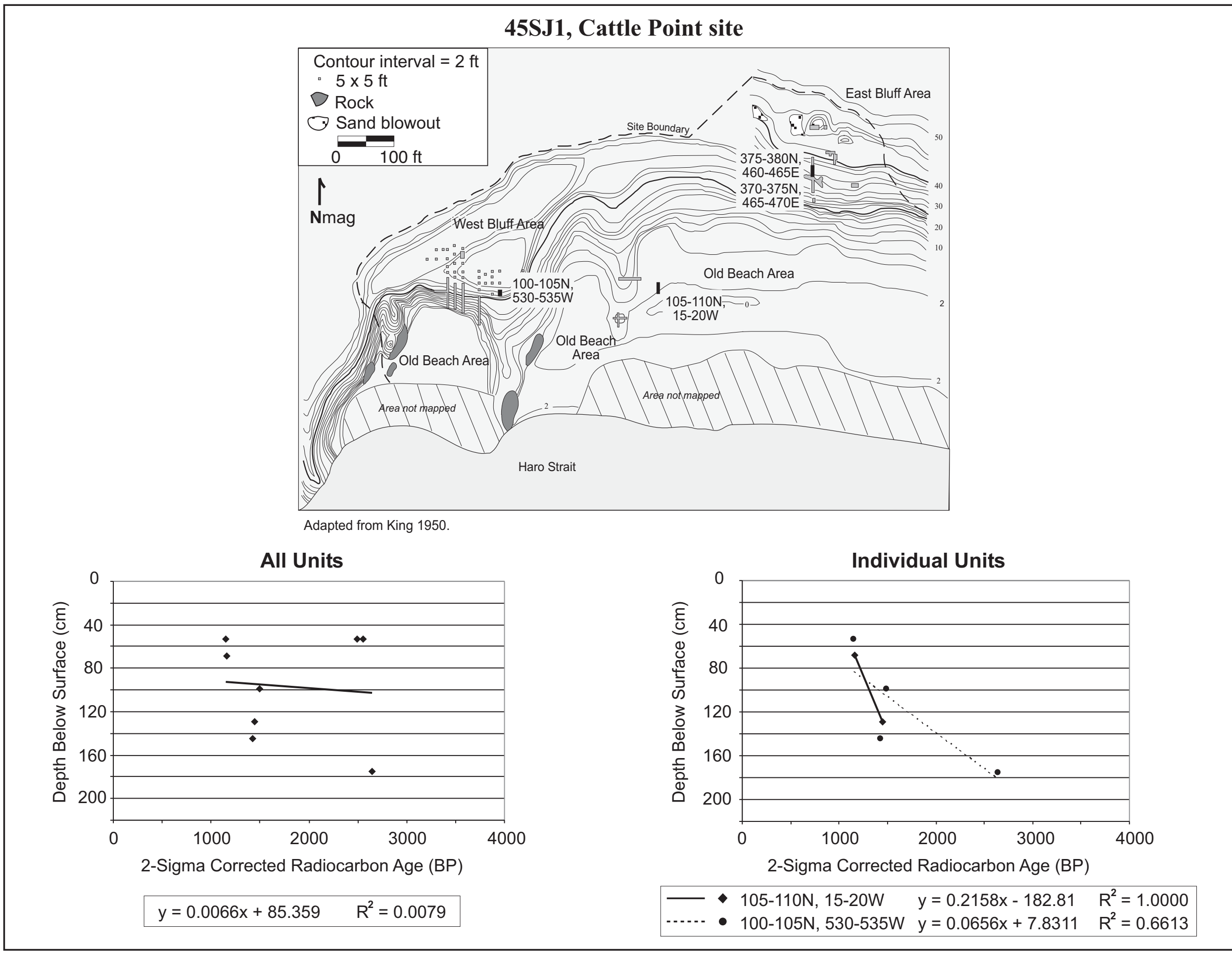


Figure 3. 45SJ1, Cattle Point site. Topographic map of the site and location of excavation units, accompanied by accumulation rate data. Graphs show depth below surface versus 2σ calibrated radiocarbon age (BP) for (1) all units and (2) individual units. Slopes of regression equations represent accumulation rates in cm/yr.

0·06 (Table 3, Figure 5). The individual unit rates were generally higher and more strongly correlated, except for two units with negative accumulation rates. For the most part, the individual units show intermediate to rapid accumulation, as represented by Line B in Figure 2. The negative rates in Unit 105,365 and Unit TGH may again reflect disturbance, but a more likely possibility is that the charcoal and other particles accumulated so rapidly in these units that the time represented in the counting errors inherent in radiometric age determination overlaps the time it took for the deposits to accumulate and cause the negative values. Note that very little difference in age is seen among the samples, especially in Unit 105,365.

45SJ105, Fossil Bay

A very different impression of cultural material accumulation is apparent for the Fossil Bay site when viewed from site versus unit perspectives (Table 3, Figure 6). The all unit site accumulation rate is quite low (1·22 cm/100 yr), similar to the Line A model of slow accumulation (Figure 2), and exhibits a weak correlation of 0·02.

The site contains distinct and widely separated areas of artifact concentrations (200–300 m), as indicated by Kidd's separation of the areas into Localities A and B. Although recorded as one site, considering these areas separately produces a much clearer and more accurate picture of the accumulation rate. In Locality A, one excavation unit (2·5N, 5E) displays a unit accumulation rate similar to the Line B model (Figure 2), an intermediate accumulation. The other excavation unit in Locality A (Unit 7·5N, 7·5E) approximates Line A in the model (Figure 2), which represents no accumulation to slightly negative accumulation. In Locality B the unit accumulation rate of 2·5N0, 2·5N, 2·5W is also similar to the Line B model, but reflects a more rapid accumulation scheme approaching Line C.

