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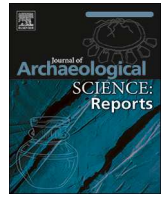
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Building a landscape history and occupational chronology at Čix^wicən, a coastal village on the Strait of Juan de Fuca, Washington State, U.S.A.



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ABSTRACT

Geoarchaeological analysis at Čix^wicən, an ancestral Klallam village near Port Angeles in northwestern Washington State, U.S.A., highlights the resilience of coastal foragers and their connection to place. Ancestral Klallam peoples occupied ever-changing beach and spit landforms growing within the shelter of Ediz Hook on the Strait of Juan de Fuca (SJDF) for 2700 years. Geoarchaeological methods were employed to define seven chronostratigraphic zones that chronologically structure the cultural deposits and allow them to be correlated to a sequence of beach development and to markers for tsunami that overtopped the site. Initial habitation prior to 1750 BP utilized a narrow beach against the bluff, then expanded with the prograding beach ridges, which grew north to create a lagoon. Stabilization of beach ridges after 1300 and 1000 BP was followed in each case by construction of a plankhouse, one of which was occupied for 800 years, and the other for 500 years. Inundation of the site, as indicated by erosional channels, backwash deposits, and structural collapse, occurred five times, and can be correlated with documented Cascadia Subduction Zone plate boundary megathrust earthquake events. The resilience of the households, who re-occupied the houses soon after the events, is striking, particularly the rebuilding of one house after it collapsed around 600 BP.

1. Introduction

The concept of “persistent places” (Gamble, 2017; McLaren et al., 2015) enriches understanding of complex coastal foragers and draws attention to the role of practice and social memory in connecting social groups to specific locations in the landscape. Persistence and place identification are well demonstrated at Čix^wicən, where ancestral Klallam peoples occupied ever-changing beach and spit landforms in the shelter of Ediz Hook on the Strait of Juan de Fuca (SJDF) for 2700 years (Fig. 1). One of the largest of the traditional Klallam villages (Gunther, 1927), Čix^wicən is situated on the shoreline of Port Angeles Harbor (Washington State, U.S.A.) on the Northwest Coast of North America (Fig. 2). Physical evidence of the village had been obscured by industrialization of the harbor in the late 19th and early 20th centuries, including construction of a sawmill in 1914 in the immediate vicinity (Kaehler and Trudel, 2006; Butler et al., this issue a). In 2004, Larson Anthropological and Archaeological Services excavated a portion of the village as part of a Washington Department of Transportation (WSDOT) project (Butler et al., this issue a). Over 500 m² of area and 261 m³ of sediment were excavated using high resolution stratigraphic methods.

This large-scale project revealed evidence of multiple plankhouse structures and the beach landforms on which they were built. Dates of cultural material suggested that over a period of ~2700 years, the beach platform expanded towards the harbor and human use followed

the emerging, evolving shoreline from intermittent use, to the establishment of more permanent long-term settlement (Sterling et al., 2006a, b). For various reasons, none of the recovered materials were analyzed beyond cataloging (Butler et al., this issue a).

Butler et al. (this issue a, b) describe the development of a research project applying a human ecodynamics framework (Fitzhugh et al., this issue) to understand the social and environmental mediation of animal resource use during the occupation history of this ancestral Klallam settlement. In this paper, we explore the progression of village establishment and growth, and its impacts on the landscape, in the context of shoreline change and catastrophic events. By integrating paleoenvironmental information, we can study coupled human-natural systems, or ‘socio-ecosystems’ to better understand processes of stability, resilience, and change in socio-ecological relationships or systems in response to the historical contingency of environmental events.

The Port Angeles Harbor and environs are within the modeled range of effects (shaking, tsunami) of large magnitude plate boundary earthquakes in the Cascadia Subduction Zone, four of which occurred during the period of site occupation; events S, U, W, and Y (Atwater et al., 2004; Atwater and Hemphill-Haley, 1997). This time period also spans the Little Ice Age and Medieval Warm Period, and an increase in sheltered intertidal habitat due to growth of Ediz Hook postulated by Sterling et al. (2006a) which is expected to have affected species distribution and abundance of aquatic animals by changing the extent and

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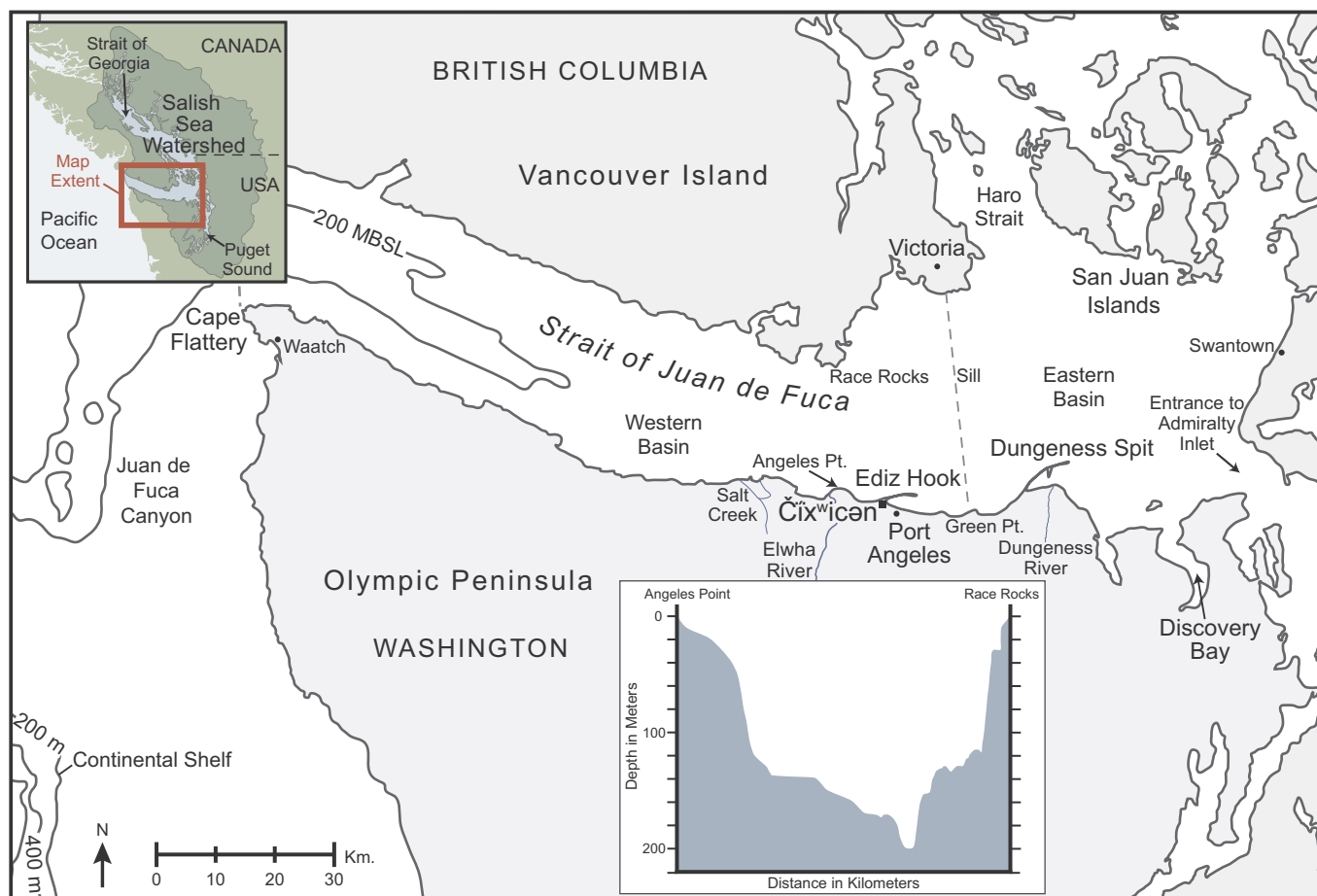


Fig. 1. Regional map showing the location of Číx^wicən, Strait of Juan de Fuca, Juan de Fuca submarine canyon, and the western part of the Salish Sea. Inset of the bathymetric profile of the Strait of Juan de Fuca, from Angeles Point to Race Rocks. Basemap and locator map adapted from Google Maps. Canyon detail from [Alford and MacCready \(2014\)](#). The Western Strait meets the Juan de Fuca Canyon where it incises the continental shelf around 250 m, maintains a depth of 180 m through most of its 100 km length, and shallows abruptly where it crosses the Victoria-Green Point sill moraine, 55 m below the surface. (Figure drafted by Adrienne Cobb).

type of shallow intertidal substrate in Port Angeles Harbor. The importance of Ediz Hook (Fig. 2) to the Číx^wicən village occupants is reflected in its Klallam name *tsiq^wáy*, signifying “sheltered harbor” (Montler, 2012). The hook defines two environmental zones: flowing currents of the SJDF with access to open water resources, and the sheltered harbor and saltwater lagoon inside the hook featuring near-shore resources. The shelter of the hook also created an attractive settlement location, reflected in a series of house constructions that track the growth of beach ridges forming the Číx^wicən spit as has been observed at other sites in the region (Grier et al., 2009). Spits are dynamic landforms, however, and changes in Ediz Hook and associated beaches can be anchored temporally by radiocarbon dates from cultural material on beach ridges. In addition, Číx^wicən’s location on the SJDF provided an opportunity to highlight human occupation of straits—an understudied habitat.

Coast Salish people are known for relatively autonomous and fluid corporate groups organized around kinship ties and labor needs (Suttles, 1951, 1990; Suttles and Maud, 1987); decisions about coping with disaster were likely made at the household level (Losey, 2007). Comparing household response strategies to catastrophic events helps us understand the durability of the social order and the sources of resilience. Several scholars (Ames, 2006; Arnold, 1996, 2006; Grier, 2006) have identified diachronic studies as a means of articulating the mechanisms by which social relationships were transmitted across generations. Empirical challenges arise however, due to the complex vertical palimpsests resulting from daily activities, storage functions

and architectural maintenance over decades (and centuries) of occupation (Ames, 2006; Smith, 2006; Trieu Gahr, 2006). The high-resolution stratigraphic excavation at Číx^wicən, which isolated floor surfaces and short-term cultural events such as construction and dumping events, allowed us to examine diachronic change in household activities with greater precision.

The task of the geoarchaeological component of the project was to define a chronological structure for the assemblages of animal remains that would allow us to see household-scale responses to short-term impacts, such as seismic events, and long-term trends, such as the effect of spit growth on the nearshore habitat. We also needed to refine the sequence of beach development forming the spit on which Číx^wicən is situated (referred to hereafter as the Číx^wicən spit) and closely examine site records for possible evidence for impacts from earthquakes in the Cascadia Subduction Zone, such as markers of tsunami events. The following inter-related questions guided the research, and are used to structure the presentation of the results:

1. How did the development of Ediz Hook and Číx^wicən spit affect the site and nearby intertidal habitats?
2. Is there in situ evidence within the archaeological site for tectonic events such as tsunamis?
3. How did occupation and activities vary with the landscape changes; i.e. spit development and catastrophic events? How did the inhabitants affect the developing landforms?

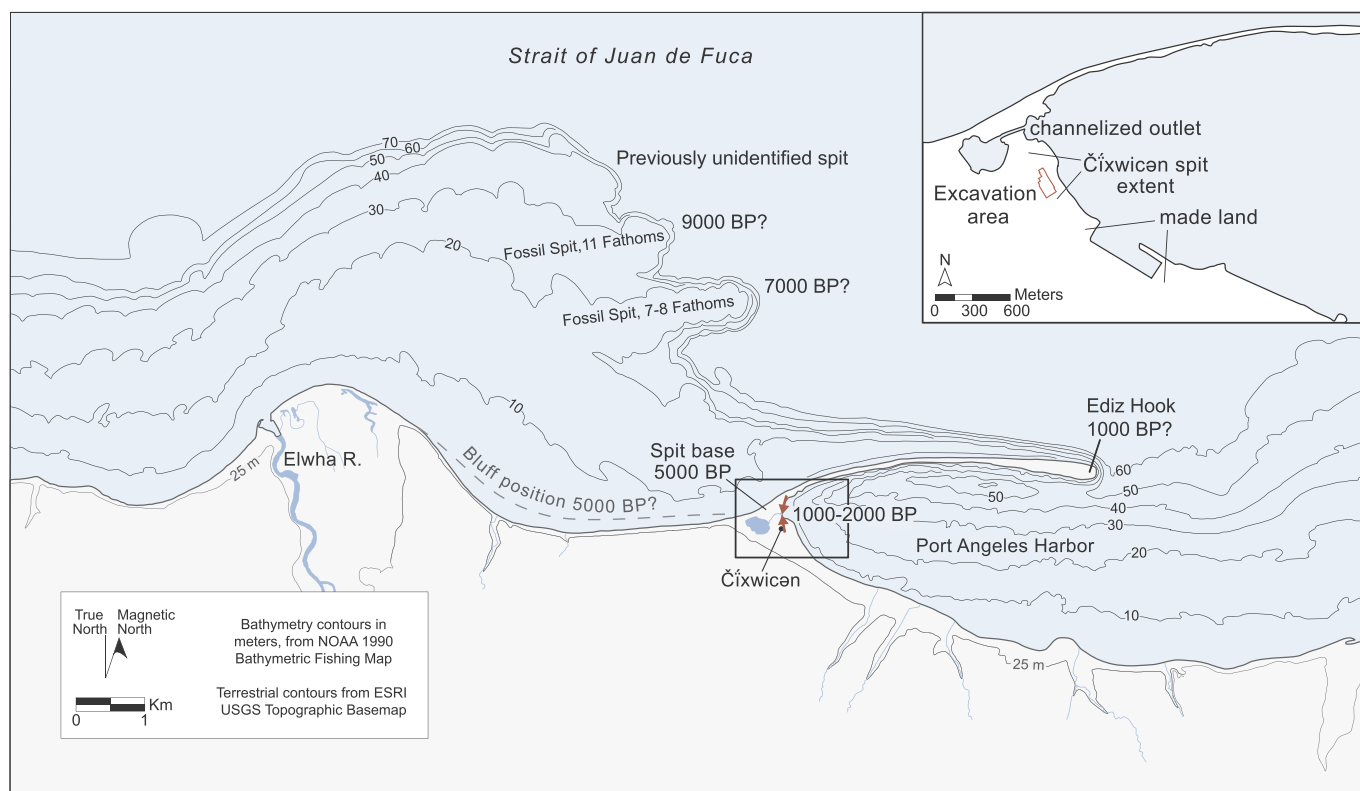


Fig. 2. Čixwicən in relationship to Ediz Hook, Port Angeles Harbor, and the Elwha River. Inset shows the site excavation area in relationship to industrialized shoreline. Bluff erosion and age of formation of paleospits, including the inner spit marked by red arrows, are from Galster and Schwartz (1990). The higher resolution bathymetry this map is based on shows an additional earlier spit. (Figure drafted by Adrienne Cobb).

2. Physiographic context

Interpretation of on-site deposits requires reference to local and regional geomorphic processes in order to recognize cultural versus natural deposition, changes in the local environment, and the hallmarks of catastrophic events. Natural depositional processes at Čixwicən are the local manifestation of physiographic processes at multiple scales. Large-scale factors, such as Pacific Ocean climatic cycles, active plate boundary and shallow surface tectonism, and the aftereffects of the late Wisconsin glaciation intersect in unique ways at this specific latitude on the continental margin. Čixwicən is near the eastern end of the Western Strait of Juan de Fuca, which trends east-west between the two mountainous regions, the Olympic Peninsula of Washington State to the south and Vancouver Island, British Columbia (Canada) to the north (Fig. 1). McMillan and McKechnie (2015) make a distinction between the outer coast and the inner waters of the Salish Sea as human habitats; they include the SJDF within the latter, yet the SJDF is better considered transitional between the two. The deep, narrow, glacially carved channel connects the Pacific Ocean and the Juan de Fuca submarine canyon with the inland Salish Sea. This distinctive oceanographic feature influences currents and tides, nearshore deposition, and landform development. The recurvate spit, Ediz Hook, is a consequence of oceanographic processes within the SJDF. Tsunami generated by near field and far field megathrust earthquakes can propagate along this channel into the inland sea. A deep layer of nutrient rich deep oceanic waters flow eastward along the channel, propelled by both Pacific tides and hydraulically controlled, wind-driven movement up the Juan de Fuca Canyon (Alford and MacCready, 2014); a less saline surface layer, approximately 100 m deep, flows westward. Tidal currents are asymmetrical and amplified by the restriction of the channel, with a range of 2.5 m. Orographically controlled winds shift from predominantly easterly in winter to westerly in the summer (Cannon, 1978). Relative to

inner waters of the Salish Sea, the SJDF, particularly the Western Strait, is characterized by conditions that are more influenced by the open ocean. Colder, more saline water and greater wave energy from winds and tides supports biota associated with open rocky shorelines of the Pacific coast (Butler et al., this issue b).

Coastal sedimentary processes in the SJDF differ from those of coastlines exposed to the open ocean (Eidam et al., 2016; Frey and Dashtgard, 2011). On strait-margin coastlines, the strong tidal exchange, current parallel to the long axis, surprise ocean swells and wave variability due to local winds are important factors affecting beach-shorefaces (Frey and Dashtgard, 2011). Tidal currents, amplified by channeling through gulfs and straits, are much greater than those in the open ocean. The southern shoreline of the SJDF is characterized by longer drift cells than are found within Puget Sound, carrying sediments derived from erosion of bluffs, including mass wasting and landslides, and from rivers entering the SJDF, of which the Elwha and the Dungeness are the largest, predominantly eastward (Fig. 1). Studies initiated in connection with the recent removal of two dams on the Elwha River (Fig. 2) provide detailed analysis of beach morphodynamics, sediment budgets, littoral transport, currents, and wave energy (Eidam et al., 2016; Gelfenbaum et al., 2009; Warrick et al., 2009, 2011); much of this relates or extends to Ediz Hook.

