

Research Article

Ancient Maya submerged landscapes and invisible architecture at the Ch'ok Ayin residential household group, Belize

Heather McKillop¹  and E. Cory Sills²

¹Dept of Geography and Anthropology, Louisiana State University, Baton Rouge, LA, USA and ²Department of Social Sciences, The University of Texas at Tyler, Tyler, TX, USA

Abstract

Pole-and-thatch structures built directly on the ground surface were likely common in antiquity in the Maya area as residences, kitchens, workshops, storehouses, and for other uses, although the actual wooden architecture normally decays and often leaves no mounded remains. Various estimates are made to account for these “invisible sites” in population estimates based on mound or *plazuela* groups. Wooden building posts and associated artifacts preserved in mangrove peat below the sea floor in Punta Ycacos Lagoon, southern Belize provide an opportunity to address population size, material wealth, and household activities at “invisible sites.” The distribution of wooden building posts and artifacts at the Ch'ok Ayin underwater site indicates it was a residential household group with several pole-and-thatch buildings around a plaza. The householders focused on salt production, with artifactual evidence of brine enrichment and brine boiling, in addition to other supporting activities, and participated in Late Classic marketplace trade for goods from varying distances. Holocene sea-level rise that flooded low-lying coastal areas also obscured ancient Maya sites, making them “invisible” in the modern landscape.

Abstracto

Las estructuras de postes y paja construidas directamente sobre la superficie del suelo probablemente eran comunes en la antigüedad en el área maya como residencias, cocinas, talleres, almacenes y para otros usos, aunque la arquitectura de madera real normalmente se descompone y, a menudo, no deja restos de montículos. Se hacen varias estimaciones para dar cuenta de estos “sitios invisibles” en las estimaciones de población basadas en grupos de montículos o plazuelas. Los postes de construcción de madera y los artefactos asociados preservados en turba de manglar debajo del lecho marino en la laguna de Punta Ycacos, en el sur de Belice, brindan la oportunidad de abordar el tamaño de la población, la riqueza material y las actividades domésticas en “sitios invisibles”. La distribución de postes de construcción de madera y artefactos en el sitio submarino de Ch'ok Ayin indica que era un grupo de casas residenciales con varios postes y edificios de paja alrededor de una plaza. Los dueños de casa se centraron en la producción de sal, con evidencia artefacta de enriquecimiento de salmuera y ebullición de salmuera, además de otras actividades de apoyo, y participaron en el comercio del mercado del Clásico Tardío para obtener bienes de diferentes distancias. El aumento del nivel del mar en el Holoceno que inundó las zonas costeras bajas también oscureció los antiguos sitios mayas, haciéndolos “invisibles” en el paisaje moderno.

The remains of ancient Maya household architecture are ubiquitous across the modern landscape in the Maya area as solitary mounds and residential plaza groups. Pedestrian surveys along transects in forested areas have revealed mounds at many sites (Culbert and Rice 1990). Airborne lidar has shown “bare-earth” views of mounds and other features on the ground through the forest (Canuto et al. 2018; A. S. Z. Chase et al. 2024; A. F. Chase et al. 2024; Thompson et al. 2022). Lidar has revealed stone architecture around central plazas as well as residential groups on raised platforms and on non-elevated areas consisting of the mounded remains of

stone buildings or pole-and-thatch buildings that decayed. Lidar imagery captures the most recent, usually the Late Classic (A.D. 550–800) or Terminal Classic (A.D. 800–900), visible architecture, but not earlier residential remains (Hiquet 2024:92). Questions remain about the contemporaneity of buildings and their uses, as well as settlement that left no mounded remains, often termed “invisible sites” (A. F. Chase et al. 2024; D. Chase 1990; Culbert and Rice 1990; Johnston 2004; Pyburn 1990).

Including the “invisible” sites in studies of Maya settlement is important to understanding ancient Maya population estimates, wealth distribution, the composition of households, and household activities (Canuto et al. 2018; Chase 2017; Chase and Chase 2014; Culbert and Rice 1990; Estrada-Belli et al. 2023; Haviland 1972, 1982; Inomata et al. 2018; Thompson et al. 2022; Yaeger and Robin 2004).

Corresponding author: Heather McKillop; Email: hmckill@lsu.edu

Cite this article: McKillop, Heather and E. Cory Sills 2025 Ancient Maya submerged landscapes and invisible architecture at the Ch'ok Ayin residential household group, Belize. *Ancient Mesoamerica* 1–22. <https://doi.org/10.1017/S0956536125000136>.