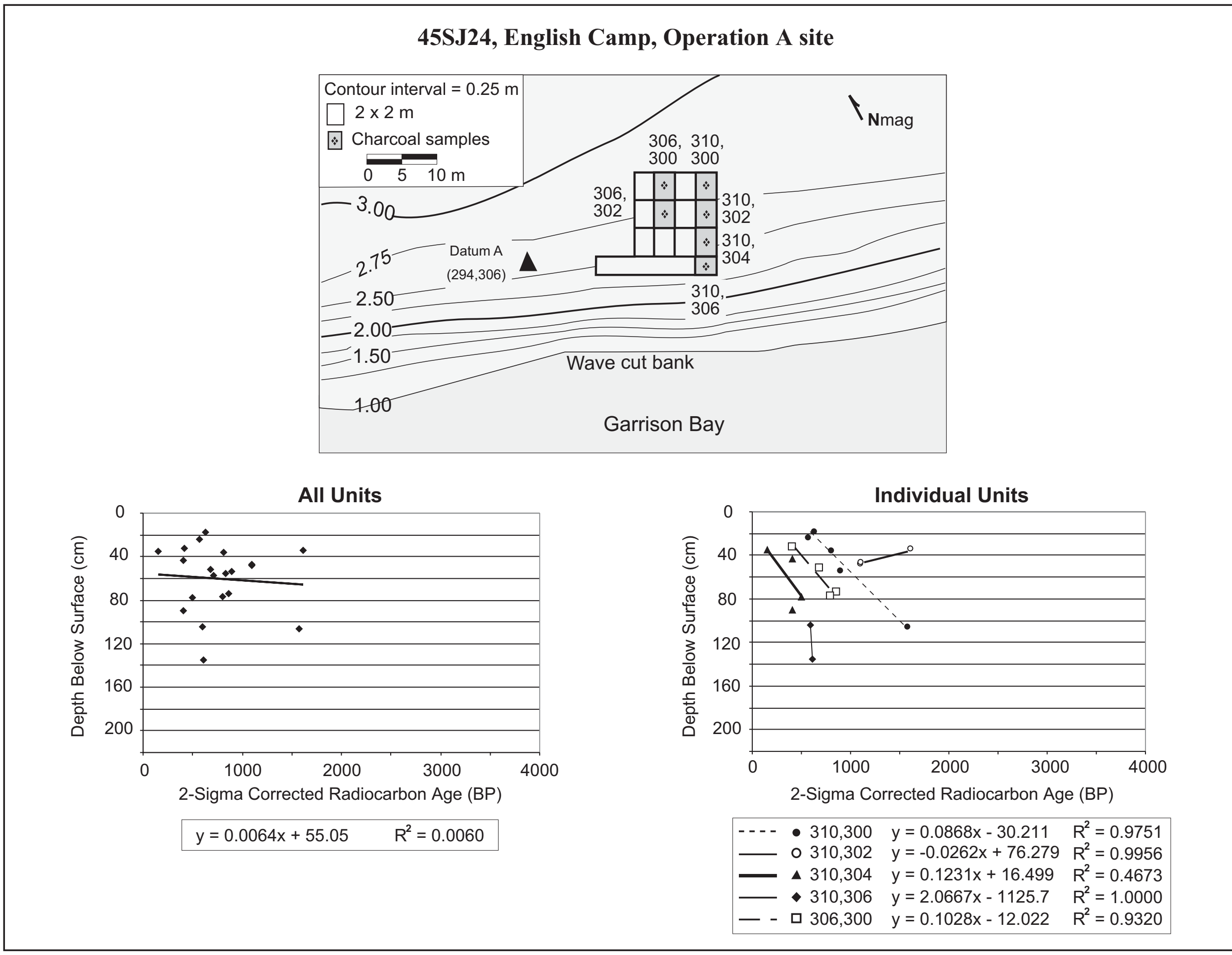


Figure 4. 45SJ24, English Camp, Operation A site. Topographic map of the site and location of excavation units, accompanied by accumulation rate data. Graphs show depth below surface versus 2σ calibrated radiocarbon age (BP) for (1) all units and (2) individual units. Slopes of regression equations represent accumulation rates in cm/yr.

45SJ254, Fisherman Bay

This site is represented by only three dated samples from one unit, and therefore our calculation serves as both the all unit site and individual unit rates (Table 3). The accumulation rate is intermediate at 5·46 cm/100 yr and is accompanied by a high correlation (0·88). This site's accumulation rate is similar to the intermediate accumulation of the Line B model (Figure 2).

45SJ278, Mud Bay

Calculations indicate an all unit site rate of 3·58 cm/100 yr and an intermediate correlation of 0·40 (Table 3, Figure 7). The all unit site rate approximates Line B accumulations (Figure 2). The individual unit rates suggest that different accumulation rates characterize this site, depending on location. Calculations of Unit 15N, 2W give an intermediate rate (3·37 cm/100 yr) and high correlation (0·99), while Unit 21N, 2W reflects a very high rate (58·54 cm/100 yr) and perfect correlation (1·00). Considering the low sample size of Unit 15N, 2W, it is unclear as to whether this high rate reflects the true accumulation character of this part of the site. In this case, the all unit site rate is probably more accurate, as it is almost identical to the accumulation rate in Unit 15N, 2W.