Coastal processes in the SJDF are also constrained by the legacy of Pleistocene glaciation. The areal extent of the nearshore zone is limited and sheltered environments, such as bays and extensive tide flats, are rare due to the steep submarine profile (Fig. 1), and steep bluffs forming much of the shoreline margin. These were cut into glacial drift deposited as the Juan de Fuca Lobe of the Cordilleran Ice Sheet withdrew in the Late Pleistocene (Downing, 1983; Schasse et al., 2004). Between 17,000–6000 years ago relative sea level fluctuated significantly with an initial rapid fall in the Late Pleistocene due to ice unloading, followed by rapid rise in the early Holocene (Engelhart et al., 2015). Sea

level stabilized just over 6000 years ago at near-modern levels (Mosher and Hewitt, 2004), after which bluff erosion slowed and coastal landforms became more persistent (Wegmann et al., 2012). On the northern coast of Washington, relative sea level was within 1 m of its current position for the last 2400 years, with a likely rising trend, based on a small sample of data points (Engelhart et al., 2015). Throughout the Holocene, wave action continued to undercut the bluffs, creating terraced beaches consisting of glacial drift (Downing, 1983). Glacial drift underlies the sands that formed the first beaches along the developing Port Angeles Harbor shoreline.

Two of the most prominent features on the southern shoreline of the SJDF are Dungeness Spit and Ediz Hook, long spits, landforms that form in areas with strongly directional sediment transport and adequate sediment supply (Fig. 1). Spits are dynamic landforms, and Ediz Hook has changed in location, configuration, and length over the Holocene, driven by changes in sea level, climatic regimes, and sediment availability. There are only two long spits along the 100 km southern shoreline of the Western SJDF, indicating that the shoreline is non-uniform and local conditions are influential. Ediz Hook depends on sediment from erosion of glaciomarine bluffs to the west, and more importantly from the Elwha River, an enduring connection revealed by a series of drowned paleospits that have formed at the eastern margin of the Elwha River delta throughout the Holocene (Fig. 2).

Landscapes in the Northern Olympic Peninsula and adjacent areas have been affected in dramatic and abrupt ways by seismic activity along shallow surface faults, deep intraplate faults, and at the continental plate boundary. The best documented are the Cascadia Subduction Zone (CSZ) megathrust earthquakes, which caused coseismic subsidence along the outer coasts of Oregon, Washington, and British Columbia as well as generating tsunami that left extensive sand sheets in coastal lowlands (Peters et al., 2007; Atwater et al., 2004). To examine cultural response, our research focused on these well-dated events, which have also been extensively modeled for hazard assessment.

Tsunami run-up of several km along coastal rivers and estuaries greatly exceeds the 1 km extent for the coastal plain (Peters et al., 2007) yet there was initial uncertainty about how far a CSZ-generated tsunami would propagate along the SJDF. Documentation of tsunamigenic sands that temporally correlated with known CSZ events at Swantown, Whidbey Island (Williams and Hutchinson, 2000), on the far eastern shoreline of the SJDF, and Discovery Bay, also in the Eastern SJDF (Williams et al., 2005), suggested that they definitely could extend far eastward into the SJDF (Table 1) (see locations in Fig. 1). However,

coseismic subsidence was not documented at either of these locations, and other sand sheets at each location likely originated from tsunami triggered by more local events, leaving some uncertainty as to their origins. Later work at Salt Creek, further west in the SJDF (Hutchinson et al., 2013) and in the Waatch Valley (Peterson et al., 2013), which was the first record from the outer coast of northern Washington, created an east-west transect along the SJDF and linked evidence of tsunami inundation beyond the limit of effects of coseismic subsidence in the SJDF to CSZ events (Peterson et al., 2013). Coseismic subsidence accompanies each event at Neah Bay, is moderate to absent at Salt Creek, and is absent at Discovery Bay and Swantown making it unlikely that coseismic subsidence would have affected Čix^wicən.

During the time span of Čix^wicən occupation, five plate boundary earthquakes are known to have generated tsunami that propagated through the Strait (Table 1). Four of these, Events S, U, W, and Y were full margin rupture events (Atwater, 1987; Atwater and Hemphill-Haley, 1997) and the extent of the fifth, represented by the Bed 2 sand at Discovery Bay (Garrison-Laney, 2017; Williams et al., 2005), is uncertain (Sherrod and Gomberg, 2014; Garrison-Laney and Miller, 2017).

Tsunami hazard modeling uses parameters estimated from past events to estimate arrival times, currents, wave amplitude and inundation areas for a specific region; modeling continues to evolve because of the application of different rupture models and other refinements. Simulation models of tsunami generated by a CSZ plate-boundary earthquake suggest high likelihood of a devastating impact on Čix^wicən (see review by Hutchinson et al., this issue and Gao et al., 2018). The first of multiple waves would reach the Port Angeles Harbor starting about 70 min after the earthquake, and less than an hour after that, the largest wave arrives, with - if it coincided with high tide - an estimated amplitude of almost 3 m. Wave amplitude estimates range from 2.5 to 6 m (AECOM, 2013; Cherniawsky et al., 2007; Gao et al., 2018; Walsh et al., 2002); any wave over 2 m in amplitude would likely overwash the spit at the base of Ediz Hook and then flow across the site area. The behavior of a tsunami wave after overtopping the neck of Ediz Hook and entering the harbor is beyond the resolution of the models.

3. Methods and materials

Excavation at the Čix^wicən site was conducted in 2004 by Larson Anthropological Archaeological Services with members of the Lower Elwha Klallam Tribe (LEKT) as part of a large-scale mitigation for a proposed development. A modified isolated block technique was used

Table 1
Summary of CSZ events represented in SJDF during Čix^wicən's occupation. See Fig. 1 for study site (geological) locations.

		Waatch/Neah Bay Peterson et al. (2013)	Salt Creek Hutchinson et al. (2013)	Discovery Bay Garrison-Laney (2017); Williams et al. (2005)	Swantown Williams and Hutchinson (2000)
	Location	Outer coast; western-most SJDF	SJDF, west of Čix ^w icən	SJDF east of Čix ^w icən	Western shore of Whidbey Island
Event	Co-seismic subsidence	Yes, 0.05–1.0 m	Possibly for Events S and Y	No	No
S	Estimated date 1660–1530 cal BP	No	Yes Run-up: 1 km upstream, 2–3 m height, did not top 4 m barrier	No	Yes
U	1260–1230 cal BP	Yes (1.3 ka event) Run-up: 4.6 km Height: 11.5 m	Yes	No	Yes
W	910–790 cal BP	Yes (1.1 ka event) Run-up: 4.0 km Height: 9.6 m	No	Yes	No
Bed 2 sands	650–560 cal BP	No	No	Yes	No
Y	1700 CE/250 BP	Yes Run-up: 3.2 km Height: 8.5 m	? possible subsidence, no deposit	Yes	No, possibly obscured by land use

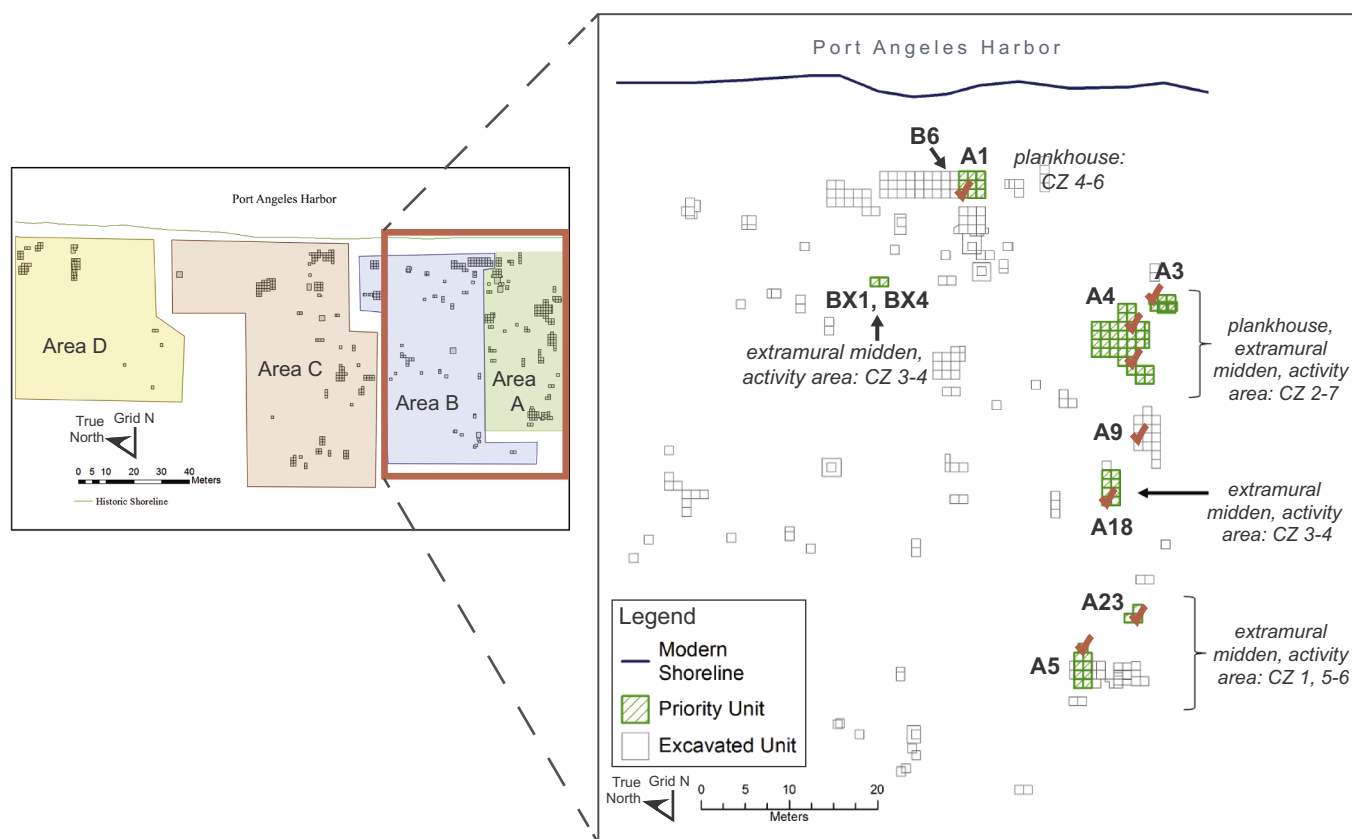


Fig. 3. Plan map of site showing overall project area (inset) and units, mainly in Area A, selected for research project. Red checks indicate location of profiles used to construct site cross-section (see Fig. 4).

(Main figure drafted by Kristina Dick; inset drafted by Laura Syvertson).

to provide horizontal exposures and horizontal and vertical control (Butler et al., this issue a; Reetz et al., 2006). Excavation was accomplished using fine stratigraphic divisions with sublevels if they exceeded 5 cm in thickness. The high-resolution facies approach to the stratigraphic excavation and recording followed Stein (1992). Excavation units totaled 518 m² in area, and 261 m³ of sediment were excavated (Fig. 3). Matrix was excavated from each uniquely defined deposit into 10 L buckets, which were water-screened through graded mesh 1" (25.6 mm), 1/2" (12.8 mm), and 1/4" (6.4 mm) or in some cases to 1/8" (3.2 mm) mesh (Kaehler and Lewarch, 2006). Charcoal samples for radiocarbon dating, soil samples, and in situ faunal and artifact samples were collected with point provenience.

The geoarchaeological component of the project was critical for providing sufficient control over site formation and chronology to isolate intracommunity social units (households) at different times and relate them to demonstrable sequences of environmental change. To achieve this goal, we defined site-wide chronostratigraphic zones (hereafter CZs) that could be related to tectonic and climatic events, and identified distinctive depositional contexts including house boundaries and house floors, which could be used in defining faunal assemblages for comparison through time and between households. We also refined the sequence of beach/spit development and sought to identify site-specific evidence of tectonic activity. Because earthquake and tsunami hazard varies with location and event, we cannot assume that a known event had an impact on a coastal village such as Čix'w'icən. The development of explicit criteria for identifying tsunamigenic traces within anthropogenic deposits is discussed in Section 4.2.

Our research project focused on eight excavation blocks largely

within Area A (Fig. 3), selected because they included the remains of at least two structures with overlapping ages and associated extramural activity areas. The blocks comprise ~75 1 × 1 m units, a substantial sample, yet only 15% of the overall excavated area. It was beyond the scope of the project to conduct detailed stratigraphic analysis for areas other than those from which faunal remains were analyzed, but geoarchaeological analysis of landforms made use of radiocarbon dates from other parts of the site and prior understanding of site development (Sterling et al., 2006a) as applicable. Further details on the methods outlined below can be found in Campbell et al. (2018)

3.1. Profile and plan construction

There were few field-drawn profiles because of the horizontal block excavation strategy, therefore, profiles across the interiors of blocks were reconstructed from the level plan map measurements. This was particularly critical for identifying house floor and fill sequences. The level maps from 73 1 × 1 m units were digitized and entered into a GIS database, and joined plan maps from adjacent units were used to document floor plans and highlight activity areas.

3.2. Radiocarbon dates

During the 2004 excavation, 52 radiocarbon samples were collected from across the site and submitted to Beta Analytic (see Supplemental File 1) for conventional radiocarbon dating. The samples comprise both bulk charcoal and structural wood. Thirteen of these dates were from excavation units in our selected areas. For our research project, we

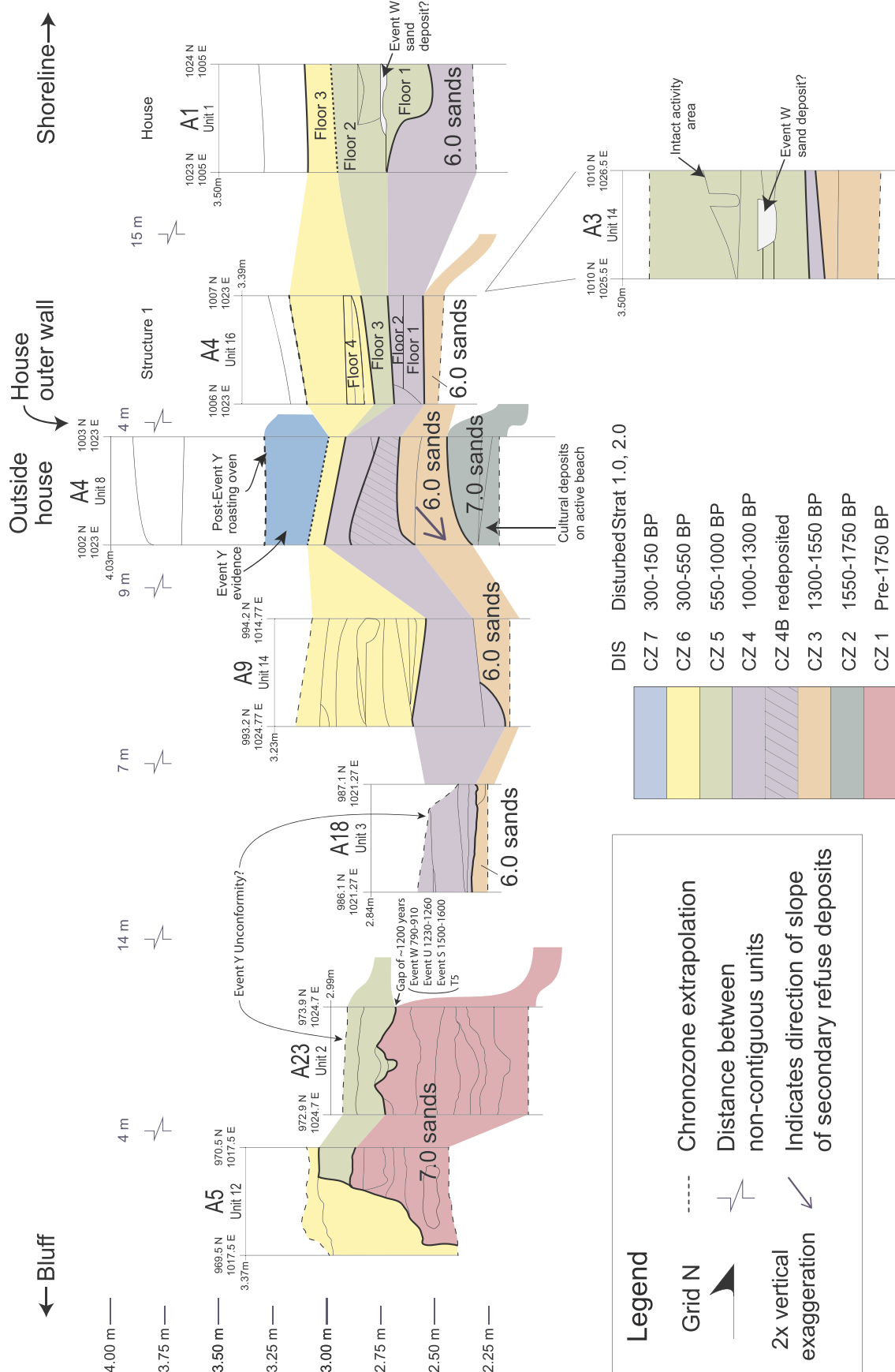


Fig. 4. Stratigraphic cross-section through the project area. See Fig. 3 for locations of units and excavation blocks. East or west walls representing all CZs in excavation block and specific erosional and depositional events were selected (except A3, N wall). Block BX-1/BX-4 omitted. Profiles 1 m wide, distance between profiles not to scale. Internal stratification within CZs indicated, but not stratum labels. (Figure drafted by Kaitlin Dempsey, Adrienne Cobb).

obtained an additional 50 high-precision AMS dates (Supplemental File 1), on samples of charcoal from short-lived species collected from water-screened bulk samples. All dates were calibrated using the Reimer et al. (2013) curve. Rounding conventions follow Stuiver and Polach (1977).

3.3. Chronozone (CZ) definition

Seven CZs were defined for the project area (Fig. 4). Within excavation blocks, they represent grouped strata of observable stratigraphic continuity or equivalence, and between blocks they are correlated using radiocarbon dates. CZ boundaries were chosen to coincide with what appeared to be hiatuses or depositional changes, and are therefore not of equal length. We selected additional radiocarbon samples from underrepresented areas and to resolve specific problems such as apparent reversals, which smoothed some of the abrupt gaps in the initial radiocarbon age distribution.

3.4. House reconstruction and depositional contexts

All excavated strata/samples were assigned to a depositional context relative to large architectural features, i.e. *extramural activity area* for all areas outside of house footprints, and *floor or fill* within the footprint of a house. Interpretation of architecture was challenging, despite relatively good preservation of floors and structural elements. Some household studies take advantage of a surface visible house depression that defines the orientation and size of the house prior to excavation (for example, Grier, 2006; Martindale, 2006). At Čix^wicān, surface expression of house platforms had been obscured by deposition of up to 3 m of fill (Kaehler and Trudel, 2006; Lenz, 2007), and excavation blocks encompassed portions of, rather than entire house structures. Horizontal and vertical boundaries of construction trenches and postholes were sometimes obscured because they had been set in sand, as well as by maintenance, repair, and rebuilding in slightly different locations on the same general house platform.