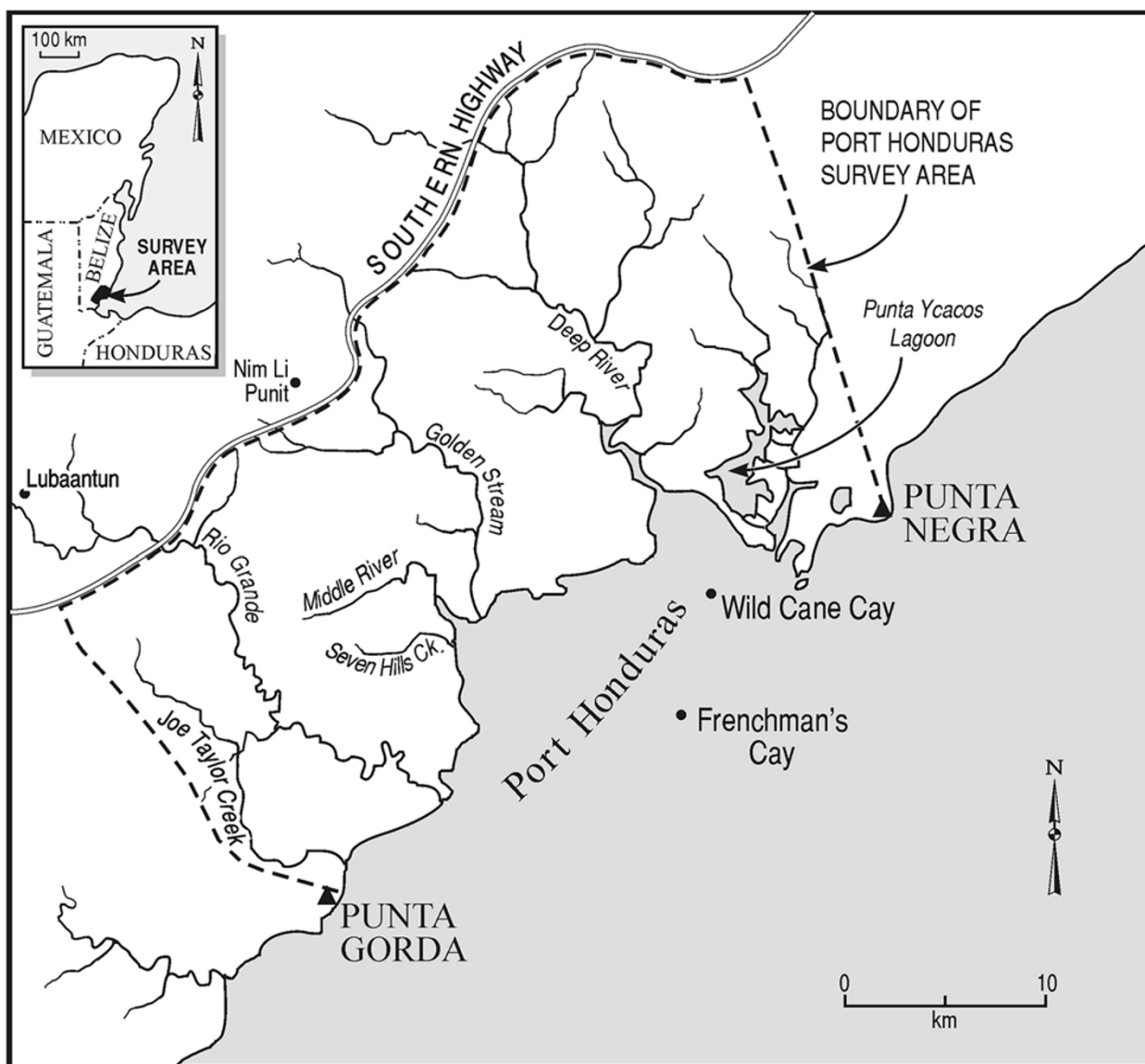


Figure 1. Map of the Port Honduras coastal bight showing the location of Punta Ycacos Lagoon. Insert shows location in the Maya area.

Thompson et al. (2022) note that “often the humblest of households remain undetectable in heavily vegetated areas” in lidar survey and that house mounds may be missed during pedestrian survey due to “dense foliage, or invisible platform/‘vacant terrain’ where low-lying house foundations may be obscured by natural soil processes.” The low-lying coastal plains and shallow marine waters of Belize and the Yucatan of Mexico are flooded landscapes that contain ancient Maya sites that are invisible in the modern landscape (McKillop 2024). Invisible Maya sites that left no mounded remains in the modern landscape include underwater sites in Punta Ycacos Lagoon on the southern coast of Belize that were flooded by sea-level rise (Figure 1; Foster et al. 2023; McKillop 2002, 2024; McKillop et al. 2010). One of these sites is the Ch’ok Ayin site, a residential household group with several pole-and-thatch buildings and associated artifacts. Analysis of the material reveals the age, function, and role of the buildings in salt production and related activities, including salting fish, pottery production, and woodworking.

The underwater sites in Punta Ycacos Lagoon add missing dimensions since the sites left no mounded remains of pole-and-thatch buildings of residences, salt kitchens, and other structures used to supply dietary salt needs for the nearby coastal and inland Maya (McKillop and Sills 2022, 2023, 2025). Although pole-and-thatch buildings constructed directly on the ground without stone foundations are regarded as the lowest tier of Maya architecture (Gonlin 2007; Thompson and Prufer 2021; Yaeger and Robin 2004), the Late Classic Maya at the Paynes Creek Salt Works were not impoverished. They obtained painted and decorated pottery, chert, obsidian, and jadeite from nearby and distant locations (McKillop 2019; McKillop and Aoyama 2018; McKillop and Sills 2022, 2023; McKillop et al. 2019). Unlike Maya residential household groups elsewhere who were largely self-sufficient in agricultural production, such as the inland communities of Uxbenka and Ixkuku’il in southern Belize, San Lorenzo and Chan No’ohol in the upper Belize River valley, or outlying areas of Caracol (Chase and Chase

2014:12; Thompson and Prufer 2021; Yaeger and Robin 2004), the Paynes Creek Maya may have relied on trade to obtain food in exchange for salt and salted fish (McKillop and Aoyama 2018). In a survey of 110,000 masonry structures in Guatemala and Mexico, Estrada-Belli and colleagues (2023) found that elite architecture was regularly distributed in urban and rural areas, likely to oversee the use and trade of resources. There was no elite architecture at the Paynes Creek Salt Works (McKillop 2019), underscoring that this was independent, surplus household production, evidently without local overseers (McKillop and Sills 2022, 2023).

Household archaeology and residential groups in the Maya area

Maya householders often lived and worked in plaza groups consisting of one or more buildings on a raised platform with a central open space. The uses of buildings ranged from single- to multi-family units to an extended household occupying one or more buildings, with other structures used for cooking, storage, and craft production (Gonlin 2007; Haviland 1970:193, 1985; Prufer et al. 2011; Robin 2012; Sheets et al. 2015; Thompson and Prufer 2021; Wauchope 1938:128–138; Wilk 1988; Yaeger and Robin 2004). In a study of 24,500 household groups from 23 centers in the Maya lowlands, the researchers found there was an average of three to four structures per household (Thompson et al. 2022). Excavations at Ixkuku'il revealed that there was variation over time in the number of structures, with an average of five for the Early Classic (A.D. 250–500) and only three on average during the Late Classic (Thompson and Prufer 2021). At Caracol, there were typically one to 12 structures on a raised platform arranged around a rectilinear open space in roughly cardinal directions, with residences, an eastern shrine that was not used as a residence, and other structures used for a variety of purposes (Chase and Chase 2014). Excavations in residential household groups at Caracol indicate that they were used for an extended family with probably no more than one or two nuclear families (A. S. Z. Chase et al. 2024).