45SJ280, Watmough Bay

Calculations reveal an all unit site accumulation rate of 4·14 cm/100 yr and a correlation of 0·51 (Table 3, Figure 8). Individual unit rates for Unit 0N, 24W and Unit 1N, 9W are intermediate (14·92 and 5·03, respectively) and correlations are very strong (0·80 and 0·89). The high correlations and large sample size support the interpretation that Watmough Bay accumulated according to different rates, depending on the location, but both of the rates conform to a Line B model (Figure 2) of intermediate accumulation.

Interpreting the Calculation

Although very few problems are associated with the calculation of accumulation rates, many factors should

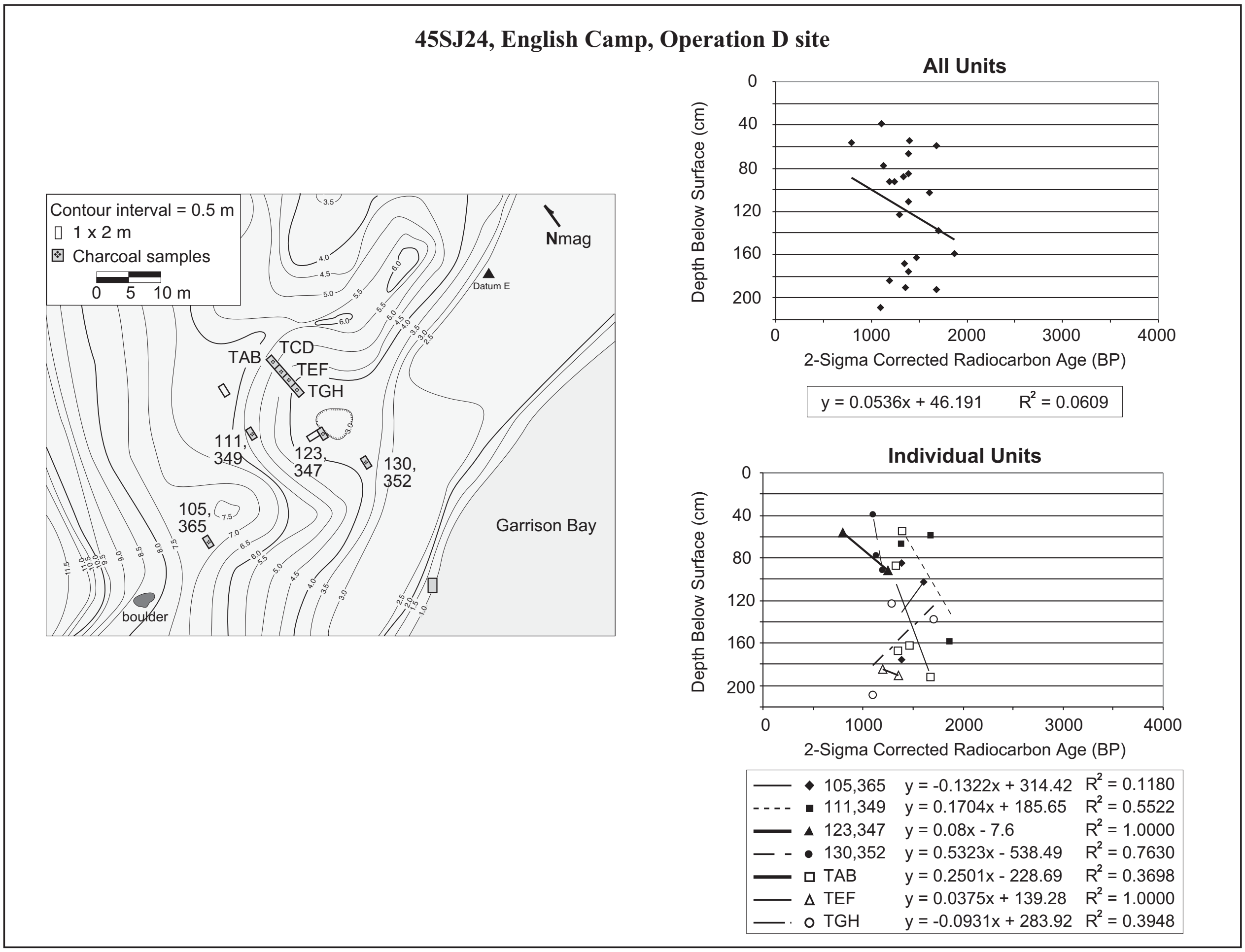


Figure 5. 45SJ24, English Camp, Operation D site. Topographic map of the site and location of excavation units, accompanied by accumulation rate data. Graphs show depth below surface versus 2σ calibrated radiocarbon age (BP) for (1) all units and (2) individual units. Slopes of regression equations represent accumulation rates in cm/yr.

be considered when interpreting the calculation. Specifically, the factors are: (1) size of the deposit being dated, (2) period of time (duration) over which the accumulation occurred, (3) number of samples dated, (4) horizontal and vertical distribution of samples across the deposit, (5) the date of deposition versus the actual sample age, and (6) difference between conventional C-14 age and calibrated age.