We found schematic models of shed and gable roof forms, both of which were present in Klallam villages in the historic era (Gunther, 1927) helpful in a heuristic, not prescriptive way, for interpreting fragmentary arrangements of structural element. Descriptions of post sizes, spacing, relationship between roof support posts and exterior walls, trenches, bench width, entryway and hearth placement were derived from ethnohistoric and archaeological information (Gunther, 1927; Matson, 2003). Overlaying the models on compiled feature maps aided in determining which orientation and house style was the best fit, i.e., which matched the greatest number of archaeological features (e.g., hearths, large and small posts, trenches, or wall planks) at expected locations.

This process is illustrated for a house identified in block A1 (Fig. 5). We checked multiple orientations of both roof support types, and found that aligning two large postholes, Features 15 and 19, with expected locations for large roof support poles on the shed roof schematic, resulted in reasonable matches for smaller postholes on the eastern outer wall (Feature 18 and one not designated as a feature), and southern support wall (Feature 13). It also led to the recognition that a previously ambiguous pit feature (Feature 21) was a preserved remnant of a foundation trench. A palimpsest of hearths with associated activity areas, Features 5, 6, 8, and 12, falls into the general area expected.

The portion of each house exposed by excavation varies; one measure that can be used to understand comparisons is the square floor area. In A4, the total floor areas excavated are: Floors 1 and 2 = 13.5 m², Floors 3 and 4 = 20 m². In the A1 house, 10 m² of each floor was exposed and excavated. Definition of inner compartments within houses is left for future research. Successive occupations of house platforms were indicated by vertically separated floors. Although formed through use, not construction, the floors were the house feature most consistently observed in the field because these compact, organic-

rich, horizontal layers contrasted with both beach sands and secondary refuse deposits.¹ Relating the successive floors to the house plan to trace continuity of use is not simple. Maintenance and rebuilding itself can obscure the surface of origin of posts and relationship to specific floors. Further, the floors in traditional Coast Salish building styles may not contact the walls because of an intervening ‘bench’ area, particularly in the shed roof style. Specific floors are not likely to be traceable through this area, characterized by massive bedding rather than stratification (Smith, 2006).

3.5. Identification of basal sand deposits

During the 2004 excavation, archaeologists identified two distinct sand sheets comprising the beach ridges underlying the archaeological site (Sterling et al., 2006a: 12–16) and designated these Stratum 7.0 and Stratum 6.0. Stratum 7.0 is stratigraphically below 6.0 site-wide, and the associated radiocarbon dates are older. It has a higher proportion of coarse sand and is less well sorted than the overlying Stratum 6.0, consistent with a less protected shoreline, conditions resulting from a shorter, less sheltering Ediz Hook. Excavators noted that these sand sheets were often separated by intervening deposits of reworked occupation midden (Sterling et al., 2006a: 12–16), which may have resulted from shoreline disruptions caused by tsunami (discussed in more detail in Section 4.2.2).

4. Results

4.1. How did spit development affect the site and nearby intertidal habitats?

Although low in profile (maximum elevation 3.6 m NAVD88), the 5.6 km long Ediz Hook spit today redirects the waves and currents in the Strait and influences circulation and sediment transport within the harbor. Its position, although not its length, has been relatively stationary since sea level stabilized at near modern levels in the mid-Holocene (Wegmann et al., 2012).

Galster (1989) and Galster and Schwartz (1990) suggest the spit migrated to its current basal anchoring point around 5000 years ago and elongated to its present length by 1000 years ago, with an inner spit forming 1000–2000 years ago and creating a lagoon. Wegmann et al. (2012) cite the same anchoring date but point out that progradation of deltas and beaches around the shoreline of Port Angeles harbor began slightly earlier, at 5500 years ago. Coastal bluff erosion also slowed as the quasi-stable spit blocked the dominant wave energy from the west. Sterling et al. (2006a) argue that the increased sheltering of Port Angeles Harbor as Ediz Hook grew was reflected in seaward expansion of beach berms, upward fining of sand grain size, and a decrease in erosive events in beach deposits at the Čix^wicān archaeological site.

Assuming most shellfish harvesting took place locally and soft substrate in the harbor increased over time due to decreased wave energy, we expected to see harvesting of burrowing clams increase and a concomitant decrease in the frequency of rocky substrate taxa. However, changes in invertebrate taxa did not support this expectation. We found a more complex pattern of change overall, most significantly that the greatest accumulation rates of soft sediment clams occurred during the early occupation of the site (Butler et al., this issue b). The abundance of invertebrate taxa preferring a rocky habitat increased

¹ Coast Salish plankhouses typically did not have constructed floors, although mats may have been spread on some surfaces. Gunther (1927: 187) specifically mentions for Klallam houses that floors are not intentional, but result from long-term trampling. In a typical Northwest Coast dirt-floored plankhouse, the floor can be described as a ‘floor midden’ a palimpsest formed from gradual accumulation of food wastes, fires, and workshop production (Grier, 2006; Samuels, 2006). At Čix^wicān, floor middens were described in some areas as spongy and fibrous, suggesting mats and wooden planks were incorporated as well as food waste.

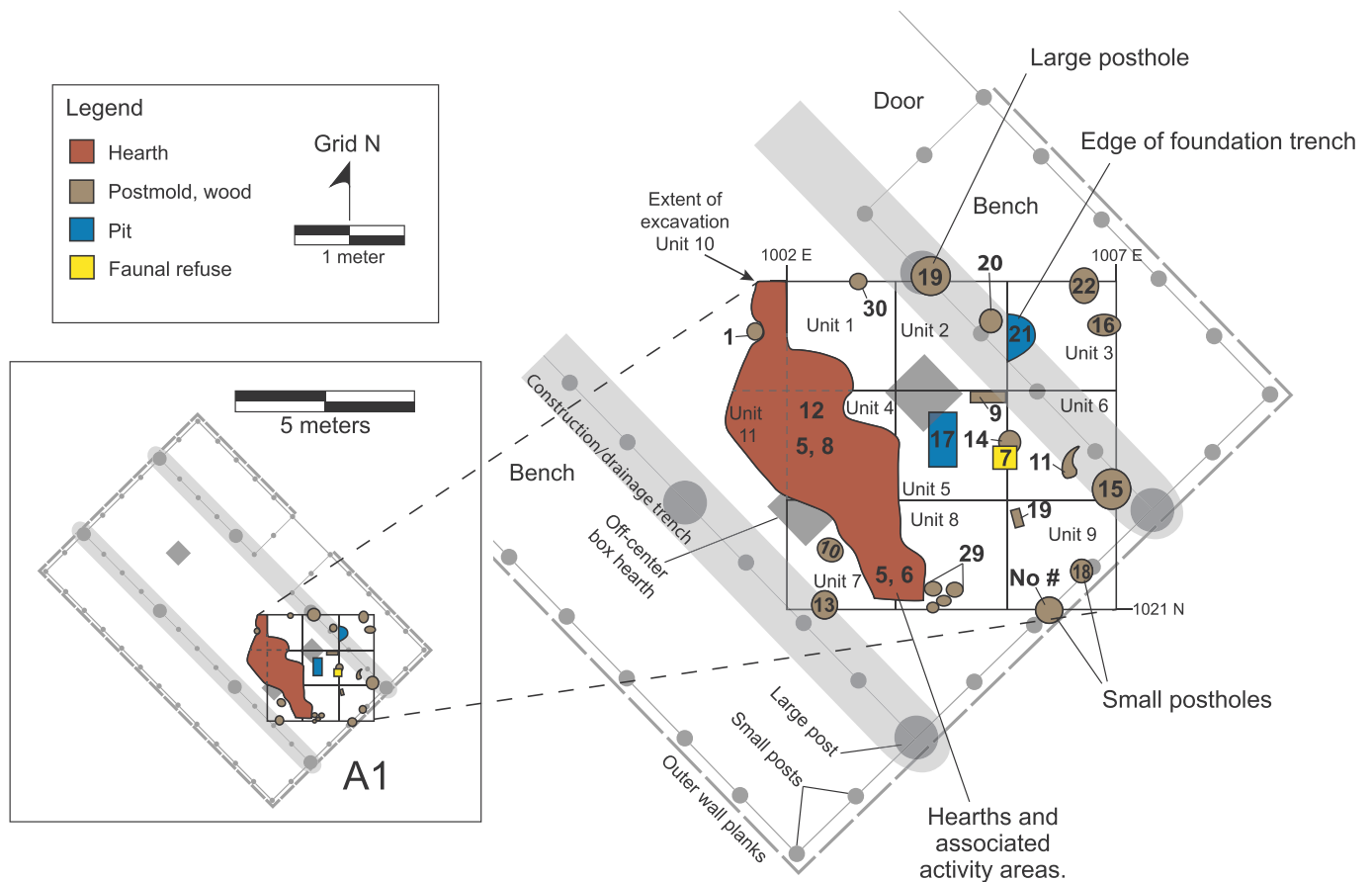


Fig. 5. Plan map of excavation block A1, showing archaeological features and their relationship to a schematic overlay of a shed roof house plan. Inset shows extent of excavated portion of house in comparison to a 20 × 30 foot house. (Figure drafted by Kaitlin Dempsey).

over time in the faunal assemblages, suggesting the intertidal substrate became rockier during later phases of site occupation.

This led us to re-evaluate the initial premise and consider alternative models for the nature of the inner harbor circulation and sediment transport, and also for the timing of spit growth and lagoon formation. Age estimates for anchoring of the spit are loosely constrained by ages from expanding creek deltas, while estimates for the closing of the lagoon and the extension of the spit are not constrained by chronometric ages on sediments. Recent studies of other high latitude spits show episodic rapid elongation punctuated by stillstands at the decadal and centennial scale in response to climatic drivers, extreme storm events, and volcanic eruptions, not solely sea level (Allard et al., 2008; Lindhorst et al., 2010; Nielsen and Johannessen, 2009; Poirier et al., 2007). Our reconstructed growth of the Čix^wicən spit based on radiocarbon ages from the site and models of spit development, discussed below, agrees with the time frame suggested by Galster and Schwartz (1990) for the formation of the lagoon. However, based on the links between inner and outer spit development and our reconstruction of substrate changes, we suggest that their estimate of 5000 years for initial spit growth is too old, and that the spit began to grow subaerially (above the water level) closer to 3000 years ago.

Spit growth begins with development of a spit platform, in this case through littoral transport at the eastern edge of the submarine delta of the Elwha River (Fig. 6). The most recent platform, composed of mixed grain sediments dominated by fine and medium sands (Warrick et al., 2009), would have extended somewhat east of the present spit base,

into what is now the western part of Port Angeles Harbor. As the platform grew in height, the spit would become subaerial and continue to grow out into the SJDF, elongating to the east.

As a spit in a highly asymmetric current regime elongates, it creates a shadow zone that is protected from the direct impact of the same wave energy that builds the spit (Ashton and Murray, 2006). Within the shadow zone, the circulation is generally reversed, driven by the ebb current and deflection of the dominant flood current around the end of the spit. The inner shore of the spit is steepened by the currents, which flow fastest at the inner corner, eroding the neck. A common feature in simulation models that explore the conditions under which spits form (Ashton and Murray, 2006: Figures 9e, A2b; San-nami et al., 2014; Serizawa et al., 2012: Figures 2g, 5f) is the development of a second spit in the inner bend, due to beach accreting predominantly in the opposite direction of the outer spit. A spit may also form in the opposite direction, from the landward side of the main spit. A lagoon will be created as the inner spits grow across the angle of the neck.

Correlative features can be found on 19th century maps of the Port Angeles vicinity (Fig. 7), depicting harbor and shoreline landforms no longer apparent on 20th century maps because they were obscured or altered by filling of the tidelands, channelizing of creeks, dumping of massive amount of mill waste, and other industrial activities (Wegmann et al., 2012). In the approximate location of Čix^wicən, an “Indian Village” is indicated on the shoreline seaward of the lagoon, on the spit that creates the eastern margin of the lagoon. Small creeks are shown parallel to the shore at the base of the bluffs, and other creeks are

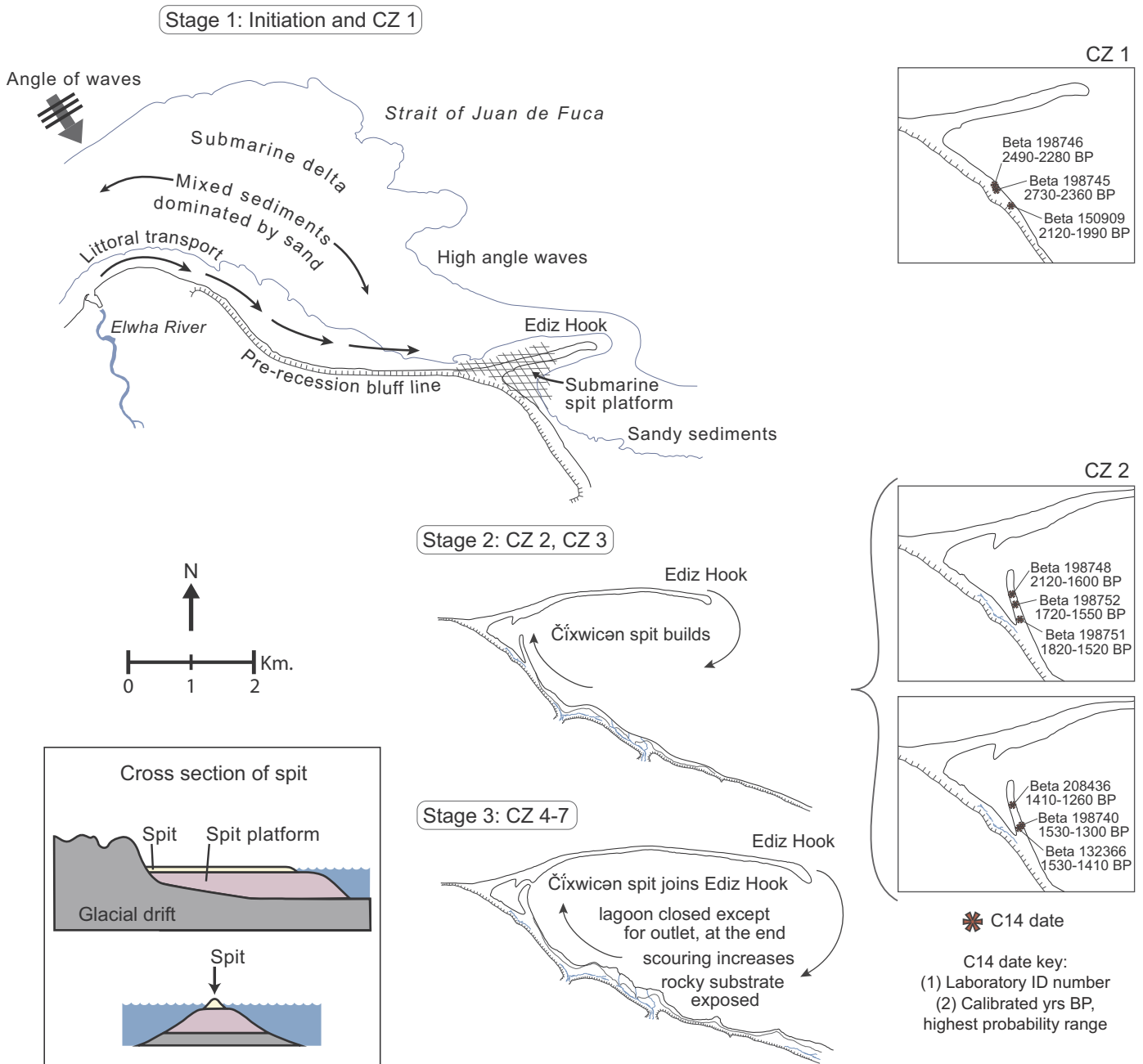


Fig. 6. Model for growth of Ediz Hook and Čixwicən spit. Development of the inner spit is based on radiocarbon ages from the northernmost location and highest elevations in each stage to constrain the timing. Incident wave angle from Warrick et al. (2009: Figure 14). Cross-sections of spit platform adapted from Nielsen and Johannessen (2009). Bathymetry from NOAA 1990 Bathymetric Fishing Map. (Figure drafted by Adrienne Cobb).

deflected westerly below the bluffs, indicating beach ridge accretion parallel to the shore, primarily in a westerly direction. The “horse shoe bends” of the lagoon outlet suggest that barrier spits grew from both the inner shore of the harbor and the inner shore of Ediz Hook. The largest bend suggests the dominant spit growth pushed the outlet north. Bathymetry and bottom texture of the harbor show expected circulation features inside a recurvate spit, based on general models (Ashton and Murray, 2006). The steep inner shore face of Ediz Hook indicates the erosive power of the internal circulation (Fig. 7) and the sand substrate reflects a faster current in contrast to the finer silt and clay, or “sticky,”

substrate observed throughout most of the harbor. The area indicated as a soft bottom potentially represents an area of turbulence associated with a localized eddy. We interpret the substrate along the harbor shoreline recorded as “hard” as a rock-armored surface.