Residential groups on platforms included some buildings with stone foundations, some with stone walls, and others just pole-and-thatch built directly on the ground (Chase 1990; Culbert and Rice 1990; Johnston 2004). Excavations at Chan No'ohol revealed “ephemeral non-mound structures” that were barely elevated above the ground surface and that sometimes even lacked facing stones (Yaeger and Robin 2004:157–159). The structures were interpreted as ancillary buildings. In contrast, the mounds visible on the ground surface were taller, always had facing stones, and were interpreted as residences. Most San Lorenzo structures were residential and had wattle and daub superstructures on low platforms composed of river cobbles, with some faced with limestone (Yaeger and Robin 2004:154). Even small mounds in rural Copan had platforms or stones outlining the perimeter of buildings (Gonlin 2007). At Komchen in the northern Maya lowlands, some Preclassic pole-and-thatch structures were built directly on the ground surface, but later houses and other buildings were constructed on piles of small stones or “chich” piles, as at other sites such as Sayil,

Becan, and Dzibilchaltun (Ringle and Andrews 1988:182–183). Diane Chase (1990) noted that kitchens at Santa Rita Corozal “resemble vacant terrain structures” and are often in plazas and sometimes marked by “barely raised lines of stone building pads.” Pole-and-thatch structures were likely common at Tikal for residences, workshops, kitchens, and more (Haviland 1985), an observation underscored by the dominance of modern Maya pole-and-thatch buildings (Wauchope 1938).

The lack of stone in the mangrove landscape of Punta Ycacos Lagoon may explain why pole-and-thatch structures at the Ch'ok Ayin site and elsewhere at the Paynes Creek Salt Works were built directly on the ground surface and lacked stone foundations or stones marking the perimeter of buildings. The Early Classic Maya settled along the shores of Punta Ycacos Lagoon, a large saltwater system in southern Belize (McKillop 2019). The sea floor in the lagoon system is anaerobic red mangrove peat (*Rhizophora mangle*). The peat was deposited as sea level rose during the Holocene. Peat forms when red mangroves grow vertically to keep their leaves above water, trapping detritus and other matter in their prop roots. Mangrove peat extends to 11 m in the inshore lagoon between the Belize barrier reef and the mainland coast in southern Belize (Cameron and Palmer 1995). Mangrove peat extends over 4 m below sea floor in Punta Ycacos Lagoon, the location of the Paynes Creek Salt Works (McKillop 2005a). The peat preserved building posts and other wood, leaving footprints of building walls in the sea floor. Rising seas later flooded the sites, leaving them underwater. The lower portions of the building posts were preserved below ground in red mangrove peat.

The lack of mounded remains in Punta Ycacos Lagoon may be due to wave action that spread soil when the sites were inundated by sea-level rise and submerged below the water. There are three earthen mounds in the mangrove flats near the lagoon that were mounds of soil discarded from the brine-enrichment process (Watson and McKillop 2019). Discard mounds of soil depleted of salt are common at brine-boiling sites elsewhere (Reina and Monaghan 1981; Sills 2016; Williams 2023) and were likely nearby most salt kitchens at the Paynes Creek Salt Works.

The Paynes Creek Salt Works

The Paynes Creek Salt Works developed in response to a need for dietary salt for the coastal and inland Maya in southern Belize during the Classic period population increase (McKillop 2002, 2005a, 2019; McKillop and Sills 2022, 2023). Beginning in the Early Classic, the Maya constructed pole-and-thatch buildings along the shores of a saltwater lagoon in southern Belize to make salt in specialized salt kitchens (McKillop 2019; McKillop and Sills 2025). They were similar to those used in the Maya highlands and elsewhere worldwide prehistorically and historically (Andrews 1983; Reina and Monaghan 1981). The location was desirable since the shallow lagoon was hyper-saline in the dry season compared to the nearby open sea, which reduced wood fuel needs for boiling brine in pots over fires to make salt. The brine-boiling pottery, briquetage, was abundant at the salt works. This was