Factor 1—Size of the deposit

The size of the deposit under consideration dictates whether calculating a *site accumulation rate* or multiple excavation *unit accumulation rates* is more appropriate. The sites considered in this research are extremely large and contain layers of variable thickness. Therefore, individual excavation unit accumulation rate calculations are more appropriate. Unit accumulation rates describe more realistically the intensity of use for different activity areas and provide a progression of occupation for a given site. For example, at the Watmough Bay site (45SJ280) (Figure 8), the accumulation rates for individual units result in two lines of unequal slope. But if the outlier sample of very recent age (and shallow depth) is removed and considered separately, then three different periods of occupation appear, each of which accumulated very rapidly (steep slopes on regression lines). The earliest occupation is represented by the three samples in Unit 1N, 9W, falling in the range of 380 BC to AD 5. The next occupation is represented by the three samples from Unit 0N, 24W, falling in the range of AD 395–890. The last occupation is represented by one sample from the top of Unit 1N, 9W and suggests that people returned to the location as recently as AD 1665–1950. The slopes of the lines are not overlapping but are similar in steepness, suggesting that the settlement pattern for this site was occupation for short periods of time during which abundant material accumulated rapidly.

Factor 2—Period of time (duration) over which the accumulation occurred

The period of time over which the accumulation occurred affects the resolution of the accumulation rate

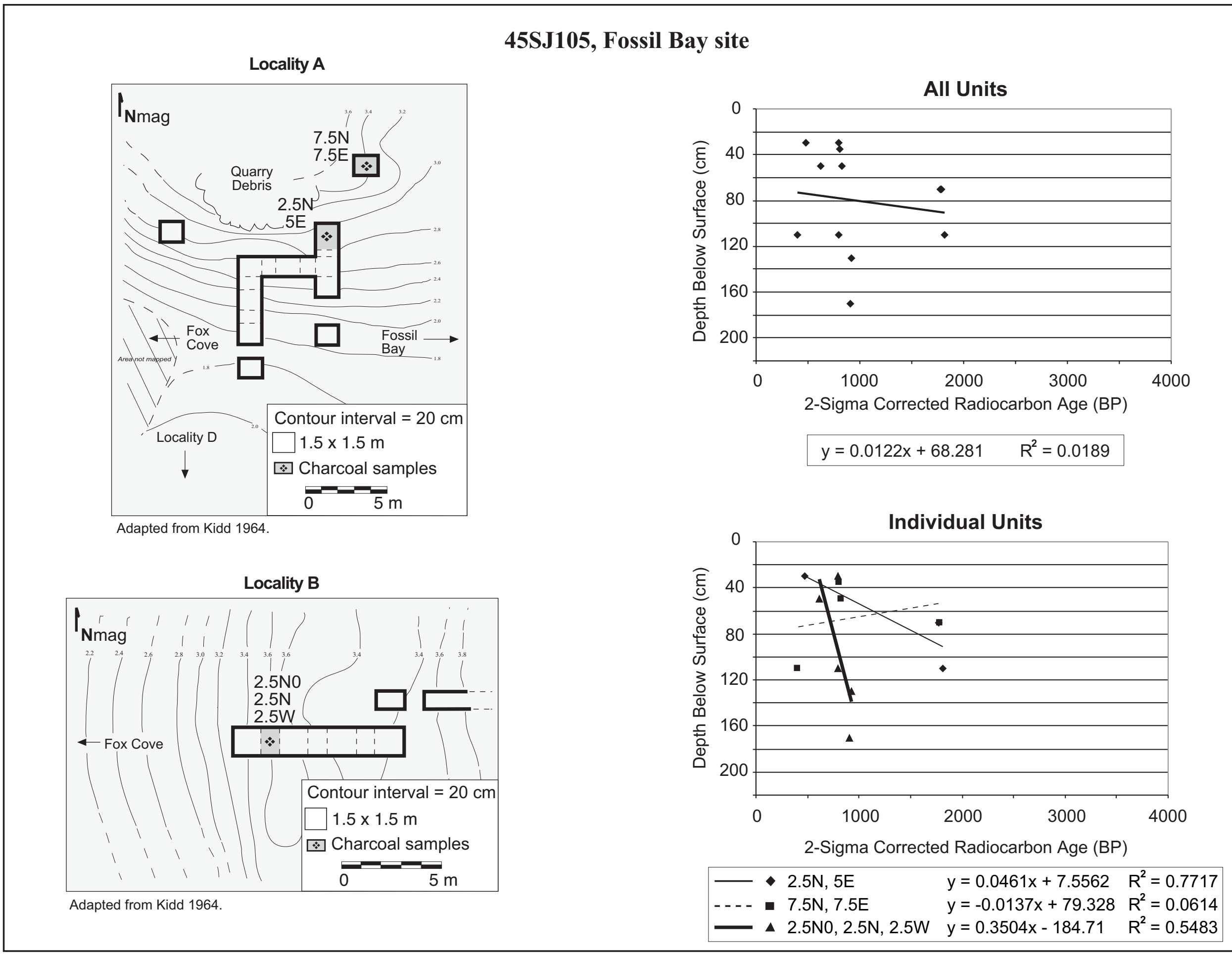


Figure 6. 45SJ105, Fossil Bay site. Topographic map of the site and location of excavation units, accompanied by accumulation rate data. Graphs show depth below surface versus 2σ calibrated radiocarbon age (BP) for (1) all units and (2) individual units. Slopes of regression equations represent accumulation rates in cm/yr.

and the interpretations that follow. The settlement patterns represented in our sites occurred within the last 1500 to 2500 years. Because these sites were 200 to 300 m wide and 2 m thick the duration of time was short compared to the size of the deposits. For example, in the case of the English Camp site (45SJ24), Operation D (Figure 5), the duration of time over which the deposits accumulated was so short that the regression lines produced from the individual unit accumulation rate calculations were nearly vertical. Our interpretation of this phenomenon is that people arrived at the site and quickly deposited over 2 m of shell midden within a 500-year period, after which they left. Previous to these dating results the interpretation was that the shell had accumulated over much longer periods of time (Carlson, 1954, 1960). We can imagine, however, smaller sites occupied over longer periods that would require different sampling strategies.