We created a realistically scaled schematic diagram of the growth of Čixwicən spit, using the western and northern shorelines of the lagoon/marsh system combined from maps made in 1852 and 1898 to represent the inner shoreline of the spit neck when it began to form and using ages and locations of radiocarbon dates from the site to map spit growth (Fig. 6). The earliest archaeological materials range from ca. 2700 to

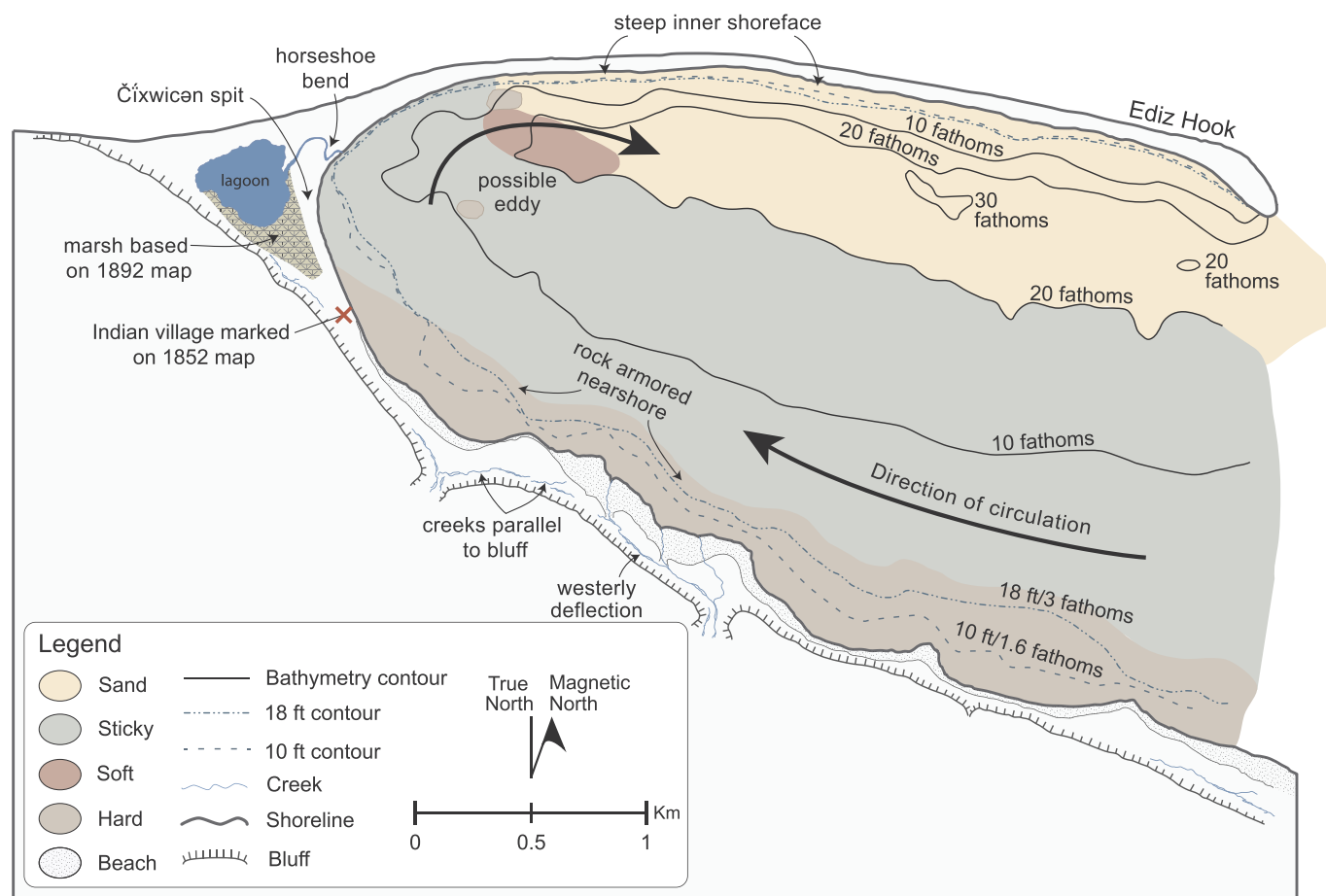


Fig. 7. Ediz Hook and inner harbor, circa 1852, showing bathymetry, substrate, local drainages, and location of 'Indian Village.' Source map: U.S. Coast Survey – 1852 Preliminary Survey of False Dungeness (Alden, 1853). Bathymetric contours were interpolated from over 400 soundings (in fathoms) in the harbor (not shown). Substrate was reconstructed from bottom textures recorded with soundings. Marsh location and dimensions based on Gilbert (1892), which Wegmann et al. (2012) consider accurate on the basis of GPR transects. (Figure drafted by Adrienne Cobb).

1750 cal BP and are associated with wave cut terraces rather than sandy beach berms (CZ 1 in Fig. 6). The dates shown from CZ 2 and CZ 3 represent the uppermost and northernmost beach berms. These dates are in agreement with the estimate made by Galster and Schwartz (1990) for the growth of the inner spit. This calls into question their estimate that the initial formation of Ediz Hook was 5000 years ago; a lag of 3000 years for the formation of inner spits seems too long. Inner spits begin forming relatively early in simulation models (Ashton and Murray, 2006; Serizawa et al., 2012; San-nami et al., 2014). An estimate of less than 3000 years ago for when Ediz Hook began to grow subaerially would be more consistent with the timing of the growth of the inner spit.

A later initiation date for Ediz Hook might help explain evidence of intensive use of burrowing clams in the early phases of occupation in the project area. Initially, the nearshore substrate on the east side of the spit base would have been a sandy productive clam habitat, and apparently was present by CZ 1 (2150–1750 cal BP) (Butler et al. this issue b). As Ediz Hook grew, it cut off littoral transportation of new sediment from the Elwha River, and the sediment sources inside the Hook were limited to the low bluffs of the inner shoreline and the former delta edge spit platform itself. The sandy substrate was re-worked to form spits inside the neck (Fig. 6). The net loss of sediment along the harbor shoreline would have led to exposure of a rocky nearshore substrate, home to rocky shore benthic vertebrates and kelp. This could represent either a re-exposed wave cut glacial drift terrace or a lag deposit left by rapid erosion; either scenario would reflect erosion/lack of deposition.

An analog for this inferred shift in nearshore substrate is found in changes to the eastern Elwha River delta due to damming of the river in the early 20th century.²

The alternative interpretation that development of Ediz Hook was initiated closer to 3000 years ago is speculative and challenges a model more congruent with prior interpretations of the role of sea level change (Wegmann et al., 2012). The model presented here at least raises questions about the net effect on accretion within the harbor when spit growth both redirects wave energy and also cuts off long-shore drift from a substantial sediment supply. Alternative explanations

²In the early 21st century, almost 80 years after the dam was constructed, nearshore sediment textures differed greatly to the east and west of the river mouth (Warrick et al., 2009). The nearshore to the west was sandy throughout, while east of the mouth, the nearshore was a mixed sand-to-cobble surface (Warrick et al., 2009). This is an exception to the general pattern for mixed sediment beaches, which typically have gravel foreshores coupled with sandy low-tide terraces, and in Puget Sound, such exceptions are associated with rapid erosion (Finlayson, 2006). Warrick et al. (2009) suggest the eastern delta was formerly characterized by a sandy foreshore, a productive clamming habitat, which eroded after sediment input was reduced, perhaps by an order of magnitude, by damming the Elwha River. As the downdrift sandy foreshore retreated, a cobble low-tide terrace supporting a bull kelp canopy broadened towards the land.

Also note that a net loss of sediment is consistent with the narrow supra-tidal beach in the Hollywood Beach area reconstructed by Wegmann et al. (2012).

for apparent changes in harbor substrate were not explored but could involve the overprint of shorter-term events on long-term growth of the spit since 5000 years ago. For example, extreme events such as tsunamis could cause detachment of the spit at the neck and re-initiation of spit growth, or transport sediment out of the harbor. A chronometrically controlled sedimentological study of Ediz Hook would be required to examine these possibilities further.

4.2. Can we independently confirm that earthquakes and tsunami affected the site area?

In addition to long-term landform evolution that served as a backdrop to human occupation at Čix^wicən, the location was impacted by punctuated events such as earthquakes and tsunami. Tsunami sands are documented at four locations spanning the SJDF from the western to eastern boundaries, and models predict inundation of the Port Angeles Harbor shoreline³. Therefore, the tectonic effect we are most likely to see at Čix^wicən is tsunami inundation (Table 1). The most commonly cited form of evidence for tsunami inundation along the shorelines of the CSZ, as elsewhere, consists of spatially extensive, anomalously coarse-textured deposits in low-energy sedimentary records in the upper intertidal zone, such as coastal marshes (Peters et al., 2007). Sand layers akin to those in coastal marshes have occasionally been noted in cultural deposits at village sites in the region (e.g. McMillan and St. Claire, 2005: Fig. 22), but such features have rarely been accredited to tsunami (however, see Hutchinson, 2015 and Hutchinson and McMillan, 1997 for exceptions). Archaeological sites have figured in the investigation of CSZ earthquakes, but largely in the context of coseismic subsidence (Cole et al., 1996; Minor and Grant, 1996).

An extensive geological literature based on tsunamigenic deposits preserved in “natural” landscapes establishes criteria for attributing deposits to paleotsunami, rather than other extreme flooding events (Engel and Bruckner, 2011; Morton et al., 2007). The telltale presence of marine microfossils in such layers indicates high-energy, landward-directed surges of seawater as the source (Hemphill-Haley, 1996), and temporal correlation with known seismic events points to tsunami, rather than storm surges, as the generative mechanism. Otherwise, tsunami deposits are highly variable; the amount of erosion and the bedding characteristics differ as the velocity and turbulence of the inundation can change rapidly over short distances and within sets of multiple waves. Multiple layers may not occur if backwash is redirected to localized channels or exits parallel to the re-entrant, or may not be distinguishable. Fewer studies focus on erosion as a signature, although tsunami cause more erosion than deposition (MacInnes et al., 2009).

The identification of tsunami deposits in archaeological sites is complicated by several factors. In this region, precontact villages were built on higher ground, above the high tide limit, yet often still within the local tsunami run-up zone. The types of deposits associated with villages are markedly different from those in coastal marshes; they are less spatially extensive, more variable in sediment size, cohesiveness, and clast types, and are likely to contain allochthonous biota; this changes which criteria for the identification of tsunamigenic deposits are most useful. Other challenges to unequivocally demonstrating the presence of tsunami deposits within habitation sites arise from archaeological practice. Not only are archaeological excavation areas generally too small to reveal the spatial extent of tsunamigenic deposits, but definitive critical attributes such as mineralogy, grain size, bedding, and micro-faunal assemblages are rarely described in field or laboratory records.

Worldwide, only a small number of studies focus on recognizing paleotsunami deposits within the anthropogenic stratigraphy of archaeological contexts; our analysis contributes an important case study

³ The Port Angeles harbor shoreline is also considered a high liquefaction susceptibility area (Palmer et al., 2004).

for future research on the impacts of tsunami. Criteria clarified with respect to archaeological contexts, and expanded to include ones that are uniquely cultural, are shown in Table 2 based on historic and pre-historic analogs from cultural deposits elsewhere in the world (Addison et al., 2010; Bruins et al., 2008; Clouard et al., 2017; Dey et al., 2014; Gutiérrez Mas et al., 2016; Hoffmann et al., 2015; Sieh et al., 2015), including observations of archaeological sites damaged by recent tsunami (Addison et al., 2010; Johnson et al., 2015) which offer a glimpse at what the erosional surface might look like prior to reburial.

In the case of Čix^wicən, we consider landward transport of beach sand, erosional features, and reworking of cultural deposits entrained by waves, if temporally correlated with a known seismic event, as primary evidence pointing to tsunami overwash. Tsunamigenic sands described at coastal lowland sites along the SJDF tend to be 1–2 cm in thickness; we might expect to see thicker sand layers at Čix^wicən, which is located downflow from one of the most abundant sand sources within the SJDF. Structure collapse could be related to tsunami damage or to coseismic shaking; the latter could also be represented by liquefaction features. Unconformities measured primarily by radiocarbon age sequences, and abandonment of cultural activity areas are consistent with, but not directly attributable to, tsunami inundation. We assess these sources of evidence for each of the four plate-boundary earthquakes of the last two millennia, as well as a fifth that may have a local origin.

4.2.1. Event S (1660–1530 cal BP)

Only tentative evidence of Event S was observed in the project area, and no distinct occupation hiatus is indicated in the summed radiocarbon probability distribution based on dates from the entire site (Hutchinson et al. this issue). Stable beach surfaces prior to Event S are limited to the farthest inland areas (Figs. 4, 6) (excavation blocks A23 and A5), and A4. It is worth noting that deposits dating to 2150–1750 cal BP (CZ 1) in A23 and A5 are directly overlain by deposits dated to after 1000 cal BP (CZ 5) (Fig. 4). The vertical boundary is abrupt and horizontal, and there is a distinct change in the sediments; traits consistent with an erosional unconformity. Based on radiocarbon dates the gap is approximately 1200 years in A23 and 1100 years in A5, which encompasses not only Event S, but also U and W, so linking the unconformity to a particular event is not possible. An erosional event consistent with the time frame of Event S is evident in the A4 block. Cultural use of a stable beach surface is indicated by a hearth (Feature 171) and an alignment of poles (Feature 191) (Fig. 8) associated with three radiocarbon samples whose age ranges overlap but fall largely prior to the age range for Event S. Cultural materials were redeposited in the lee of ripples within a runnel sloping predominantly to the southwest. Large pieces of charcoal were found to the north of the pole structure and in the hearth, indicating that the eroding current was restricted to a channel. The radiocarbon age associated with these materials has a large time range that partially overlaps Event S but plausibly predates it as would be expected if the material was eroded and redeposited by a tsunami generated by Event S.

4.2.2. Event U (1260–1230 cal BP)

Based on site-wide radiocarbon ages, Hutchinson et al. (this issue) suggest a sharp decline in occupation occurred at Čix^wicən immediately following Event U correlated with dated deposits indicating truncation of beach ridge development and use at about 1300 BP. Here we present more contextualized radiocarbon ages and evidence of erosion and entrainment on existing beach ridges from the study area that further supports the interpretation that a tsunami linked to Event U overtopped the site.

Fig. 9 shows all AMS radiocarbon dates falling between 1400 and 1000 cal BP, arranged by excavation block. Also shown are the next youngest radiocarbon dates in the block. In each of these excavation areas, ages up to, and overlapping the estimated time range of Event U, are followed by a hiatus of at least 100 years before the next youngest

Table 2

Criteria for identifying tsunamigenic deposits within archaeological sites. Table addresses contextual evidence from cultural sources, e.g., oral history or texts, but does not include geological contextual evidence such as temporal correlation with known earthquake events through radiocarbon dating.

Criterion	Evidence	Archaeological examples	Applicability at Čixwīcān
Erosional contact	Contact abrupt locally, unconformity widespread in site	Dey et al. (2014)	Yes, Event S, U
	Erosional channels Rip-up clasts, eroded surface Scouring pits from eddies	Sieh et al. (2015) plucking of plaster floor, rip up clasts of plaster Johnson et al. (2015) scouring created by constructed “obstacles”	Yes, Event Y discussion
Mixed marine and terrestrial materials in deposit, displaced anthropogenic materials	Non-anthropogenic marine fauna (microfauna fresh shells). Additional observations like articulation, weathering, source depth and independent record of cultural use may be necessary to distinguish larger marine organisms (fish, bivalves) that are anthropogenic	Bruins et al. (2008) marine microfauna with oxen bones, ceramics Hoffmann et al. (2015) articulated marine bivalves with midden-derived shells Sieh et al. (2015) angular and rounded coral with ceramics Johnson et al. (2015) displacement of glass, ceramics	Relevant observations not made
Evidence of high velocity and force	Collapse of structures, transportation of large, heavy materials	Johnson et al. (2015) collapse of stone walls Addison et al. (2010) large grinding stones moved and redeposited, collapse of stone walls	Yes, collapse of walls, A4 house, Bed 2 Event
Uprush and backwash of successive waves	Multiple layers, lower layer may be sand, upper layer may incorporate more cultural material	Sieh et al. (2015) uprush and backwash together 0.3–0.7 m, Clouard et al. (2017)	Yes, clean sand underlying redeposited midden material in A1
Weak sorting and lack of cross-bedding due to deposition from turbulent water, bedding varies with velocity	Evidence of current transport contrasts with midden deposition, organized activity areas, or cultural constructions. Multi-modal chaotic deposition indicated by highly variable clast sizes, random orientation (graded bedding may occur where velocity slows, imbrication of plano-convex or tabular clasts indicates high velocity)	Bruins et al. (2008) large building stones, oxen bones, imbrication of tabular materials, layers of pebbles Hoffmann et al. (2015) poorly sorted sandy deposit 0.33–0.4 m thick, stones plucked from wall in random orientation in sand matrix, imbricated shell at top of deposit	Yes, vertical fining in Strat (5.12.10) in A3, Event W Orientation, sorting of clasts in erosional channel, A4, Event Y
Anomalous sediments and context	Landward transportation of beach sand, sediments inside buildings	Clouard et al. (2017) anomalously thick two-layer tsunamigenic deposit within abandoned building construction project. Gutiérrez Mas et al. (2016)	Yes, clean sands in A1 and A3, Event W Sand with collapsed planks in A4, Bed 2 Event.
	Rapid abandonment, rapid reburial.	Not a strong criterion alone, many possible causes.	Yes, activity area in A18, Event U
Evidence of cultural response	Changing settlement patterns, site abandonment (indirect contextual evidence, not strong alone)	Barnes (2017) , abandonment of Middle Yayoi settlements after rice paddies flooded, Goff and McFadgen (2003) , Hutchinson and McMillan (1997) ; Sieh et al. (2015)	Yes, occupation hiatus after Event U
	Memorializing, clean-up, reconstruction in response	Dey et al. (2014) clean up and reconstruction at Caesarea Maritima; Gutiérrez Mas et al. (2016) clean-up Hoffmann et al. (2015) post-tsunami change to more resistant construction materials, residential grid regularized Barnes (2017) commemorative behavior	Yes, reconstruction of houses in A4, possible dedication feasting
Archival evidence, oral history	Oral history of ground shaking, land movement, flooding, large waves	Clouard et al. (2017) sand deposit in abandoned building project related to 1755 Lisbon tsunami using historical records. Multiple examples in the classical archives	Yes, oral history for Event Y regionally, not specific to site location (Ludwin et al., 2005 ; McMillan and Hutchinson, 2002)

dated material. Widespread cultural activity ended relatively abruptly at the approximate time of Event U, and did not immediately resume.

An excellent example of the linkage of erosional and depositional processes creating the unconformity defining the CZ 3/CZ 4 boundary (~1300 cal BP) is found in the southern part of block A4, although the age is not tightly constrained in this particular location. Secondary deposits of cultural material (Stratum 6.4), eroded and reworked from the backshore, are draped across a stable beach berm formed by the earlier 7.0 sands (Fig. 10). Two high resolution radiocarbon dates, (UCIAMS 161698) and (UCIAMS 132372), suggest an age of 1710 to 1570 cal BP for the older sand surface. This is the same sand surface referred to above in Section 4.2.1, however a date of 1530–1410 cal BP (UCIAMS 132366) was obtained from Stratum 6.4, which post-dates Event S, but could have been entrained by a tsunami generated by Event U.