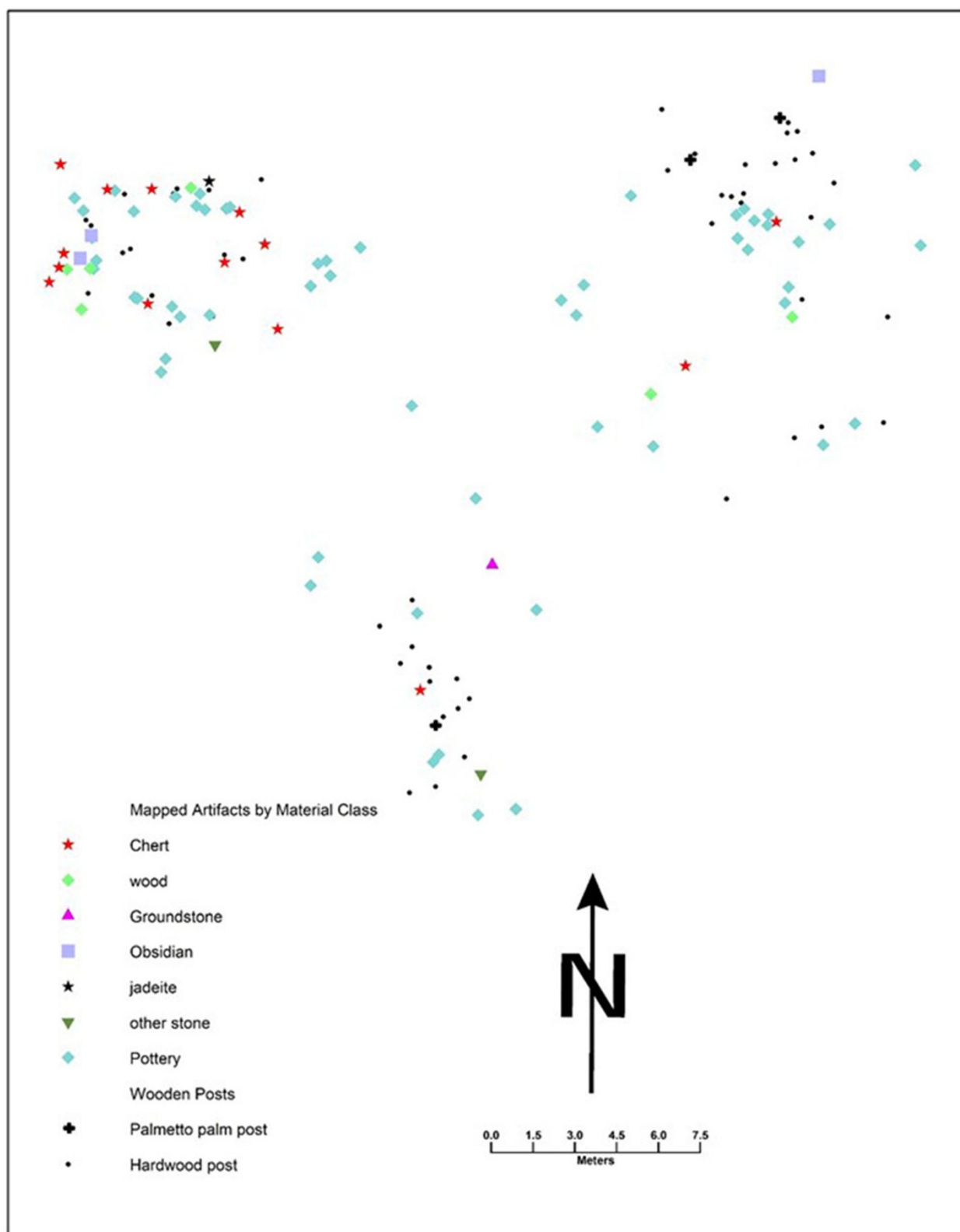


Figure 2. Map of wooden posts and artifacts by material class in the sea floor at the Ch'ok Ayin residential household group.

a common method of making salt along the coasts of Belize and Pacific Guatemala, with the long rainy season, in contrast to the arid north coast of the Yucatan of Mexico where solar evaporation was possible (Andrews 1983; Kepecs 2005).

Evaluation of ancient Maya objects found in pole-and-thatch buildings indicates that the Paynes Creek Maya participated in surplus household production of salt (Figure 1; McKillop and Sills 2016, 2022, 2023). The process resembled

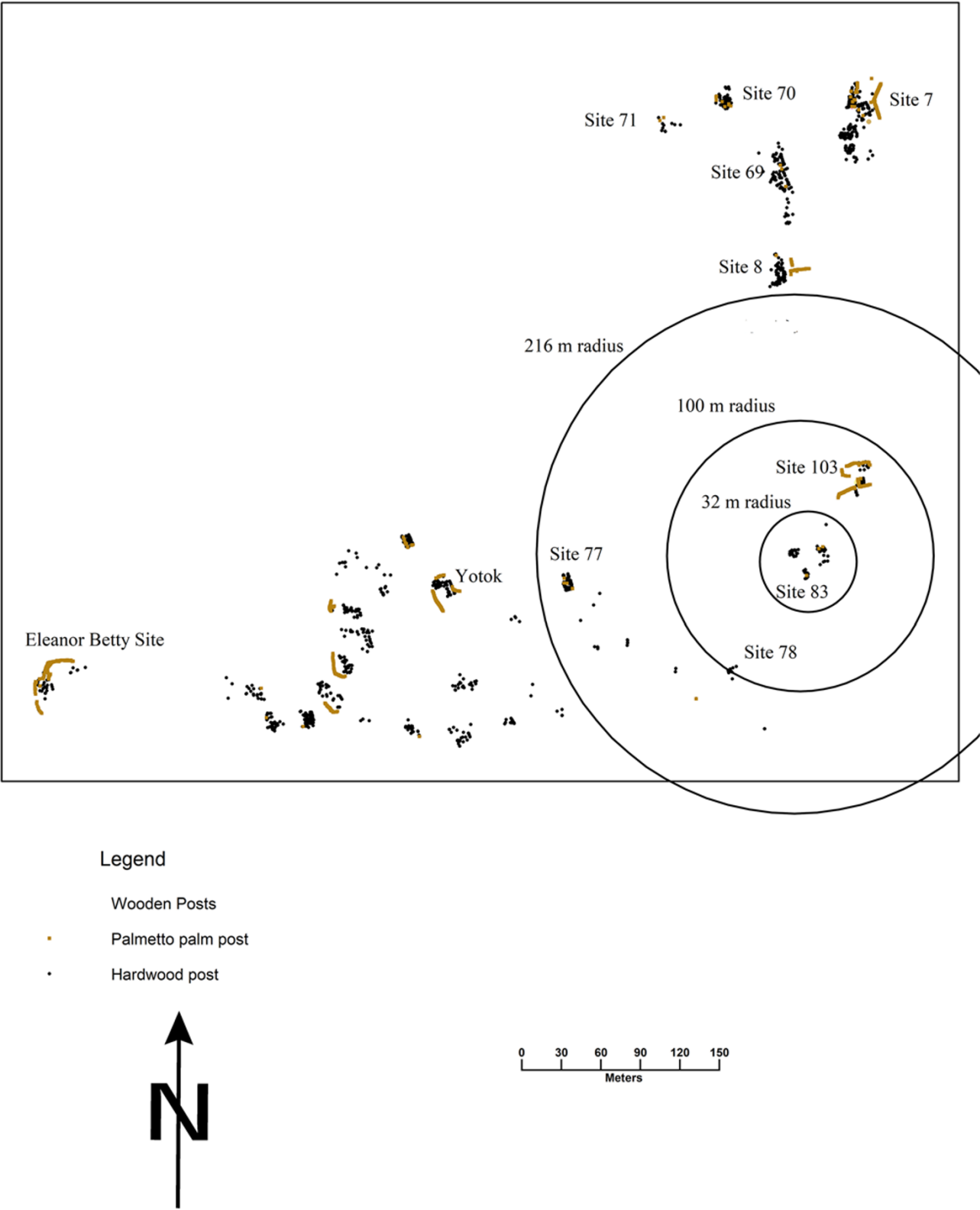


Figure 3. Map of underwater sites in Punta Ycacos Lagoon near the Ch'ok Ayin residential household group. Circles show 32 m minimum, 100 m average, and 216 m maximum distance between household groups, using distances in the study by Thompson et al. (2022).