Factor 3—Number of samples dated

The number of samples employed in calculating accumulation rates affects both the accuracy of the rates and the interpretations of the meaning of the rates. Obviously the larger the sample of radiocarbon dates the more accurate the calculation of the rate. Rates based on only two samples give the impression that all the deposits over the entire site accumulated constantly, which is probably an oversimplification of the depositional sequence. In this research, an "adequate" sample exists when the addition of another data point does not change significantly the regression line. Looking at the San Juan Islands data, the Fisherman Bay site samples are too few to describe conclusively the type of accumulation. Both English Camp Operations, however, have achieved redundancy. Obviously, as the sample size increases, anomalous samples can be more easily identified.

Factor 4—Distribution of samples

The horizontal and vertical distribution of samples across the deposits presented the biggest challenge to our ability to make meaningful interpretations. Rate calculations and subsequent interpretations are

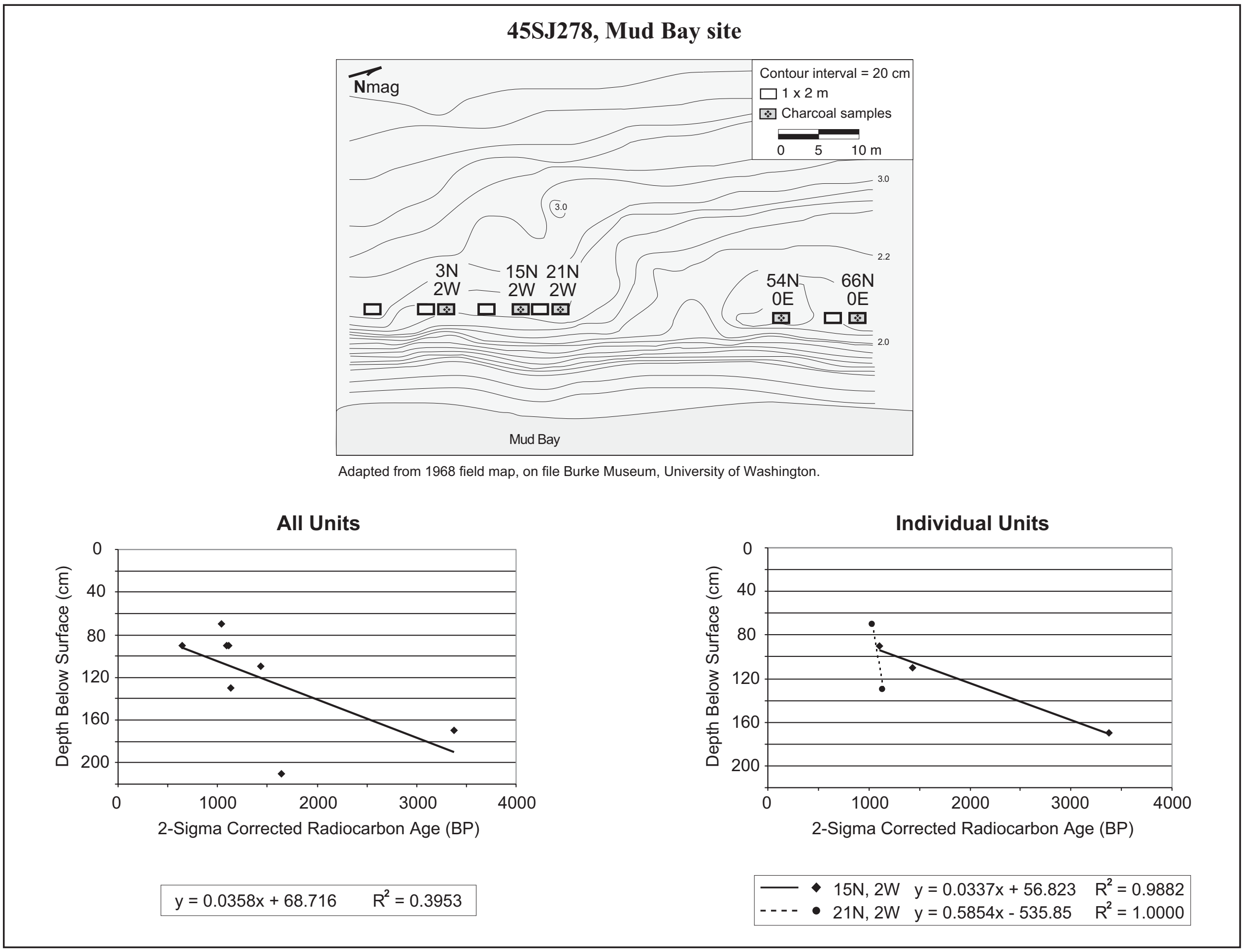


Figure 7. 45SJ278, Mud Bay site. Topographic map of the site and location of excavation units, accompanied by accumulation rate data. Graphs show depth below surface versus 2σ calibrated radiocarbon age (BP) for (1) all units and (2) individual units. Slopes of regression equations represent accumulation rates in cm/yr.

manipulated easily by selecting datable materials from clustered or unevenly dispersed locations across the site. We were constrained to the unit locations chosen by the original excavators. At the Fisherman Bay site (45SJ254) the collection from only one unit contained charcoal sufficient for dating. At English Camp, Operation A (45SJ24), Stein (1992) excavated in a specific location of the site to test a hypothesis concerning sea level fluctuations and dissolution in the groundwater table. If samples are selected from only the deepest deposit or the thickest sequence, then the accumulation rate will not be representative of the entire site, especially if the site is large and the deposits of variable thickness.