4.2.3. Event W (910–790 cal BP)

Sand devoid of cultural materials is rare within midden layers at

Čixwīcān, yet several patches of clean sand (Stratum 4.0) were exposed at similar elevations on the shoreward edge of blocks B6, A1, and A3 (Fig. 11A). Described as a loose, coarse beach sand with 5% gravel and no cultural material, Stratum 4.0 was exposed in several adjacent units at the shoreward edge of the A1 and B6 excavation blocks, extending approximately 4.2 m inland (Fig. 11A). The largest of the patches of sand is over 1.25 m in width and up to 14 cm in thickness, and the patches become smaller away from the shoreline. Constraining radiocarbon ages, discussed below, suggest that the deposits could be the result of a tsunami related to Event W.

In A3, Stratum 4.0 is a small lobate deposit 8 cm thick. Extending only 20 cm into the unit, it is 50 cm wide where truncated at the edge of the excavation block, and likely represents the distal margin of a more extensive sand deposit that once extended shoreward (Fig. 11A). It is devoid of definitively cultural materials (the shell fragments were not examined to see if they were characteristic of midden, beach, or in situ growth deposits). The sand is overlain by Stratum 5.12.10, although both share a contact with underlying stratum 5.12.3 (Fig. 11B). Stratum

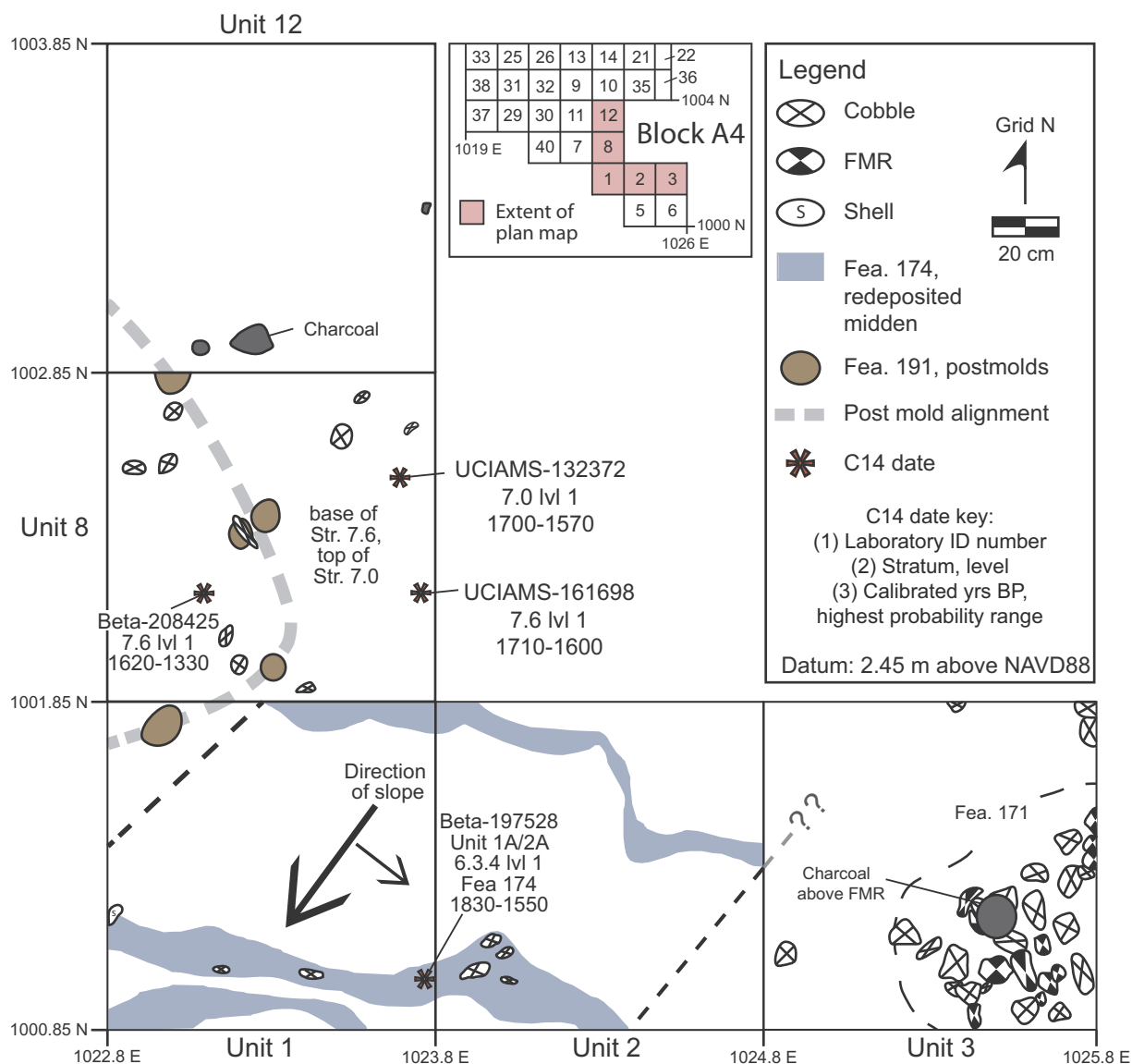


Fig. 8. Channelized erosion juxtaposed with cultural activities on a stable surface on the backshore of a beach berm in block A4. Feature 191 is an in situ alignment of poles represented by vertical postholes, associated with 7.0 sands; Feature 174 comprises reworked cultural midden deposited in the lee of ripples, within a runnel (approximate edges of runnel indicated by dashed black line), and Feature 171 is a thermal feature. (Figure drafted by Kaitlin Dempsey, Will Nolan, Adrienne Cobb).

5.12.10, 9–11 cm in thickness, extends across the excavated area, and unlike Stratum 4.0, incorporates a mix of cultural material in moderate density. The frequency of coarser clasts (gravel, shell, and thermally altered rock) decreases upwards, suggesting water-lain bedding. A sample of *Alnus* (alder) from Stratum 5.12.10 yielded a date of 910–790 cal BP (UCIAMS-142117), the same age range as Event W (910–790 cal BP) (Fig. 11C). It is possible that Stratum 4.0 and Stratum 5.12.10 represent a two-layer tsunami deposit. The clean sand of Stratum 4.0 would be a run-up deposit of marine sands while Stratum 5.12.10 could result from continued uprush or backwash picking up anthropogenic material from the surface of the site. Underlying Stratum 5.12.3, with much higher frequencies of shell and thermally altered rock, exemplifies a typical intact midden deposit that could have been eroded and redeposited.

In A1, a lens of Stratum 4.0 was found within the house, overlying Feature 12, a primary activity area that is a basal deposit of Floor 1 in A1 (Fig. 12B). Laterally, the sand ends abruptly at a large roof support post, Feature 19 (Fig. 12A), suggesting it may have filled the central, slightly lower portion of the house (see Fig. 5 for the location of the

housepost relative to the central floor area). Floor 1 is internally complex, and represents an accumulation over several centuries, with one basal date of 915–795 cal BP (UCIAMS 150913), and a date near the upper surface of 605–555 cal BP (UCIAMS 150912). A specimen of *Oplopanax* (devil's club) taken from Stratum 3, level 4, vertically just above the sand, yielded an age of 910–840 cal BP (UCIAMS 132364). This and the basal floor date are contemporaneous with the estimated range for Event W, thus it is plausible the house was inundated by a tsunami generated by Event W. The overlying date is not from a characteristic floor midden deposit, but not enough information is available to argue that it is a second tsunami layer. Hearths (Feature 8 in Fig. 12A and Stratum 3.6 and 3.4 in Fig. 12B) were constructed in this area, leaving only a small remnant of the deposit where it overlay the sand. If the sand is indeed tsunamigenic, re-occupation of the house seems to have taken place quickly, and the tsunami sand may have been preserved because a hearth was constructed on top of it.

4.2.4. Bed 2 sands at Discovery Bay (650–560 cal BP)

A tsunamigenic sand at Discovery Bay (Fig. 1) (Table 1) termed Bed

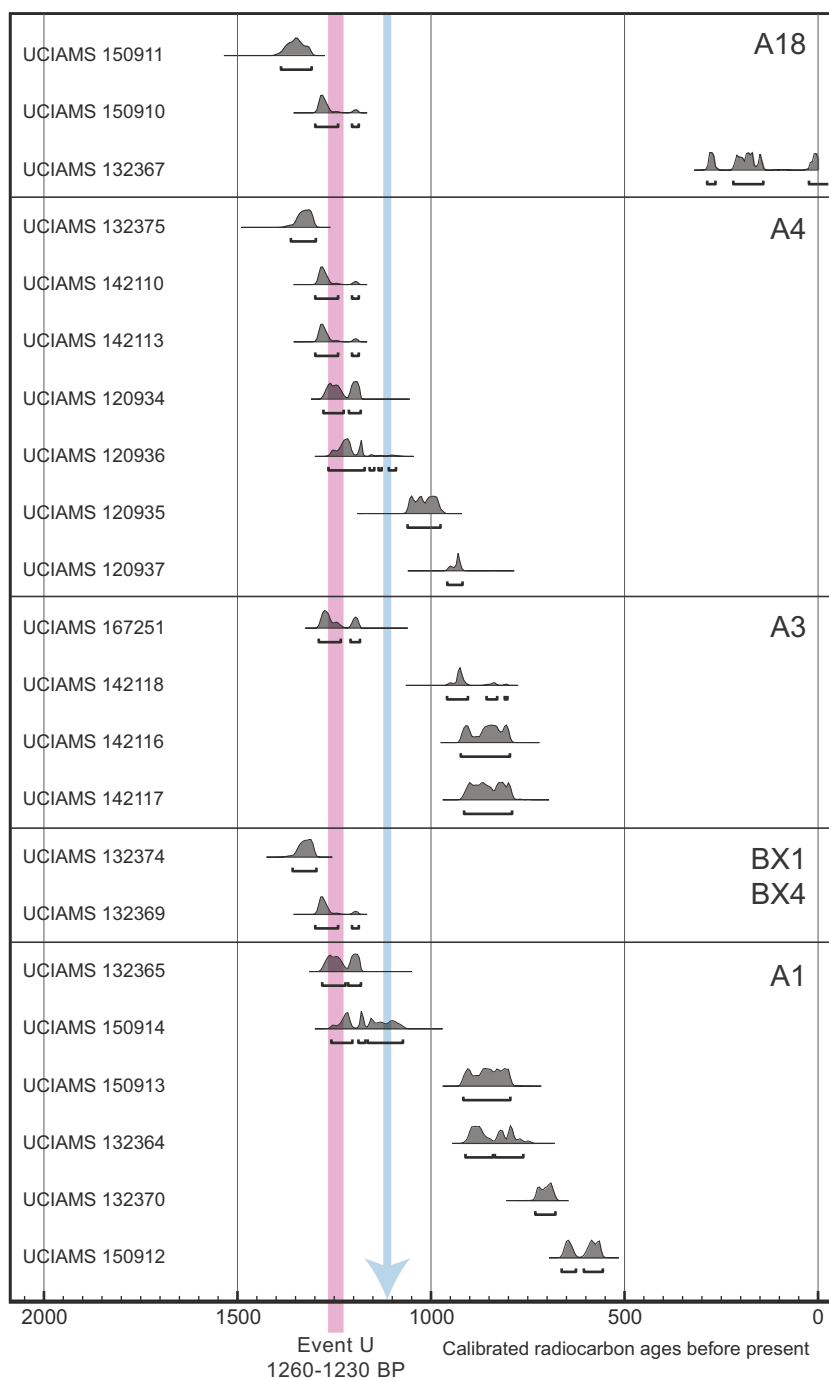


Fig. 9. Radiocarbon ages indicating hiatus postdating Event U. Blue arrow highlights gap in radiocarbon dates, pink line marks estimated age of Event U. Includes all AMS dates with conventional ages of 1400 to 1200 BP, as well as the next youngest ages in each excavation block. Calibrated using OxCal v4.3.2 Bronk Ramsey (2017) and r.5 IntCal13 atmospheric curve (Reimer et al., 2013). (Figure drafted by Adrienne Cobb).

2 because its relationship to other CSZ events is not established (Garrison-Laney, 2017) is dated to 650–560 cal BP, coeval with evidence for structural collapse at Čixw'icān. In A4, well-preserved fallen house planks made of mature wood (Fig. 13C) rest on Floor 3, and were subsequently buried by Floor 4 that began to accumulate on top of this surface (Fig. 13A). The planks themselves and the adjacent floor are dated to 805–655 cal BP (Beta 195767) and 680–650 cal BP (UCIAMS 142115) respectively (Fig. 13B). The temporal gap between these dates, and the two overlying dates from Floor 4, 515–470 cal BP (UCIAMS 142114) and 505–435 cal BP (UCIAMS 142113) is centered on the estimated age range for Event 2 (Fig. 13B). The lack of overlap between

the two series suggests at least a brief abandonment of the house, followed by re-occupation. At this time, the southern wall of the house was rebuilt about a meter to the south, as indicated by expansion of the floor in that direction. If the wall collapse is linked to the Bed 2 event, the immediate cause could be either shaking or tsunami damage. Clean sand is found on top of and underneath the planks (Fig. 13C), supporting the latter as the primary cause of collapse. In surveys of tsunami damage to archaeological sites, both Johnson et al. (2015) and Addison et al. (2010) observed undermining and collapse of walls (stone rather than wood) by tsunami scouring.

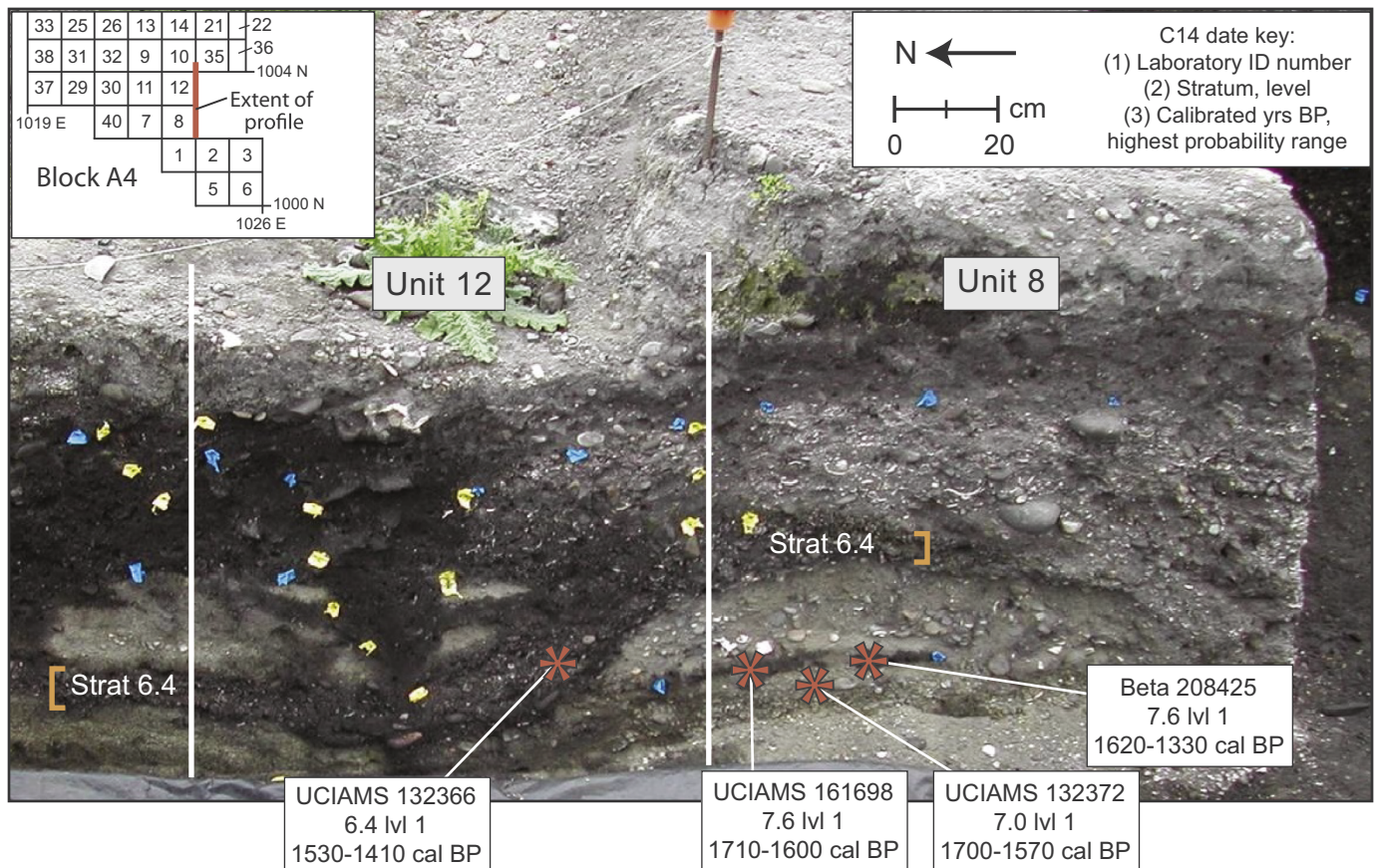


Fig. 10. Midden redeposited by backwash (Stratum 6.4) on beach berm, excavation block A4. Radiocarbon ages are consistent with entrainment by an Event U tsunami. Grid north is shoreward.

Photo courtesy of WSDOT and the Burke Museum (figure drafted by Sarah Sterling).

4.2.5. Event Y (1700 CE/250 cal BP)

Event Y, dated to 250 cal BP, or exactly 1700 CE according to archival records (Atwater et al., 2005), apparently had a direct impact on the site, as indicated by both widespread and localized erosional features consistent with tsunami, and possible liquefaction features that might be direct effects of shaking. First, radiocarbon dates suggest an extensive unconformity (Fig. 14). The latest radiocarbon dates in A4 and A18 post-date Event Y by just a few years (Fig. 14). There is almost no overlap between this suite of dates, which center on 250–150 cal BP, and an earlier suite of dates that fall between 500 and 300 cal BP. When these dates are modeled in OxCal as two different series, the interval between them is a narrow probability distribution from 323 to 172 cal BP, centered on 290 cal BP (Fig. 14). Because we attempted to date the uppermost cultural material in each excavation block, the consistent end point of the earlier dates suggests an erosional surface.