salt making at Sacapulas, a community in the highlands of Guatemala, where families collected salty water from a salt spring (Reina and Monaghan 1981). Universally, the

salinity of salt water is enriched before brine boiling in order to reduce the boiling time and the amount of wood fuel (McKillop 2019; Williams 2023, Yankowski 2019). Brine



Figure 4. Photo of archaeologists and wire flags marking locations of wooden posts at the Ch'ok Ayin residential household group.

enrichment consists of pouring salty water on salty soil in raised containers and collecting the enriched brine below (Williams 2023). At Sacapulas, the families enriched the salinity by pouring salty water over salty soil in a raised container and collecting the saltier water below in a pot. Then the salt-enriched brine was transported to a family salt kitchen, where the brine was boiled in open clay bowls over a fire (Reina and Monaghan 1981). At the Eleanor Betty site, a wooden canoe repurposed as a container for salty soil had a clay funnel below to channel the enriched brine into a pot (McKillop et al. 2014). Elsewhere at the Paynes Creek Salt Works, soil depleted of salt was discarded, resulting in earthen mounds in the mangrove mud flats at Witz Na'ab and the Killer Bee sites (McKillop 2002:46–49; Watson and McKillop 2019). Charcoal identification from residences and salt kitchens at the Paynes Creek Salt Works indicates that a variety of tree species was used for fuel and for building construction from the coastal area (Robinson and McKillop 2013, 2014). Earthen mounds were likely present at the Paynes Creek Salt Works where sea-level rise eroded and flattened the mounds. Earthen discard mounds are common at the Placencia Lagoon Salt Works (Sills 2016) and elsewhere in Mesoamerica (Williams 2023).

The Paynes Creek salt workers boiled the enriched brine in pots over fires in specialized salt kitchens dedicated to brine boiling and associated activities including storing wood fuel, brine, and salt cakes (McKillop 2002, 2005a, 2019, 2021; McKillop and Sills 2016, 2022, 2023). Brine boiling is indicated by briquetage—the broken pottery vessels, along with their clay cylinder vessel supports with globs of clay at the top

where the vessel rested and a flat glob at the other end to form a base (McKillop 2002:Figure 3.1). Excavations at Yotok, Ek Way Nal, and Ta'ab Nuk Na revealed abundant briquetage and wood charcoal in salt kitchens (McKillop and Sills 2016, 2022, 2023). Excavation of a Late Classic salt kitchen at Yotok in the West Lagoon revealed that 98 percent of the pottery in Building A was briquetage (McKillop and Sills 2016). In contrast to the abundance of salt-making pottery at the salt kitchens, a residence at Ta'ab Nuk Na had a diversity of artifacts of various materials, except briquetage (McKillop and Sills 2022).

Settlement patterns at the paynes creek salt works

The Paynes Creek Salt Works include clusters of pole-and-thatch buildings, with most sites in an 8 km² area in Punta Ycacos Lagoon (McKillop 2019). There are two sites with earthen mounds in the black mangroves bordering the lagoon (Watson and McKillop 2019). For survey purposes in the lagoon, a site was defined as a cluster of wooden posts and associated artifacts on the sea floor that were separated from other clusters by at least 10 m. The buildings had decayed and rotted in the water but the portions of the wooden building posts below the sea floor in red mangrove peat were preserved. The posts barely protruded, if at all, above the sea floor. They were discovered by systematic flotation survey in teams, shoulder to shoulder traversing back and forth across the lagoon. Survey included viewing the sea floor and feeling it with hands flat on the sea floor. A wire survey flag was placed on the north side of each post in the sea floor for later