Factor 5—Target date versus sample date

We considered at least three problems when assessing the accuracy of the actual date of deposition (target date) as compared to the measured radiocarbon age (sample date): (a) sample mixing in a disturbed area, (b) downward or upward movement of the sample after deposition, and (c) death of the sampled organism before it was burned or deposited.

(a) A number of processes mix particles and may introduce error into the calculations, including rodents, worms, roots, frost heaving, liquefaction, and sand volcanoes, as well as house posts, hearths, storage pits, trenches, and burials constructed by occupants of the site (Wood & Johnson, 1978). These phenomena can result in older samples being deposited on top of younger samples, thereby creating anomalous dates. At English Camp, Operation A (Figure 4), sample number 310,302fE1#1 has an age range of 1500–1730 BP, while samples 310,302fD2#6 and 310,302fD1#1 range between 920 to 1300 BP. The two lower samples are clearly younger than the sample above them and are therefore anomalous samples. The charcoal in this excavated unit was not translocated through the midden because there is too much silt and clay to allow movement over any distance greater than about 1 cm. A better explanation for the anomalous date is the

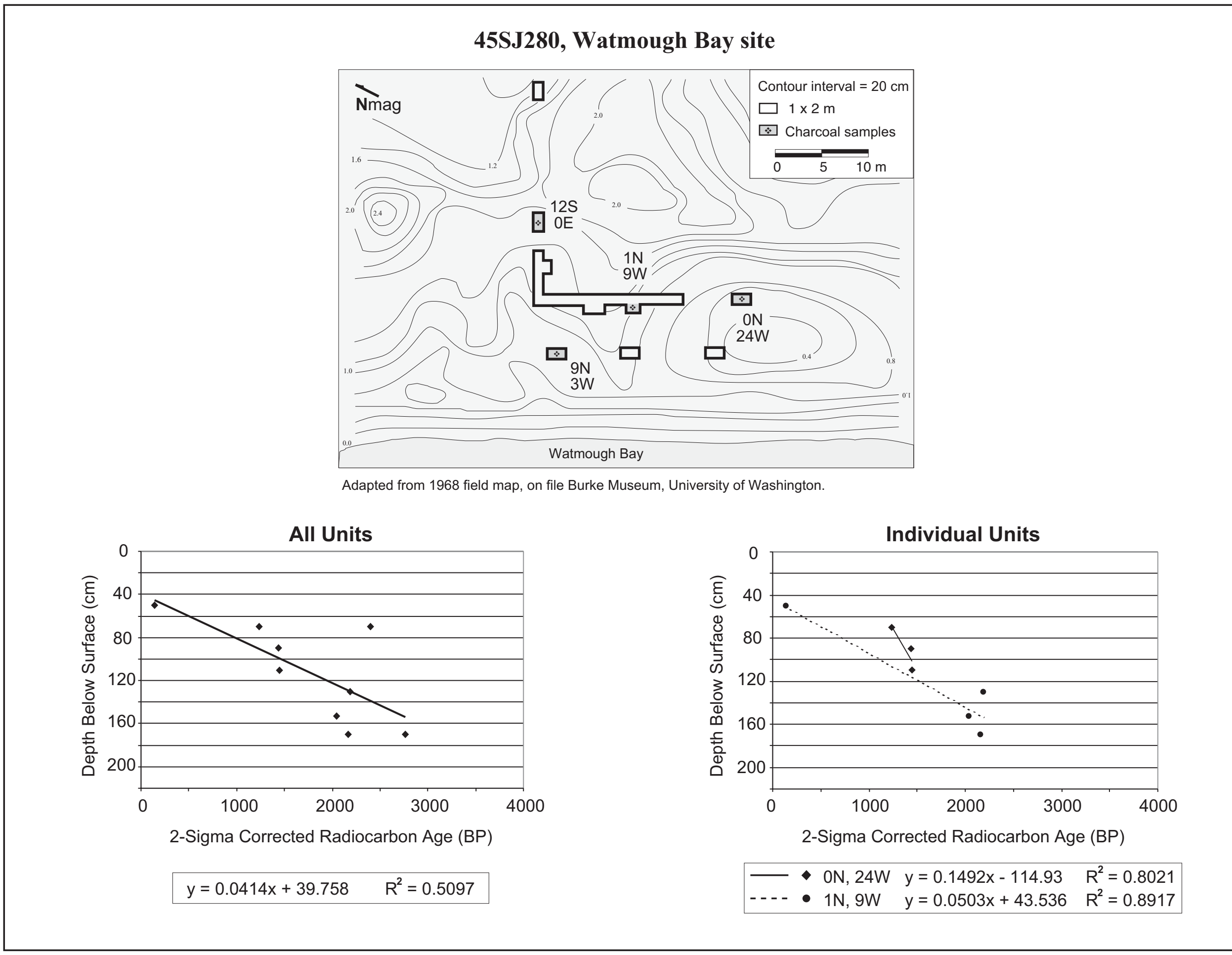


Figure 8. 45SJ280, Watmough Bay site. Topographic map of the site and location of excavation units, accompanied by accumulation rate data. Graphs show depth below surface versus 2σ calibrated radiocarbon age (BP) for (1) all units and (2) individual units. Slopes of regression equations represent accumulation rates in cm/yr.

discovery of a large pit evident in the profile after excavation. English Camp, Operation D (Figure 5), also has anomalous dates, as does the Fossil Bay site (Figure 6). We suspect that such anomalies are more common in sites that accumulated rapidly, because the error within the radiometric dating technique overlaps the experimental error of the radiocarbon technique, and dumping material quickly moves objects of the same age over large vertical and horizontal distances.