The southern part of the A4 block, which yielded three of the four radiocarbon dates falling after 250 BP (Fig. 14), offers other tentative evidence of the effects of the event, as well as recording the subsequent return of people to routine activities. A profile drawn in a construction trench before excavation of the block began (Fig. 15A, B), shows unusual vertical, branched deposits that resemble liquefaction features (Obermeier, 1996). The stratum in which these features occur is cut into by an erosional channel, the fill of which includes large clasts suspended in a finer matrix (Fig. 15A, far left). These features are tentatively attributed to Event Y based on their association and the overlying ages, although an earlier origin cannot be ruled out on the basis of the lower constraint provided by radiocarbon ages. Stratigraphically above (Fig. 15A, far right) is an intrusive cultural feature, a roasting oven (Fig. 15C), which yielded a date of 220–165 cal BP (UCIAMS-142106), postdating Event Y. A nearly identical age,

225–165 cal BP (UCIAMS 142107), was obtained from the uppermost deposit in a nearby unit.

Direct stratigraphic evidence for the event is localized, which must be partially attributable to the fact that we do not have a continuous record of the post-1700 CE landscape due to mechanical removal of industrial era deposits and disturbed underlying deposits (Reetz et al., 2006). The depth of stripping varied with the degree of historic impact. The unconformity suggested by the radiocarbon dates is not preserved stratigraphically; in each case the samples were taken from the uppermost intact deposits and the overlying deposits were treated as disturbed or historic. In A4, where both suites of dates are well represented, they do not occur in the same area of the block. Thus, although we have evidence suggesting that both the shaking and the tsunami induced by Event Y had a direct impact on the site, as well as evidence that people resumed activities soon after, there are few archaeological deposits postdating the event, and thus few animal remains to study impacts robustly (see also Butler et al., this issue b).

4.2.6. Summary

The evidence for each event discussed above varies in strength, i.e. specificity and number of criteria as well as resolution of temporal constraints (Table 3). Evidence for Event S is weakest, limited to localized erosion with a consistent but not well-constrained age range. A hiatus in site-wide radiocarbon dates as well as localized erosion make the Event U evidence stronger. Event W is represented somewhat locally by intermittent deposits of sand, commonly associated with tsunami deposition and tightly constrained temporally if the post hoc identification of a backwash deposit is correct. Evidence for Event 2 is localized but particularly convincing because of the association of sand with collapsed structural elements and a very tight correlation with the

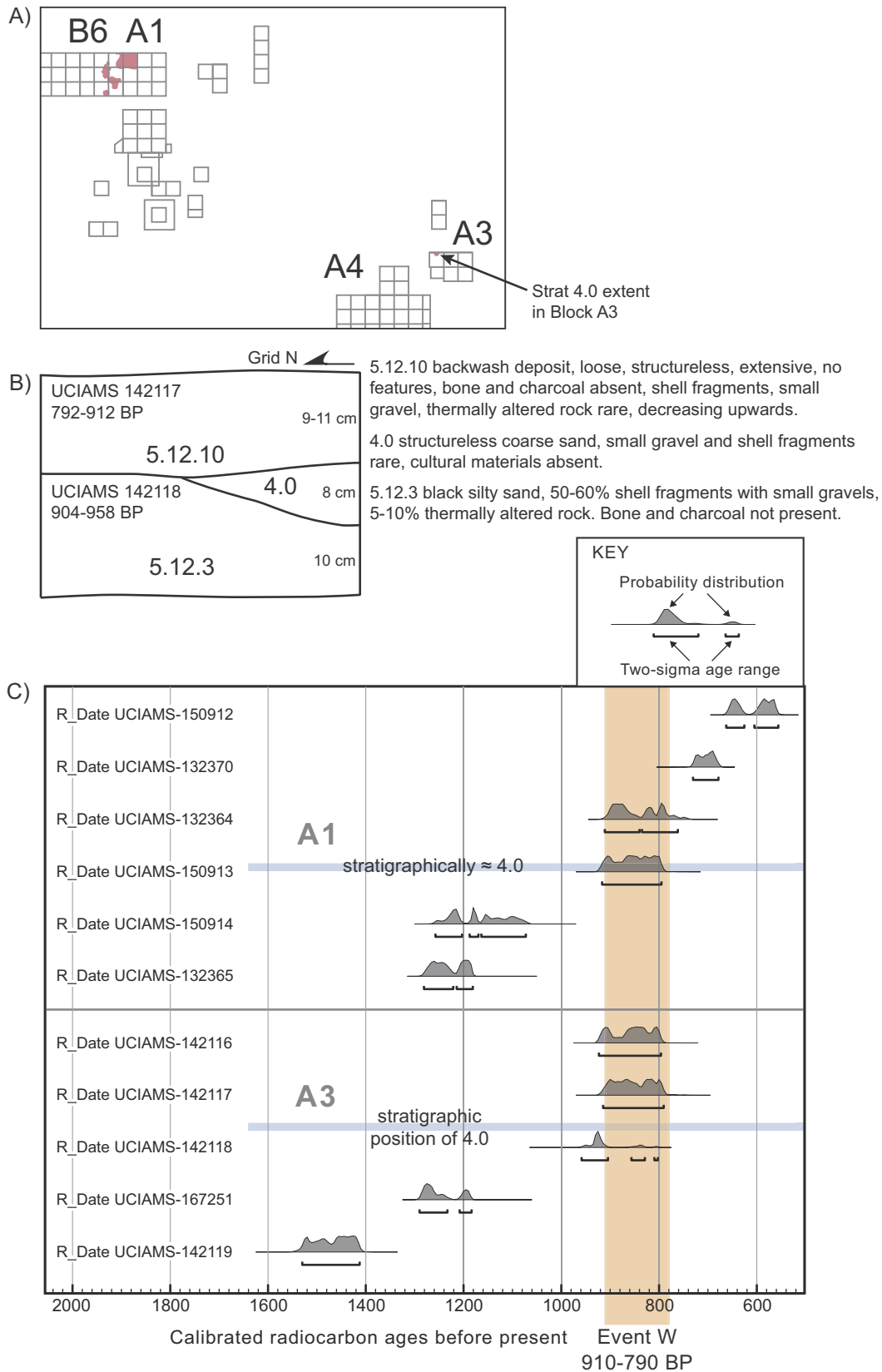


Fig. 11. Distribution, dating, and stratigraphic context of tsunamigenic sand coeval with Event W (Stratum 4.0). A) Plan map showing the patchy distribution of Stratum 4.0; B) stratigraphic context of Stratum 4.0 in A3; C) age constraints on Stratum 4.0 sands in A1 and A3. Radiocarbon ages calibrated using OxCal v4.3.2 Bronk Ramsey (2017) and r.5 IntCal13 atmospheric curve (Reimer et al., 2013). (Figure drafted by Kaitlin Dempsey and Adrienne Cobb).

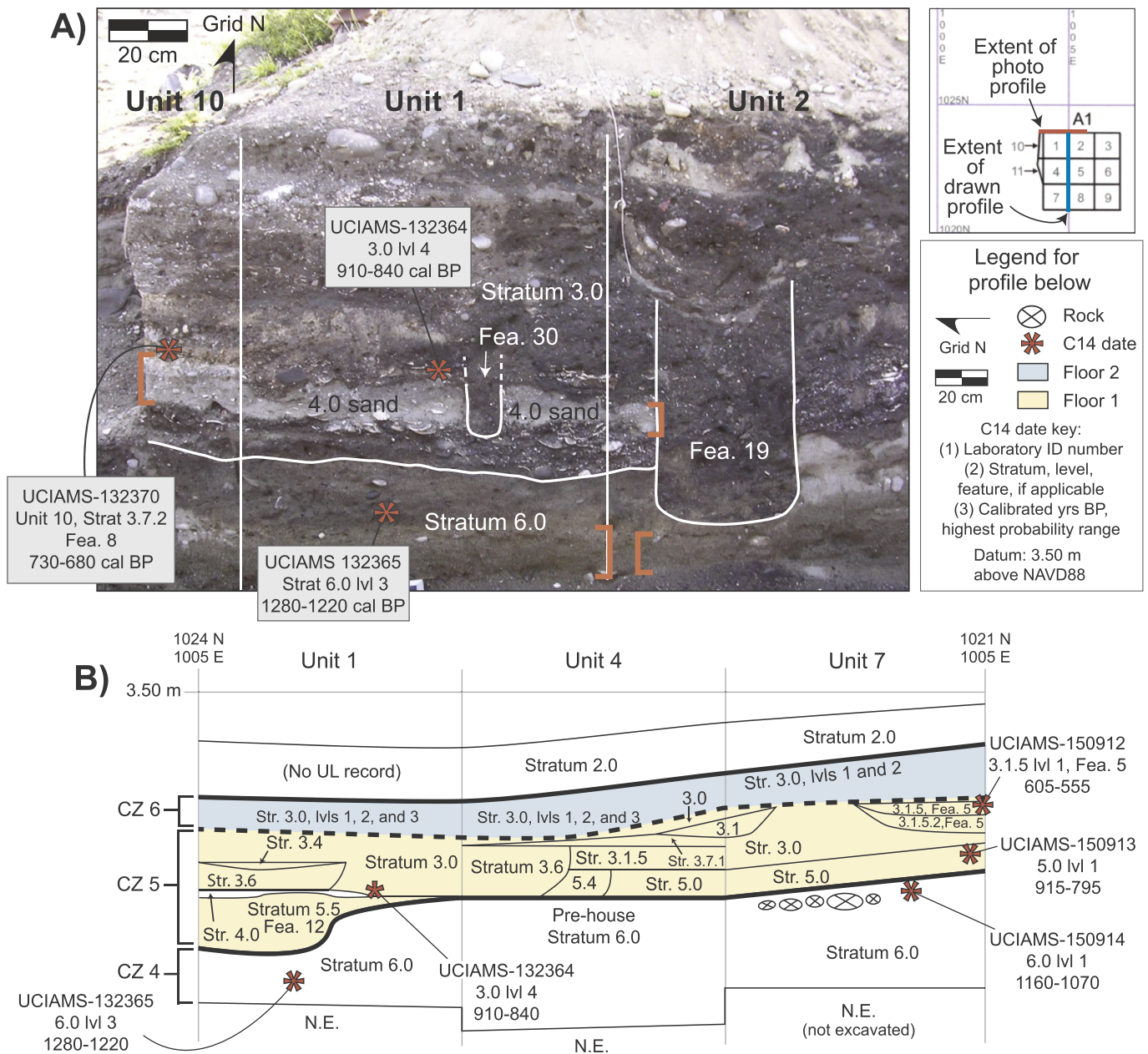


Fig. 12. Stratigraphic context of tsunamigenic sand (Stratum 4.0) in block A1. A) Profile of north walls of Units 1 and 2, facing north, B) profile of east walls of Units 1, 4, and 7, facing east, reconstructed from Unit Level records. Photo courtesy of WSDOT and the Burke Museum (figure drafted by Kaitlin Dempsey and Adrienne Cobb).

estimated age of the tsunami. Localized evidence of shaking and erosion attributed to Event Y is further supported by a hiatus in radiocarbon dates across a larger area.

4.3. How did the inhabitants respond to dynamic development of the beach/spit landforms? How did the inhabitants affect the developing landforms?

The types and intensity of cultural activity at Čixwícən in part reflect a response to the nature of the beach landforms and their expansion by beach/spit aggradation. In turn, human activities influenced the developing landforms physically, chemically, and biotically. The normal processes of beach aggradation and growth themselves are episodic, with periods of growth punctuated by periods of stability, to which people readily adapted. Other processes, tectonic events in particular, were more abrupt and punctuated the gradual changes.

This section presents a broad-brush outline of where extramural

activities and house construction took place during each CZ, in the spatial context of the northward growth of beach ridges, and in temporal relationship to inundation events. It provides a framework to structure future analysis incorporating systematic analysis of artifacts and features, which were beyond the scope of this project, in addition to faunal remains. A stratigraphic cross-section through the project area (Fig. 4) and a schematized summary of beach ridge development and cultural activity derived from it (Fig. 16) demonstrate the complex history of the landform and cultural use areas. The cross-section is aligned grid north-south, roughly perpendicular to the historic shoreline, or shore-normal in geomorphic terms.

4.3.1. CZ 1 (2150–1750 cal BP)

The earliest cultural activities at the site are farthest inland on what we believe would have been a narrow beach built on a wave-cut platform at the base of a low bluff of glaciomarine sediment (Figs. 6, 16).

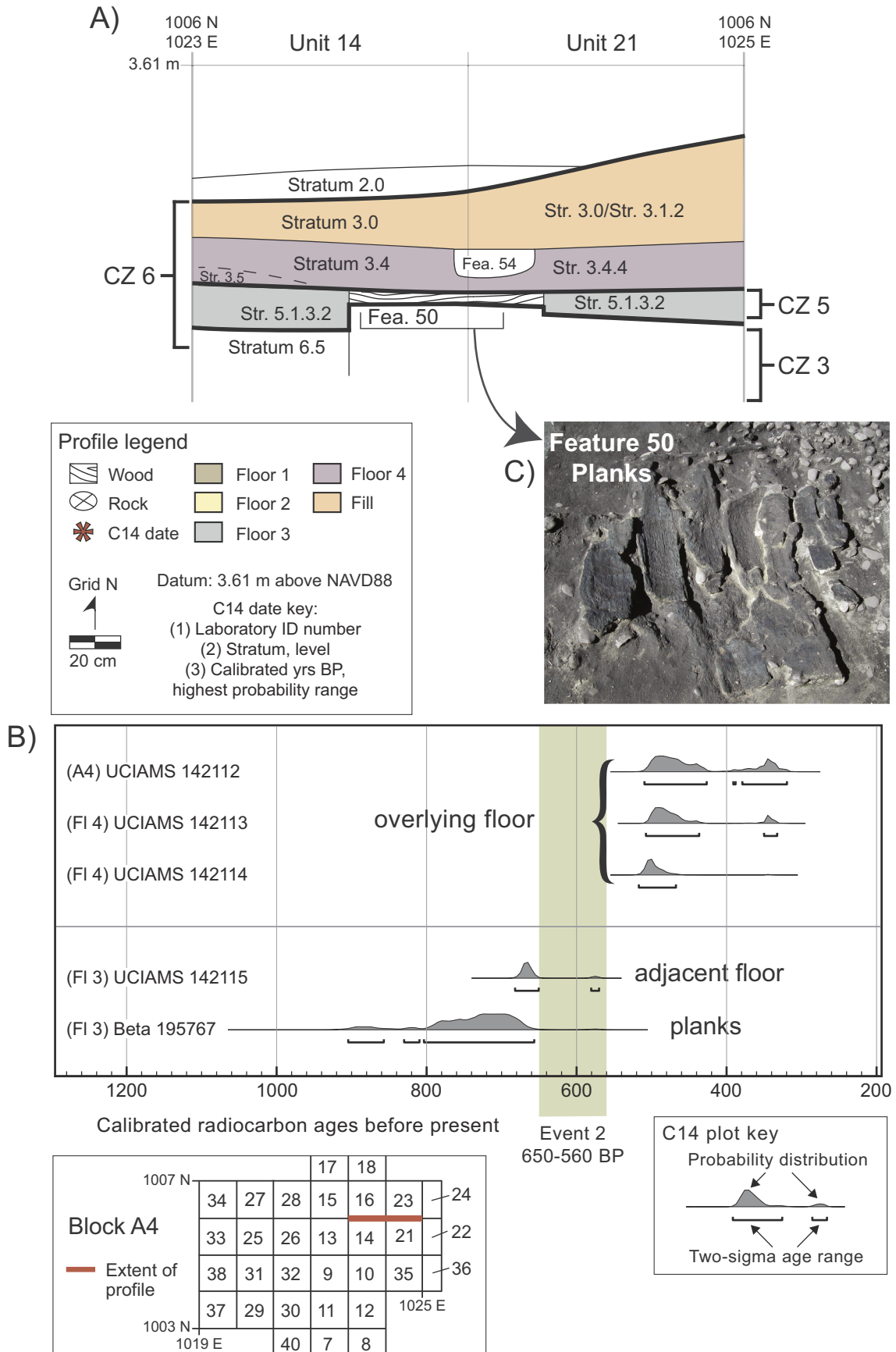


Fig. 13. Dating of collapsed planks in A4, CZ 6. A) Stratigraphic profile with radiocarbon dates, reconstructed from Unit Level records; B) probability plot of calibrated radiocarbon dates arranged stratigraphically; C) photo of planks in situ showing sandy (light-colored) sediment. Excavation did not continue below the planks. Radiocarbon ages calibrated using OxCal v4.3.2 Bronk Ramsey (2017) and r.5 IntCal13 atmospheric curve (Reimer et al., 2013). Photo courtesy of WSDOT and the Burke Museum (figure drafted by Adrienne Cobb and Kaitlin Dempsey).