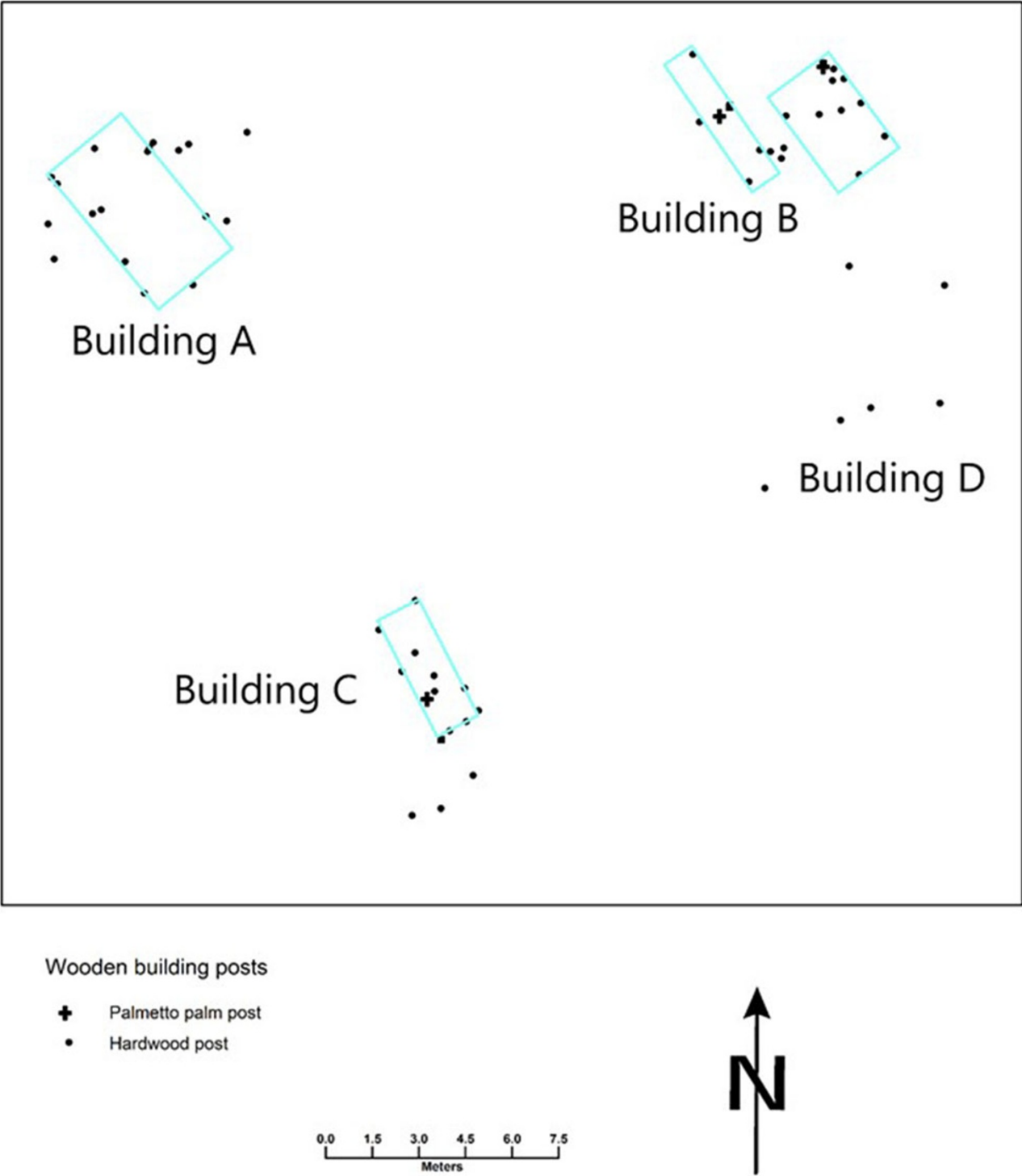


Figure 5. Map of wooden posts and building outlines.

mapping with a total station. The pattern of posts was not evident until the map data were downloaded to a computer and entered in the project GIS. Posts included hardwoods and palmetto-palm posts. The rough tops of hardwood posts were almost indistinguishable from the mangrove peat. Since the hardwood posts formed the walls of rectangular structures, finding the posts led to impromptu searches for patterns to follow walls and find building corners. The palmetto-palm

posts were more difficult to identify during survey since the interior of the posts had decayed leaving only a thin, hard bark. Since the palmetto-palm posts formed lines at the edge of sites, finding one or two of these posts initiated an opportunistic search following the line to find more posts. Both the systematic flotation survey and opportunistic searches following known posts led to the discovery of buildings at many sites. At some sites, mangrove peat had grown over the posts

and obscured them partly or entirely, so that the extent of buildings was undefined.

A total of 4,042 wooden posts have been mapped that mark the walls of structures at 70 underwater sites in Punta Ycacos Lagoon, with additional sites discovered but not yet mapped (McKillop 2019). Maps of structures, post diameters, and tree species for building construction are available elsewhere (McKillop 2019). Built directly on the ground without platforms or stone foundations, the pole-and-thatch buildings at the Paynes Creek Salt Works were likely as common in antiquity as they are in traditional Maya villages (Haviland 1985; Wauchope 1938; Wilk 1988). Although the mounded remains of artifacts which were associated with pole-and-thatch structures that perished are widespread, the lower portions of the actual pole-and-thatch buildings were preserved below the sea floor at underwater sites at the Paynes Creek Salt Works in Belize, including the Ch'ok Ayin site discussed here.

The Ch'ok Ayin site: A flooded Late Classic Maya household group

The distribution of pole-and-thatch buildings and associated objects at the Ch'ok Ayin site reveals a Late Classic (A.D. 550–800) residential group where a Maya household lived and worked at salt production and related activities (Figure 2). The Ch'ok Ayin site provides a model for other flooded coastal Maya sites in Belize and the Yucatan coast of Mexico that lack preserved wooden buildings, as well as providing an example of Classic Maya pole-and-thatch architecture. Not only are the Paynes Creek Salt Works invisible in the modern landscape, they are underwater and below the sea floor. Lacking the preservation of the wooden architecture, the Ch'ok Ayin site would be a distribution of objects embedded in the sea floor—likely a common occurrence in coastal areas subject to flooding from sea-level rise in the Maya area and beyond, and a sobering reminder of the fate of low-lying areas worldwide today.

The formation of mangrove peat mirrored sea-level rise, creating a flat sea floor in the lagoon that obscures the fact that buildings at Ek Way Nal and Ta'ab Nuk Na sites were constructed at different times from the Early Classic, through the Late Classic, and Terminal Classic periods (McKillop and Sills 2022, 2023, 2025). Only the portions of wooden posts in the peat below the sea floor were preserved.

Distances from the Ch'ok Ayin site to other nearby sites were compared with a large study in the Maya area which indicated that the distance between the center of each household group ranged from 32 to 216 m with a mean distance of 101 m (Thompson et al. 2022:15). Eight sites are located within 216 m of the Ch'ok Ayin site (Figure 3). Two of the sites—Site 103 and Site 77—have wooden structures defined by rectilinear distribution of posts. The other six sites lack well-defined wooden architecture. Site 103 and Site 78 are near the 100 m average distance between sites in Thompson et al.'s (2022) study, at 70 m and 103 m respectively. Site 8 is just beyond the maximum distance of 216 m. However, traveling by boat to other sites in the lagoon was likely easier than walking on overland trails between inland sites. The linear arrangement of many of the underwater sites in Punta Ycacos Lagoon

Table 1. AMS radiocarbon dates for building posts at the Ch'ok Ayin residential household group

Building	Post	Lab #	Age b.p.	Age a.d.
A	5	OS-175155	1290±10	a.d. 660±10
B	40	OS-175291	1300±15	a.d. 650±15
C	19	OS-175156	1300±10	a.d. 650±10
Area D	28	OS-175157	1250±10	a.d. 700±10

suggests they were located along former shorelines and that buildings were constructed farther from the shore as sea level rose (McKillop 2019).