(b) Many kinds of sites contain interconnected pore spaces preserved between the large gravel-sized objects, which allow small objects such as charcoal to be translocated downward (or upward if groundwater can "float" them). These pore spaces can fill with air, water, fine-grained sediment, organic matter, or artifacts, and act as conduits for surface water and ground water. The shell middens observed during excavation have pores filled with silt and clay that clog the movement of charcoal along these pathways, eliminating this problem in our study. But this problem can cause anomalous dates to appear in the data.

(c) In northwestern North America, trees such as Western red cedar (*Thuja plicata*) and Douglas fir (*Pseudotsuga menziesii*) frequently live for 800 to 1000 years. The heartwood from these species cannot give precise dates for the cutting event, because it stopped exchanging carbon with the atmosphere long before the tree was cut. To prevent the inadvertent dating of old wood, we selected charcoal from only small twigs or branches and from only short-lived tree species.

Factor 6—Conventional C-14 age versus calibrated age

The calculation of accumulation rates compares the age and depth of two or more samples, and requires that these ages exist on a linear time scale. Because atmospheric C-14 activity has not remained constant in the past, conventional (uncalibrated) C-14 ages do not reflect a linear measure of time. The calibration curve is relatively flat at various times in the past and can produce many possible age intercepts for a single sample (see CALIB (Stuiver & Reimer, 1993) and OxCal (Bronk Ramsey, 1995)). This flatness results in identical 2σ calibrated date ranges, which when divided by the depth, suggest instantaneous (very rapid) deposition. For instance, English Camp, Operation A, a unit accumulation rate of 206 cm/100 years was calculated for Unit 310,306 (Table 3). This rate is an order of magnitude larger than any other calculated rate and thus warrants a closer examination. The rate was calculated from two samples, one from a depth of 104 cm and the other from 135 cm, but with similar two-sigma intercept. The intercept fell on a flat section of the radiocarbon calibration curve and therefore the dates of both samples have to be considered equal. They were roughly 30 cm apart in the same 2 × 2 m excavation unit, yet result in the same age. Even though the intercept includes a 140-year swing in possible ages, the most logical interpretation for this discovery is that the layer from which they came was deposited as one large dumping event. The layer was characterized in field notes as containing abundant whole shells, with boundaries sloping towards the water. It was interpreted during excavation as an area different from the rest. Now we suspect it accumulated rapidly relative to the other units of excavation.

Discussion

When analysing these data and after considering factors that may influence our interpretations, we compared calculated accumulation rates to the hypothetical models shown in Figure 2. Although the numerical rate calculations are the most powerful outcome of the method offered in this report, comparisons of these numerical values is difficult. For example, in Table 3, 22 unit rates are calculated. Interpreting the significance of those rates requires comparing them to each other using either a statistical method or ranking system. We chose to create ordinal categories into which each unit and site accumulation rate could be placed, in this case defined by slow, intermediate, and rapid categories. Defining the boundaries of this ordinal scale on the basis of some scientifically reasoned assumptions is problematic, but we offer an explanation that we believe can be defended with common sense. In this case, we define categories by considering sedimentation typical of a Northwest Coast shell midden.

Slow accumulation occurs at a location where material is being deposited at a rate of less than 2 cm/100 years. Most of the sites in this study were not older than 2000 years, and may be closer to 1000 years old. That means that, if we assume the older date, a site where material was constantly accumulating at a rate of 2 cm/100 years would have a thickness of 40 cm in 2000 years. Under forested conditions in the Northwest, the upper 40 cm of the biomantle is constantly mixed by pedoturbation. Material that accumulated this slowly is mixed in this process and the charcoal from such deposits would most likely result in anomalous dates.

Intermediate rates of accumulation in Northwest Coast shell middens occur where material is deposited at a rate higher than 2 cm/100 years and less than 50 cm/100 years. Material accumulating at this rate would be buried before it was mixed. Bioturbation should not be an overriding cause for disturbance in deposits that accumulated at this rate.

Rapid accumulation occurs when particles are deposited at a rate higher than 50 cm/100 years. Over a period of 2000 years, a location experiencing this rate would accumulate a thickness of 1000 cm (10 m), assuming a constant rate of accumulation for the entire period. A thickness of 10 m is a rather thick shell midden, even by Northwest Coast standards, and such rapid burial would insure the preservation of contextual relationships between sediments and layers.

When using these relative terms (slow, intermediate, and rapid) we find that most sites, calculated using all samples to obtain the site accumulation rate, fell within the category of slow to intermediate accumulation. Yet when rates were calculated for individual excavation units within a site, many rates of accumulation increased. In other words, rates for smaller excavated areas turned out to be higher than rates for entire sites. Reading top to bottom from Table 3, rates in cm/100 years of 22, 7, 9, 12, 10, 17, 8, 53, 25, 4, 5, 35, 6, 3, 59, 15, and 5 were found using excavation unit accumulation rate calculations (anomalous rates were left out of this list). These rates compared to site accumulation rates 1, 1, 5, 1, 6, 4, and 4 cm/100 years, provide a very different view of Northwest Coast middens. The assumptions of slow accumulation rates previously published (e.g., Mitchell, 1971; Kidd, 1971) have to be reconsidered, as well as the settlement patterns derived from these assumed rates.