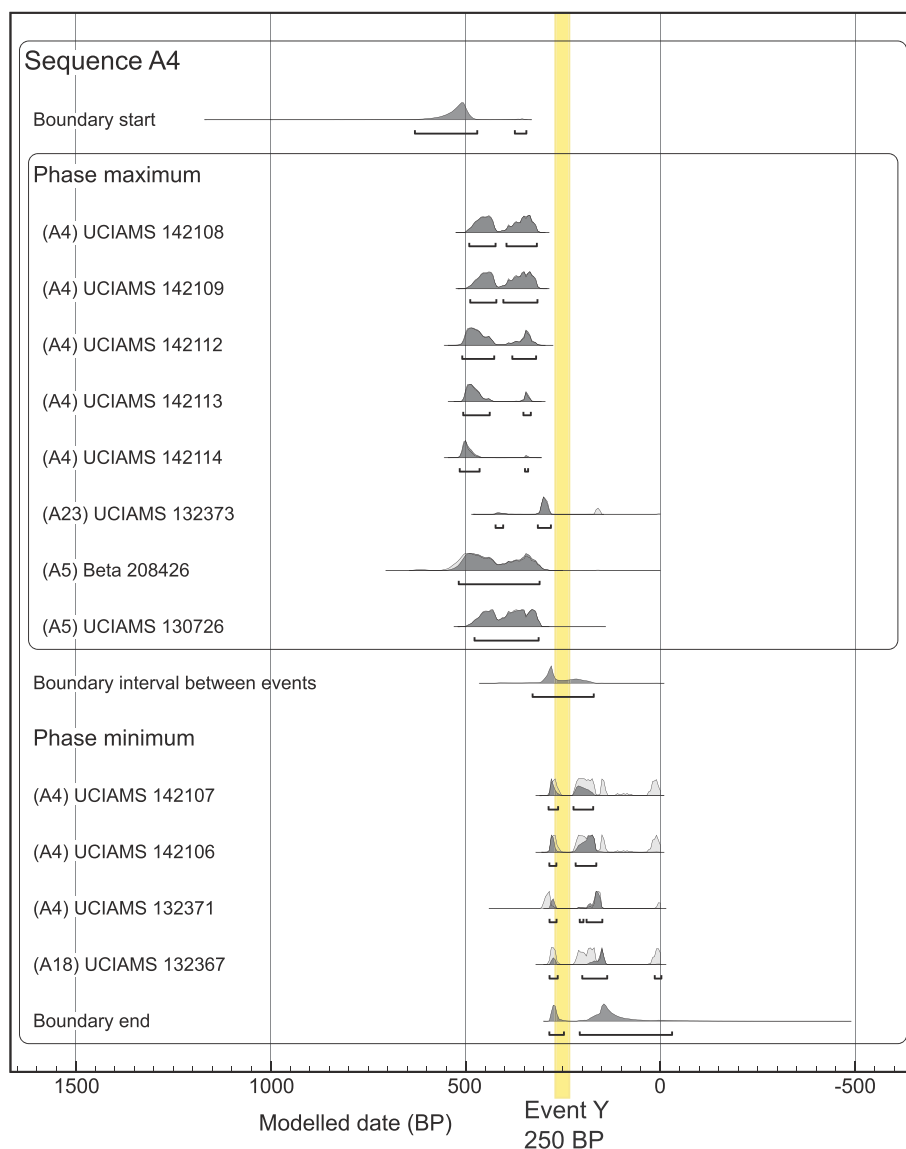


Fig. 14. Modeled radiocarbon ages constraining Event Y representation. Yellow line represents Event Y at 1700 CE/250 cal BP. All AMS dates with conventional ages of 500 cal BP or younger included. Calibrated using OxCal v4.3.2 Bronk Ramsey (2017) and r.5 IntCal13 atmospheric curve (Reimer et al., 2013).

Although exposed to higher energy than later beaches, the platform offered a stable surface for repeated food processing. In Area C (Fig. 3 inset), outside our targeted study area, shallow deposits of the lowest, coarsest sand unit, Stratum 7.0, lie on top of a relatively level surface of glaciomarine deposits; midden deposits and a slab lined feature associated with this surface date to 2490–2280 cal BP (Beta 198746) and 2730–2360 cal BP (Beta 198745) (Fig. 6). Within the project area dense cultural materials and facilities are associated with the same beach formation in A5 and A23; they range in age from 2200 to about 1900 BP. A palimpsest of multiple well-preserved thermal features was found in A5 (Fig. 17A, B) and also in A23 (4 m away, see Fig. 3). The accompanying dense shell deposits (Fig. 17C), some of which in A23 may represent secondary disposal over a bank, also indicate intense, localized activity. Large pieces of wood and a number of postholes in A5 (Fig. 17B, C, D) suggested facility construction, not clearly a house, and we treat this area as an extramural activity area. The A23 excavation units capture the active beach margin in the project area at the time of CZ 1. At the northern margin of A23, there are secondary refuse deposits sloping northeastward, and what appears to be a bank stabilization feature built of upright planks (Fig. 18).

4.3.2. CZ 2 (1750–1550 cal BP)

By about 1750 BP, the Čix^wicæn spit had begun to form, shoreward from the bluff margin (see Stage 2 in Fig. 6). People shifted some of their activities to the newly formed beach ridge (see the 7.0 sands in A4 in Figs. 4, 16) building a hearth, and a pole structure (Feature 191), similar to historic period racks for drying or smoking fish (Fig. 8). This topographic high point may have been above most winter storms, but was likely affected by the Event S tsunami, as indicated by the erosional channel cut the cultural facilities on the lee side of the beach ridge (see Section 4.2.1).

As the beach aggraded towards the harbor, the newly formed beach ridge in A4 was separated from the earlier bluff-margin beach by a swale which would have been part of a tidal inlet or lagoon approximately 30 m wide (Fig. 16) inferred from the lack of continuous cultural deposits. Natural deposits of this age in A18 and A9 are assumed to be below the base level of the excavation units.

4.3.3. CZ 3 (1550–1300 cal BP)

Considerable beach accretion of 6.0 sands occurred during this period, raising the beach ridge in the A4 area and shifting it shoreward (Fig. 16). Residents took advantage of the greater stability of the

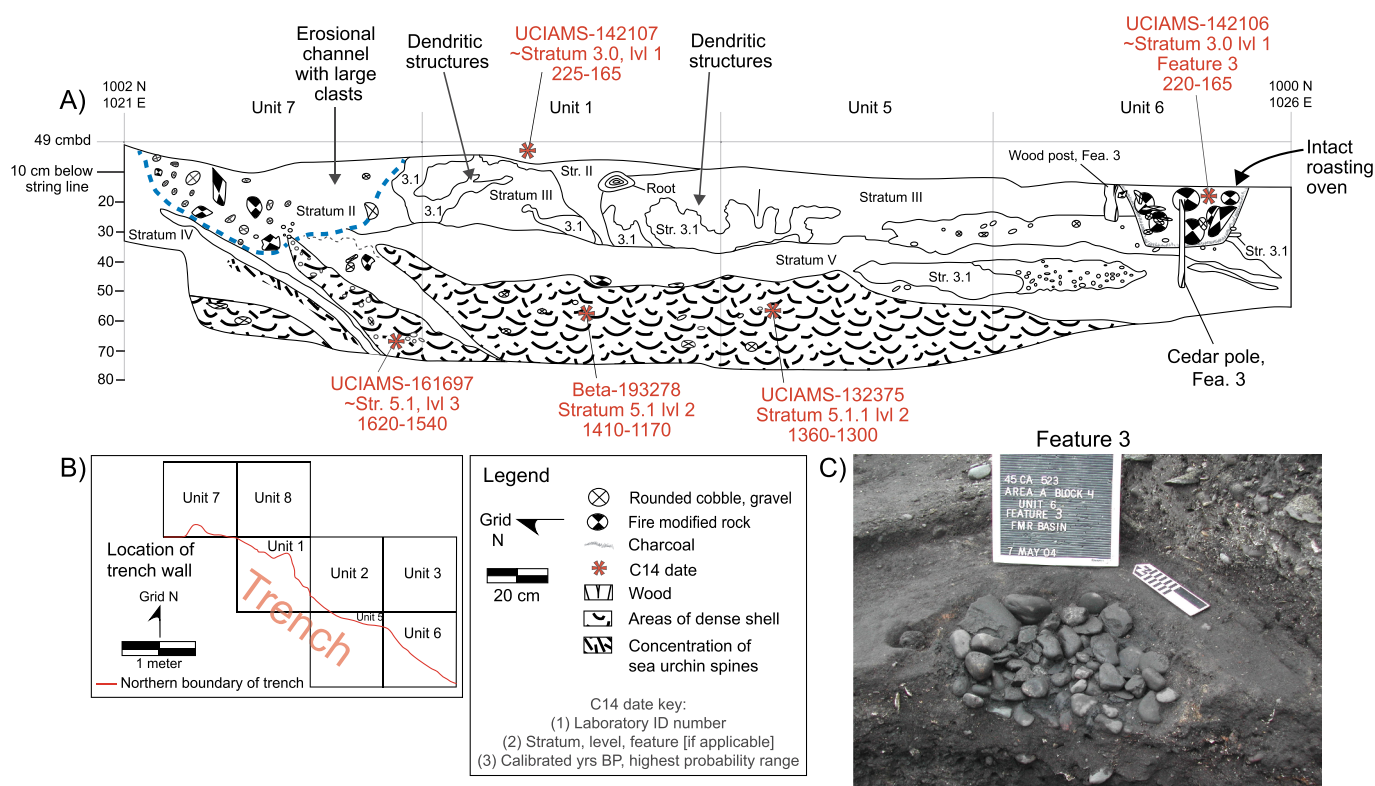


Fig. 15. Evidence for Event Y and subsequent cultural activities, A4. A) profile of non-archaeological trench. Strata labeled on this profile may have been excavated under a different name. Feature 3 profile added from Unit Level records; B) plan location of trench; C) plan view of Feature 3. Photo courtesy of WSDOT and the Burke Museum. (Figure drafted by Adrienne Cobb).

surface, and left locally dense deposits, including several hearth features in A4, in the area where the A4 house was later constructed. Cultural deposits assigned to CZ 3 appear in nearby A3 as well (adjacent to A4, not shown in Fig. 16). Beach accretion filled the tidal marsh/lagoon within the swale making this area suitable for cultural activities as indicated by a limited amount of material in A18 with an associated age of 1390–1310 cal BP (UCIAMS-150911). This beach surface may have begun forming in the A1 block at this time, however our earliest radiocarbon dates for Stratum 6.0 in A1 fall into CZ 4.

4.3.4. CZ 4 (1300–1000 cal BP)

In the period after Event U inundation reshaped the beach surface, the beach continued to build shoreward. Cultural activities not only became more widespread across the site, but included the first construction of a plankhouse, which was to be occupied for hundreds of years. In several areas across the site, processing and thermal features are found on the surface of the 6.0 sands. The swale, still a topographic low, is the locus of two specialized processing activities. Activities around a whale rib in A18 included manufacture of bone tools as indicated by debitage, as well as use of bone tools for processing other

materials as indicated by a mat creaser. Also in A18, another specialized activity, likely roasting of shellfish, resulted in a thick sequence of alternating layers of oxidized and unoxidized deposits of shell. This area may have been selected for these activities because it was somewhat sheltered in the lee of the beach ridge. The vicinity of A1 was still an active beach forefront; the beach sand surface (Stratum 6.0) is topographically lower than the 6.0 beach ridge height in A4 and the density of associated cultural materials is low (Fig. 16).

House construction began on the beach ridge in the northern part of A4, centered over the earlier hearths mentioned for CZ 3 (Figs. 19, 20). The builders constructed a shed roof style house with the long axis parallel to the shoreline. Preserved architectural details include a foundation trench dug into the sand, with associated posts, including one corner. The outer wall cladding is represented by an alignment of vertical wall plank bases and small support posts 1.5 m south of the foundation trench. Floor strata formed within a shallowly excavated central living area, approximately 4.0 m wide (Fig. 9). Two hearths mark the likely mid-line of the house but there is no clear indication of a rafter support alignment or outer wall on the northern side. The floor strata generally do not extend beyond the foundation trench to the

Table 3 Summary of CSZ seismic events and evidence at Čix'wicən.

Event ^a	Estimated age ^b	Evidence at Čix'wicən
S	1660–1530 cal BP	Evidence weak, possible erosional unconformity
U	1260–1230 cal BP	Temporally correlated erosional unconformity, erosional channels, backwash deposits, and occupation hiatus
W	910–790 cal BP	Temporally correlated tsunamigenic sand and backwash deposit
Bed 2 sands	650–560 cal BP	Temporally correlated structural collapse with sandy sediment
Event Y	1700 CE	Temporally correlated unconformity, erosional channel, possible liquefaction features

^a Nomenclature developed by Brian Atwater of the USGS and others (Atwater, 1987; Atwater and Hemphill-Haley, 1997; Garrison-Laney, 2017). ^b Based on Hutchinson and Clague (2017).

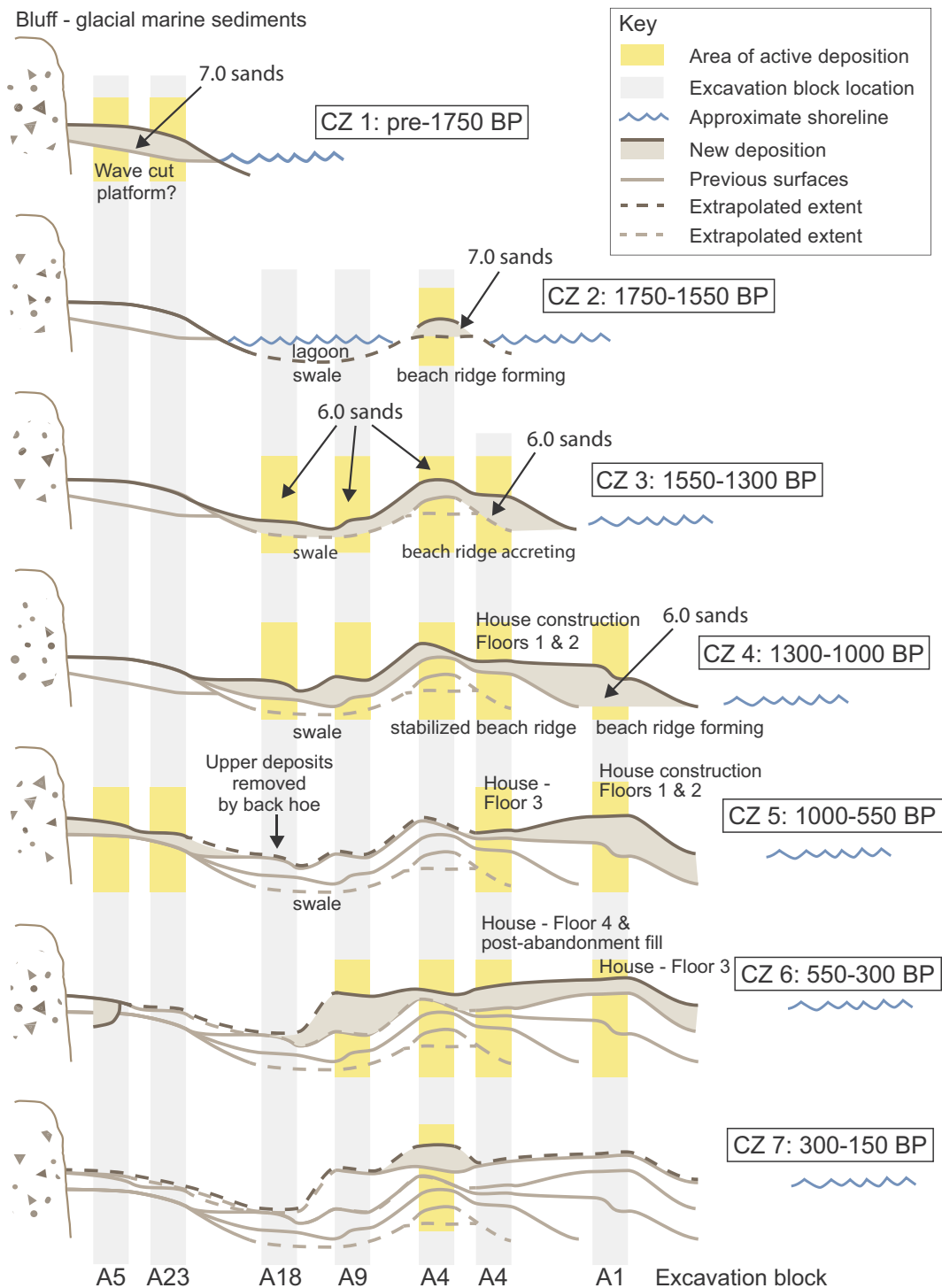


Fig. 16. Beach ridge development with associated cultural activity. Over time beach ridges grow higher and also expand shoreward. Schematized based on measured elevations from transect shown in Fig. 4. Because the focus was on excavating anthropogenic deposits, the profile does not track the full depth or extent of the natural deposits forming the beach ridges and their stratigraphic relationship. Instead, we have limiting dates for beach surfaces based on cultural activity on those surfaces. (Figure drafted by Adrienne Cobb).

outer wall, indicating the location of a bench area. Two floor strata accumulated within this house footprint (Fig. 20), vertically distinguishable in some places, suggesting a hiatus in use that interrupted the formation of the floor palimpsest (Grier, 2006). This sequence could not be traced across the entire area, and the radiocarbon ages overlap (Fig. 19), therefore, we treat Floors 1 and 2 as an aggregate. The floor strata are not continuous across the area, and may have been obscured

or incorporated in later floor development. A north-south profile (Fig. 20B) shows the foundation trench (Feature 98) and small remnants of Floors 1 and 2 in the house depression. The wall area is complex, with back-dirt piles from excavation of large postholes and the floor area, and secondary refuse piles outside the wall, many of which cannot be traced directly to initial construction, or any specific subsequent floor.

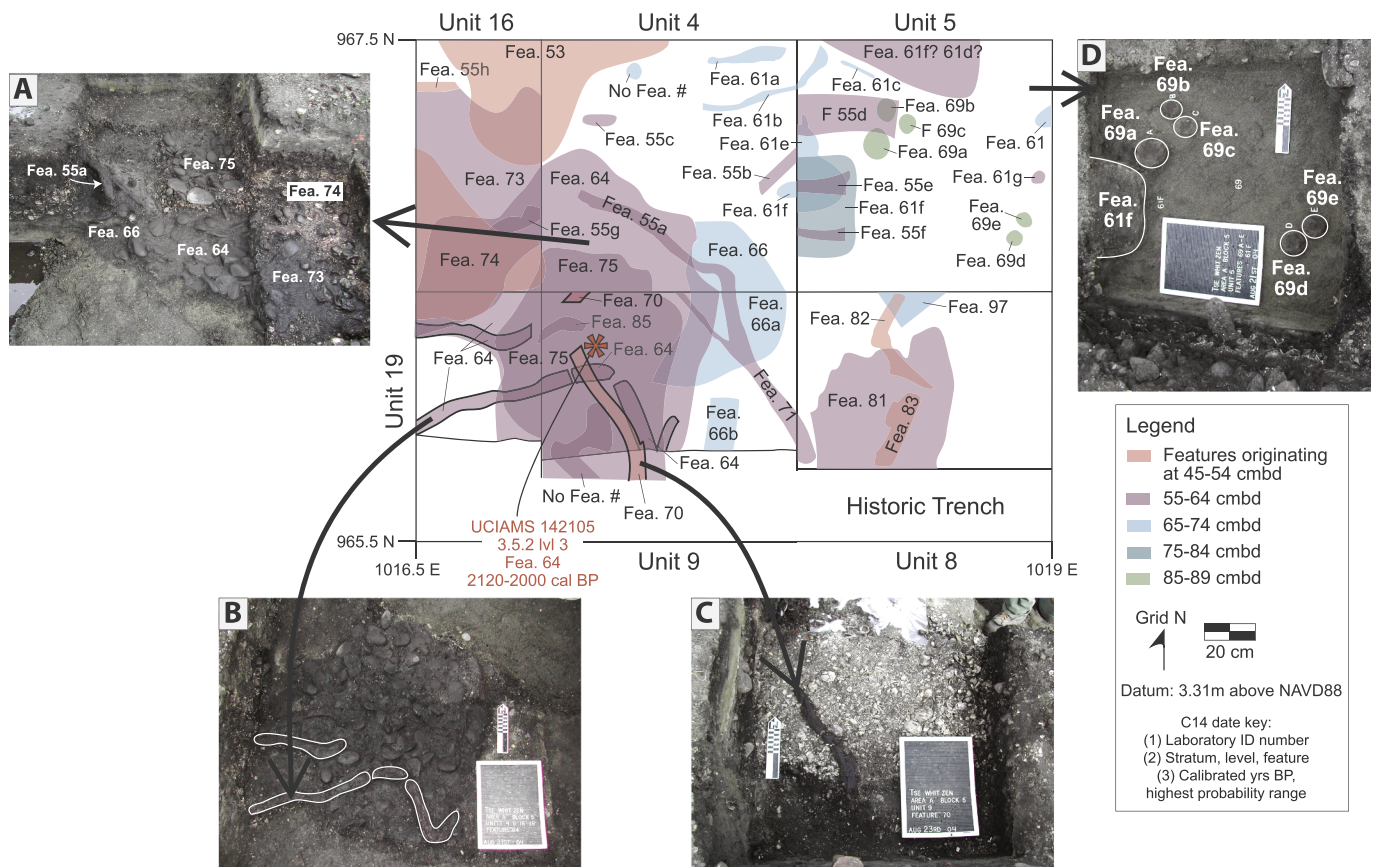


Fig. 17. Densely packed and superimposed archaeological features indicate intensive activity in CZ 1 (southern portion of block A5): A) stacked thermal features 64, 66, 75, with associated wood, Feature 55, facing south; B) wood, Features 55 and 61 and thermal feature 64; C) dense shell deposit with wood, Feature 70; D) postholes, Feature 69a-e and pit, Feature 61f, facing west. Depths represented: 2.42–2.86 m above NAVD88. Photos courtesy of WSDOT and the Burke Museum (figure drafted by Kaitlin Dempsey).