The Ch'ok Ayin site measures 32 × 27 m in area (864 m²) as recorded by clusters of wooden posts and associated artifacts embedded in the sea floor. The site was discovered during flotation survey by systematically traversing back and forth across the lagoon. Wooden posts and artifacts were flagged for mapping (Figure 4). Survey resulted in the discovery of 56 hardwood posts and three palmetto-palm posts, and associated objects. Mapping the posts and artifacts revealed four clusters of posts demarcating the outlines of rectangular buildings (Figure 5). The long axes of the buildings are oriented approximately 32 degrees west of north, which is the same as most buildings at other sites in the lagoon (McKillop 2019:68–73, Figures 4.4–4.6).

Radiocarbon dating from four posts at the Ch'ok Ayin site provides construction dates for each building. The sample included post 5 from Building A, post 40 from Building B, post 19 from Building C, and post 28 from Area D (Table 1). The patterning of wooden posts and associated objects at the Ch'ok Ayin site reveals Building A was a residence, whereas Buildings B and C were salt kitchens, with brine enrichment in the open areas outside the buildings. The cluster of wooden posts for Building D does not define the outlines of a building.

Salt production: briquetage and storage jars

The salt-making pottery was locally made using granitic sand temper and clay available in the lagoon system near the salt works (McKillop 2019). The briquetage belongs to the Punta Ycacos Unslipped ceramic type as defined for the Paynes Creek Salt Works (McKillop 2002:54–72, Figures 3.3–3.8). Brine enrichment took place outside buildings, as indicated by the presence of clay funnels outside Buildings A (VVV) and C (Y). Pieces of two funnels were in Building B (II, PPP), and another two partial funnels in Building D (BB and FFF; Figures 6, 7, Table 2). A small bowl with multiple holes on the base and sides may have been a sieve or funnel (object AA).

Brine-boiling jars, bowls, and basins with solid clay cylinder vessel supports (objects AAAA, EE, and QQ) are at the site (Figures 7, 8). They resemble those described for Stingray Lagoon and other sites in the lagoon, where a jar or bowl was supported by three solid clay cylinder supports over a fire (McKillop 2002:Figures 3.1, 3.10–3.14). The cylinders were placed at an angle in a glob of clay with a flat base (McKillop 2002:Figure 3.15). A glob of clay was formed over the top of the cylinder with a concave surface on which the pot rested (McKillop 2002:Figures 3.16–3.18). The recovery of a spout