We now realize that these sites and areas defined by individual excavation units did not always accumulate slowly over long periods of time. In Figures 3–8, one can easily see that deposition began and ended over discreet and short periods of time, approximately 500 years in duration. In the sites we sampled, each area within the site accumulated at intermediate or rapid rates (for a period less than 500 years), and in most cases the duration of accumulation in any given excavation unit was short.

For example, at the Cattle Point site (Figure 3), Unit 105–110N, 15–20W accumulated at a rate of 21·58cm/100 years, starting about 1500 BP and halting at 1000 BP. At British Camp, Operation D (Figure 5) the calculated rates for most units was intermediate, occurring over a duration of 500 years. At the Fossil Bay site (Figure 6) the duration of accumulation of one unit was less than 500 years, another unit was anomalous (inverted dates to depth), and another was over a period of 1500 years. At the Mud Bay site (Figure 7) Unit 21N, 2W accumulated over less than 500 years, while the other unit, with one very old date at the bottom, ranged over 2500 years duration. At Watmough Bay site (Figure 8) one unit accumulated quickly starting at 1500 and stopping 1250 years BP, while another unit accumulated quickly from 2500 to 2000 years BP with an additional depositional event capping the unit dating to the last 300 years.

A close examination of these duration data suggests that the accumulations longer than 500 years actually can be divided into two periods of accumulation. The first was a deposition event (deepest), followed by an unconformity (unseen in the profiles), and overlain by a later period of accumulation. The unconformities were invisible until this dating project alerted us to its presence. Because others excavated many of these sites, and the notes do not contain the necessary descriptions to look back and identify an unconformable surface, we can only suggest that the multiple occupation scenario is the best interpretation.

Even though we identified periods of accumulation, separated by unconformities, we have not identified the cause of the accumulation and its cessation. We do not know if a few people deposited large quantities of material, or many people deposited small quantities, and we cannot assess the reasons for the absence of deposition for long stretches of time. We know, however, that these calculations are the first step in explaining such episodes and they are absolutely necessary for the next step to reconstruct settlement patterns.

Conclusions

Estimating the accumulation rates of stratigraphically complex sites has led to erroneous conclusions concerning occupation history of single locations as well as regional settlement patterns. When accumulation rates are calculated using radiometric ages and depths, the complexity of occupation history can be empirically identified. Most sites are large and contain a variety of materials dropped by people, rivers, wind, and gravity. These materials were not transported to all areas at the same time or rate, and this inequality of transport can be calculated using the method of accumulation rates forwarded in this report. Archaeologists often think of accumulation rates in terms other than quantitative expressions. They have been taught to interpret accumulation rates on the basis of qualitative information, such as evidence of house building, shellfish processing, or pit construction. Instead, the calculation of accumulation rates will provide a quantitative description of the depositional environment and will lend even more data for subsequent interpretations of settlement patterns.

Individual excavation unit accumulation rates as a method of calculation are recommended in this study over the calculation of site (all unit) accumulation rates. The calculation is essentially a statistical analysis of corrected radiocarbon ages and depths for each excavation unit and provides a robust measure of accumulation. When the area from which the samples are collected is small (compared to the site as a whole), then discreet differences appear and can lead to stronger interpretations. Complex archaeological sites, such as shell middens, require that accumulation rates be calculated on the scale of the individual unit, which in turn requires more dated samples.

The accumulation rate calculations performed in this study demonstrate that shell middens in the San Juan Islands consist of discreet areas where deposits accumulated rapidly over short periods of time (approximately 500 years) followed by longer periods of abandonment (approximately 1000 years). We can no longer look at a late Holocene shell midden in the Northwest Coast and say with any certainty that people lived at that location for the last 2000 years. These accumulations rates are much higher than most archaeologists previously reconstructed, and the durations of occupation much shorter. Rather than thinking of these sites as accumulating slowly over longer periods and continuously occupied, we now can determine the actual time of deposition for each area of the site.

This study suggests to us three final conclusions. (1) Archaeologists need to ask for funding to date adequately any site excavated. We dated 82 samples, which admittedly represents a large financial investment, but was still inadequate to date all these sites. The time has come to be responsible and analyse the material we remove from the ground using the best possible procedures. We have the technology to extract quantifiable information about the past, when previously we were forced to estimate. We should ask for all the funds necessary to perform the appropriate analyses.

(2) Calibration reflects a statistical level of significance involving a probability. We cannot stress enough how important it is to fight the urge to discuss and report only measured C-14 ages. These numbers are not calendar years and their use will continue to confuse rather than help us decipher the chronology of the past. Accumulation rates, in particular, are calculated using the probability and precision offered by calibrated ages.

(3) Many collections of previously excavated sites contain samples suitable for calculating accumulation rates. They are not, however, being utilized to their fullest potential. These collections exist in repositories and provide a wealth of information to archaeologists with appropriate research questions. For regions that have experienced chronological difficulties, a study that calculates accumulation rates using dated samples from archived collections could make significant contributions.

We conclude with the suggestion that calculating accumulation rates is appropriate not only for shell middens, but will be especially helpful to researchers excavating equally complex sequences such as found in caves and rockshelters, coastal and alluvial settings, and older sites where significant post-depositional alterations have complicated the depositional sequence. The time for relative derivations of accumulation rates is over.

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