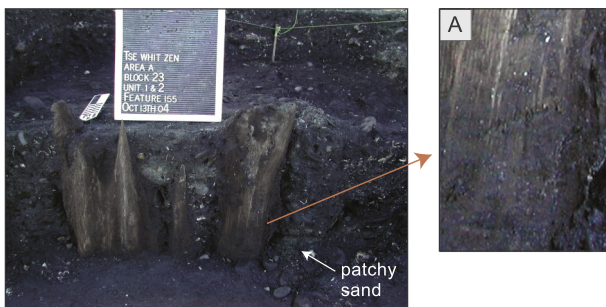


Fig. 18. Bank stabilization structure (Feature 155) in A23 built using weathered planks placed upright. A) Closeup of cut marks. Photo courtesy of WSDOT and the Burke Museum.

4.3.5. CZ 5 (1000–550 cal BP)

Cultural activity was widespread across the area between 1000 and 550 BP (Fig. 16) likely reflecting a larger village size or an increased number of occupants, as a house was constructed on the newly stabilized beach surface in the A1 area and the A4 house continued to be inhabited. Early in this period, Event W (910–790 cal BP) generated a tsunami that inundated the site leaving patchy clean sand deposits and a backwash deposit in A1 and A3 (see discussion in Section 4.2). Tsunami inundation may account for other observations that we did not cite as strong evidence of tsunami: a break in use of the A4 house and the absence of materials of this age in the swale area (Fig. 16).

The A4 house may have been temporarily abandoned, based on a layer of fill that accumulated near the western margin of the excavated

area (not shown in the profiles selected here). The house depression was re-occupied, however, with a minimum of structural modification (Fig. 19). A rafter support post was placed slightly south of the existing trench (see Feature 37 in relationship to Feature 98 in Fig. 20B). A third floor formed within the same central area as Floors 1 and 2. Towards the end of this time period, occupation was again disrupted by a tsunami linked to the Bed 2 sands (650–560 cal BP) that resulted in collapse of a wall or roof portion, which came to rest directly on the floor (Figs. 13, 19, 20A). Feature 92, a 1.0 m by 0.5 m roasting platform containing remains of more than 150 individual urchins, may be indicative of a commemorative or dedicatory feast held by this household in connection with re-occupation.

House construction began in the A1 block indicating further transgression of the shoreline and stabilization of the beach ridge (Fig. 16). The shed roof house (Figs. 5, 12) was occupied before Event W occurred and occupation seems to have been only briefly interrupted (Fig. 12B). Cultural activities resumed in A5 and A23 with sheet midden deposited directly on top of much older deposits (Fig. 4).

4.3.6. CZ 6 (550–300 cal BP)

People began to re-use the area after disruption by the tsunami event of 650–560 cal BP (Bed 2 sands) (see Section 4.2 discussion above) with intensive food processing activities in A3 and A9. Within A4, the inhabitants of the house responded to structural collapse (see discussion in Section 4.2). A layer of fill formed on top of Floor 3, suggesting that the house was abandoned for some time after the collapse, but later reoccupied, as evident from Floor 4, located above the fill (Figs. 13, 20A). Given the uncertainty in radiocarbon ages (Fig. 19D) it is not possible to estimate how much time elapsed. For the first time,

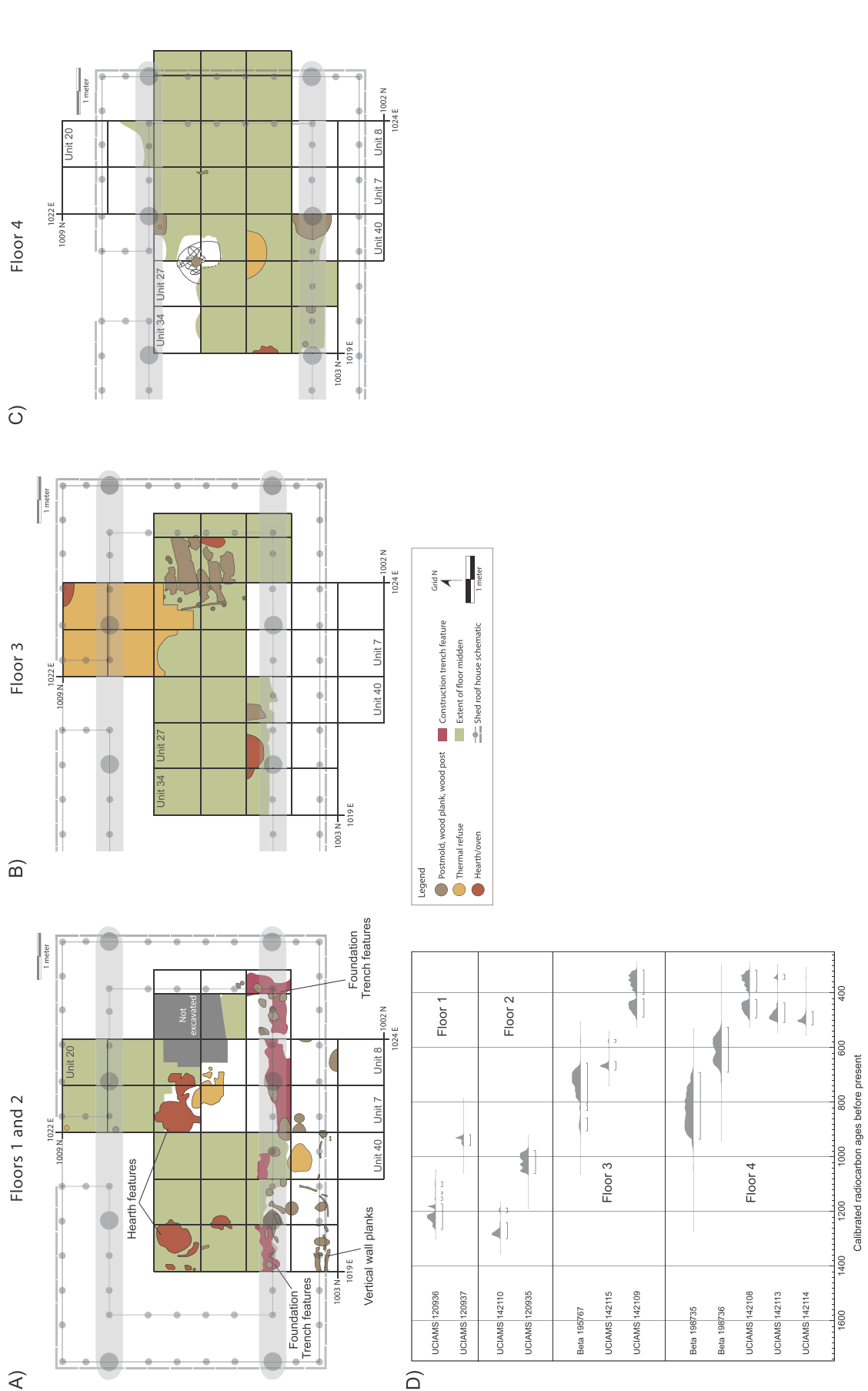


Fig. 19. Plan map of successive floors and associated structural elements within the same house platform in block A4. A) Floors 1 and 2; B) Floor 3; C) Floor 4; D) radiocarbon dates from Floors 1–4. Vertical relationships between the floors are shown in Fig. 20. (Figure drafted by Kaitlin Dempsey and Adrienne Cobb).

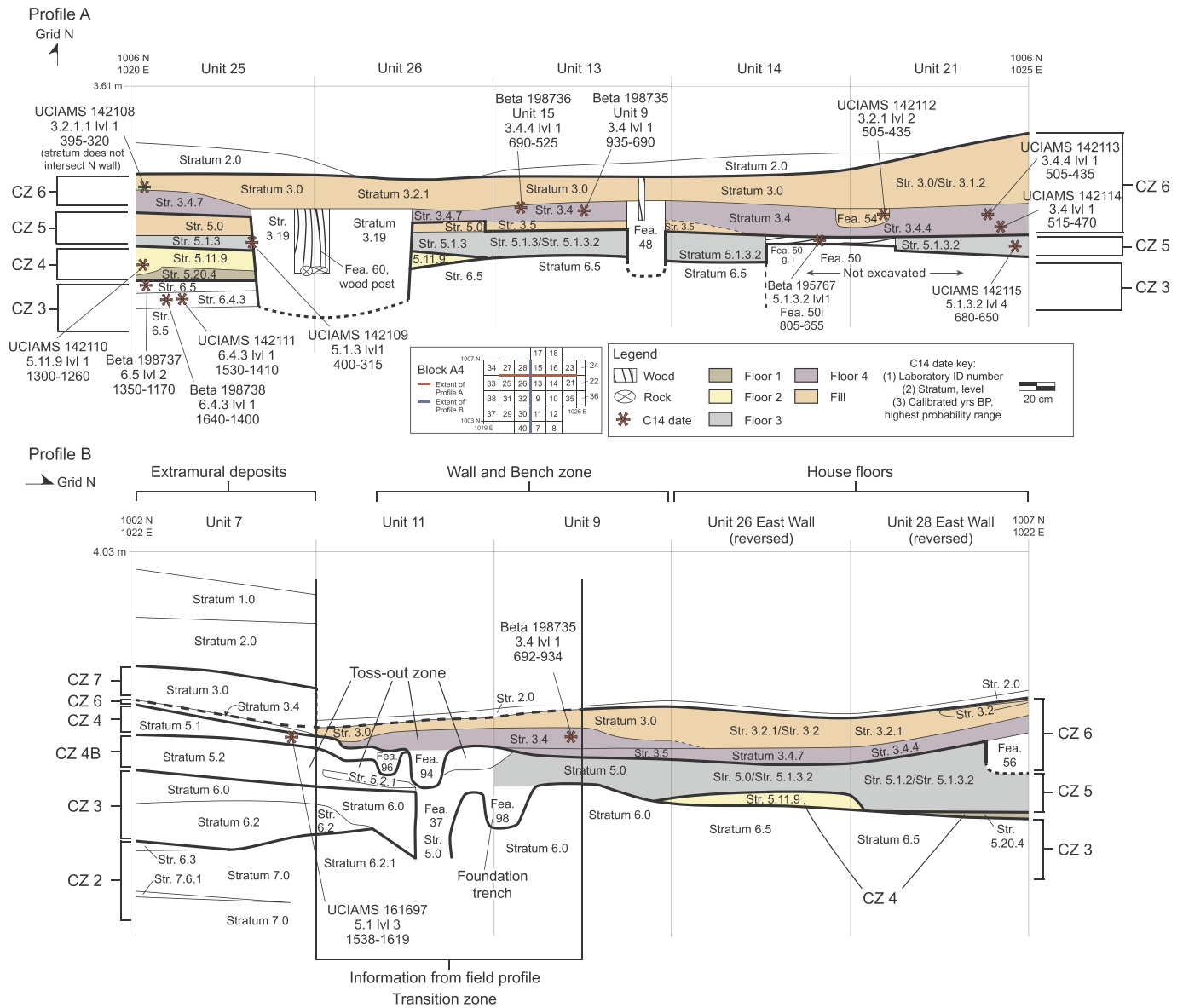


Fig. 20. Profiles through house in block A4 showing vertical relationship between pre-house activity surfaces and the subsequent series of floors and fill layers. Profile A is east-west and Profile B is north-south as shown in inset block map. Profiles reconstructed from Unit Level records. (Figure drafted by Kaitlin Dempsey).

the house was rebuilt to a slightly different plan, with Floor 4 extending further south and the southern wall shifting south as well. Occupation was subsequently interrupted again; an extensive layer of fill on top of Floor 4 suggests that the walls had been deconstructed/removed and the inner space was accessible (Fig. 20).

Occupation of the house in A1 continued, with the formation of a second floor (Figs. 4, 12). No direct evidence of an impact similar to that in the A4 house was noted. Although this house is closer to the historic shoreline, it would not necessarily be more or even equally vulnerable to tsunami inundation if the current followed existing swales between beach ridges.

4.3.7. CZ 7 (300–150 cal BP)

Information on cultural activities for CZ 7 are limited as deposits were restricted to the two topographically highest locations. The most intriguing record is the intact thermal feature in the southern part of A4. This deep oven filled with thermally altered rock has two cedar stakes adjacent to it, perhaps guides for re-excitation when pit steaming was complete. This feature is intrusive into surfaces that may

reflect impacts of event Y (see Section 4.2), demonstrating the return of people to traditional activities in an area that had been devastated.

5. Discussion and conclusions

The ancient inhabitants of Čix^{wic}an, the ancestral ‘strong people,’ developed an effective adaptation to the unique characteristics of an oceanic strait (see Butler et al. this issue b), and showed resilience in the face of multiple tectonic events that exacerbated the inherent dynamism of the coastal landscape. Our approach allowed us to address the cultural adaptability and resilience behind the longevity of occupation at Čix^{wic}an. Successive generations of inhabitants responded to developing beach landforms and to changing intertidal habitats. Households rebuilt and re-occupied houses after tsunami inundation resulting in 800 and 500 years use of the two house platforms respectively. While the depositional history of the site reflects evidence of seismic disruption and brief periods of abandonment, the benefits of the “sheltered harbor” formed by Ediz Hook clearly outweighed the costs of occasional earthquakes and tsunamis.

To some extent, longevity is reflective of investment in the landscape. Human construction and refuse disposal in shell midden sites can influence natural depositional processes both deliberately and unintentionally (Grier, 2014; Marquardt, 2010; Onat, 1985). Daily practices, such as dumping of refuse and building of temporary structures such as racks, when repeated over and over, have the potential to change deposition and erosion locally and have a long term impact on the stability and growth of the beach platform. We are not in a position to describe how the inhabitants affected the overall spit development; that would require a spatially more extensive analysis. But we can point to small-scale examples of the interplay between human activities and natural deposition within the project area. Construction of a bulwark in A23 and deposition of shell refuse and thermally altered rock in CZ 1 contributed to infilling of the swale as did sloping deposits of shell refuse at the south side of A4 in CZ 2. The presence of thermal features with dense rock and facilities involving alignments of poles in an area regularly experiencing beach swash and overwash (A4, CZ 2, see Fig. 10) may have locally affected sediment transport and deposition and contributed to stabilization of the beach ridge.

House construction transformed the landscape to an even greater degree physically, with leveling, excavation, and concentrated refuse accumulation. The relationship of the groups who rebuilt houses at Čix^{wicən} and the previous occupants cannot be established directly, but regional ethnography suggests that house locations were curated and conveyed with them a corporate identity (Marshall, 2006). Houses and house platforms represent a substantial investment; it could take years for a household to accumulate needed resources and social capital to build a house (Trieu Gahr, 2006). Fill layers indicating periods of non-occupation in the A4 house do not negate the possibility that the household had a continuing identity; unfortunately the radiocarbon ages don't provide enough resolution to estimate the length of time between building episodes (Fig. 19D).

We suggest that as many as five tsunami may have overtopped Čix^{wicən}. The strength of the evidence varies with the specific event; however even tentative interpretations are worth sharing to increase awareness that impacts of CSZ events other than coseismic subsidence can be detected in archaeological sites in this region. Along the Cascadia plate margin the rich record of multiple full rupture events offers archaeologists the possibility of documenting the impacts of tsunami, subsidence, uplift, and shaking on local peoples and contributing to understanding the resilience of communities in the wake of natural disasters. We agree with Barnes (2017) that archaeologists working in tectonically active areas need to practice “seismic archaeology” which requires engagement with the knowledge of the natural processes and their implications for past peoples. Awareness of how tsunami deposits might manifest within an archaeological site prior to excavation is critical. Tsunami deposits in Northwest Coast midden sites, and coastal middens elsewhere, could potentially be mistaken for sheet midden deposits as dumping can mimic the chaotic turbulence of tsunami. Archaeological sites sometimes provide better preservation than the surrounding landscape due to subsequent rapid burial or voids created by structures, as well as greater chronological resolution (Bruins et al., 2008; Clouard et al., 2017; Gutiérrez Mas et al., 2016) and thus potentially contribute to understanding paleotsunami and their effects on human habitation.

Further research at Čix^{wicən} could test sediments identified as possibly tsunamigenic for evidence that is more diagnostic of tsunamigenic origin, such as marine microfauna. Stratigraphic records from other areas of the site could be incorporated to test the interpretations of tsunami events offered here and address the role of tsunami inundation in the development of the larger landscape especially in relationship to spit growth and changing intertidal habitat.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jasrep.2018.10.005>.

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