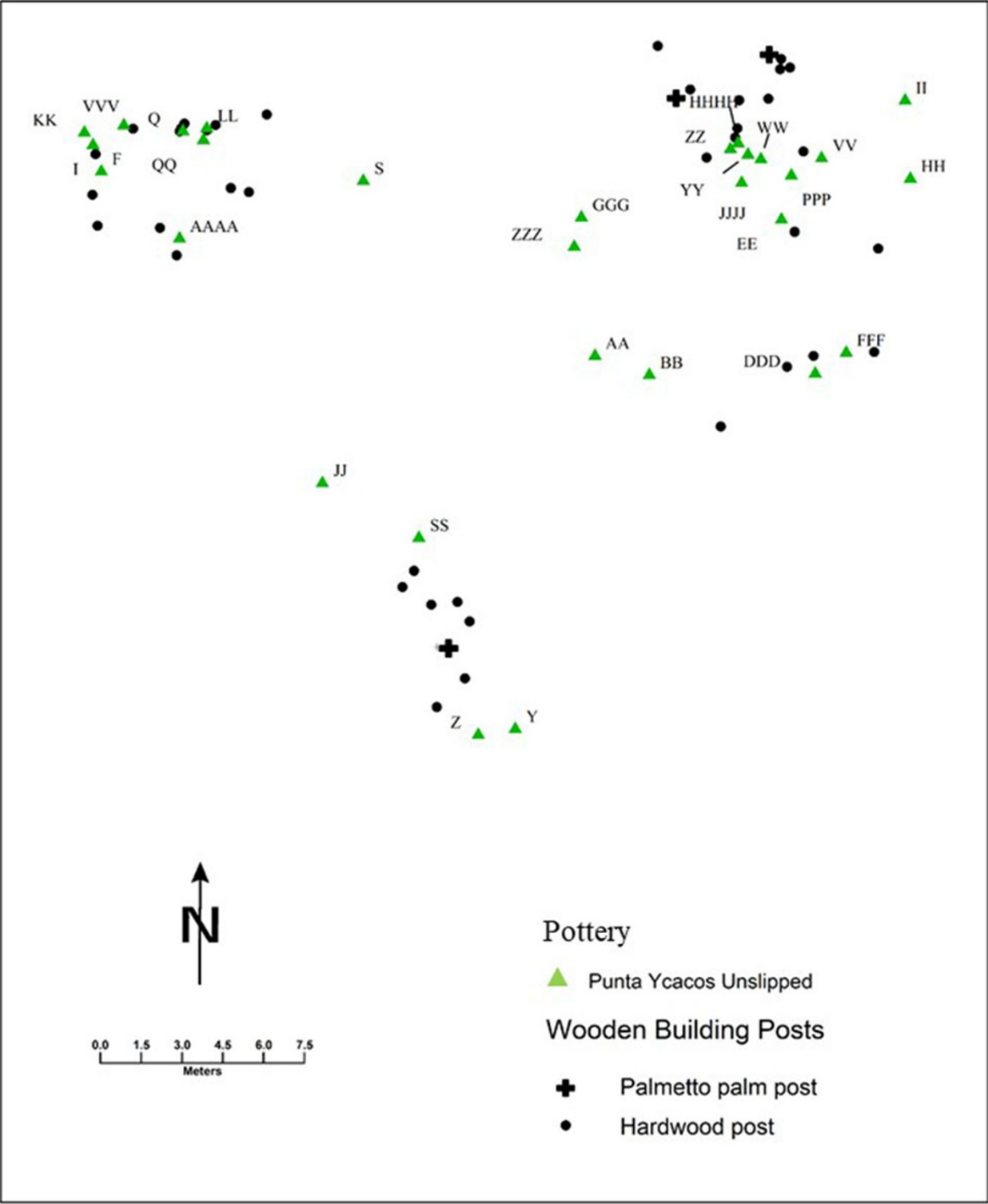


Figure 6. Map of wooden posts and Punta Ycacos Unslipped pottery.

from large jar (I) and a small pot with a spout (GGG) at the Elon site suggests pouring brine into a dozen or more pots as the water evaporates with spouted vessels as at Sacapulas. Alternatively, the Maya at the Ch'ok Ayin site used calabash bowls such as those preserved in peat at Stingray Lagoon site and the Eleanor Betty site (McKillop 2019:130).

With a variety of bowl and jar vessel forms, some may have been used for brine boiling and others for hardening the loose, wet salt into salt cakes. At Sacapulas, a couple of dozen open bowls were used for brine boiling, with the bowls turned upside down to harden the salt inside the bowls, which were broken to remove the salt cakes (Reina and Monaghan

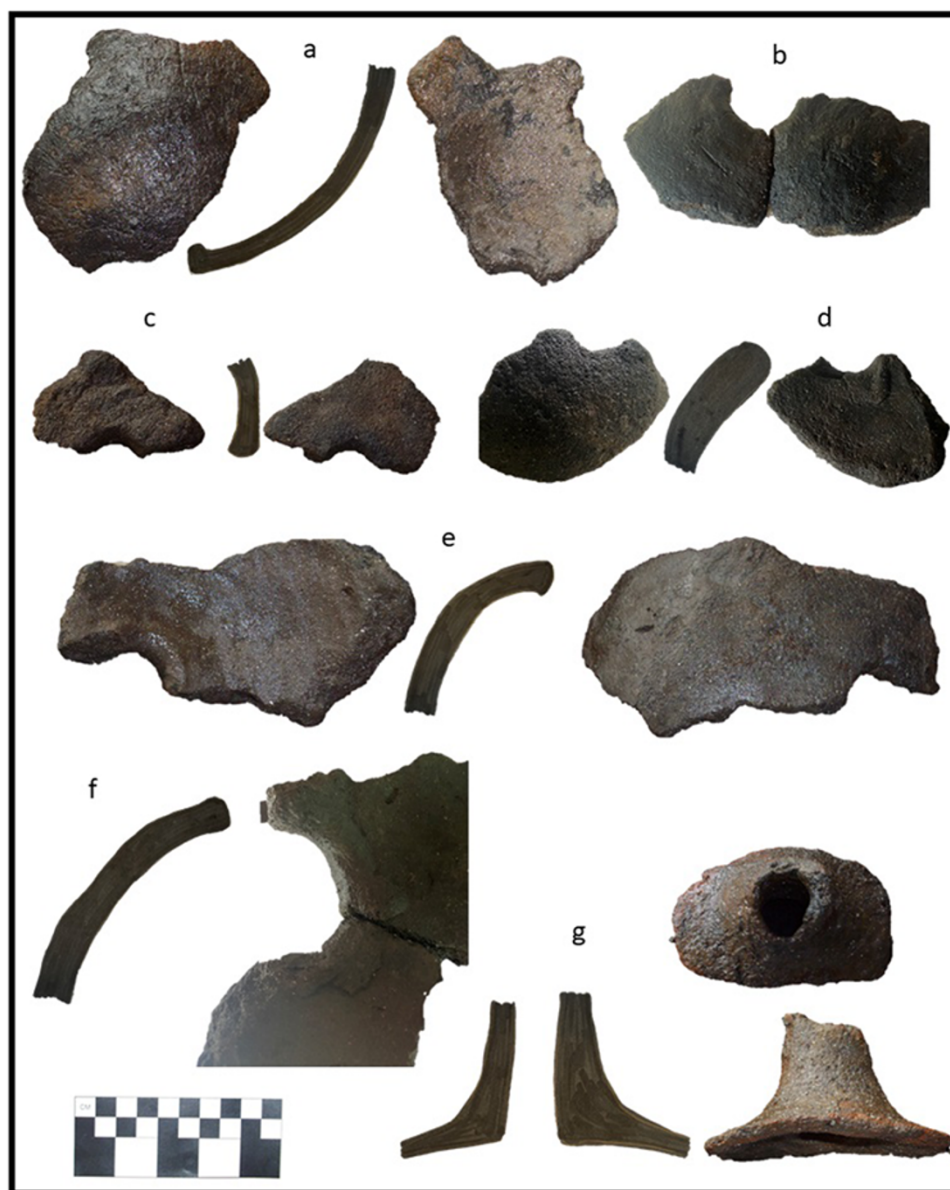


Figure 7. Fragments of clay funnels used to channel brine from a container laden with salty soil that had salty water poured through. For map locations, see Figure 6. For descriptions, see Table 2. (a) 83 Y, (b) 83 PPP, (c) 83 BB, (d) 83 FFF, (e) 83 II, (f) 83 VVV, (g) 83 I.

1981). In some cases at Sacapulas, loose wet salt was poured into fiber or clay forms to make hardened cakes and then the pots were broken to reveal the hardened salt cake. That process results in broken vessels at the salt kitchens. In contrast, at a salt works on Bohol Island in the Philippines, brine was hardened in jars, and then transported in the same jars for regional exchange (Yankowski 2019). In that case, the jars are absent from the production locale but instead found at the consumer locations.

Other objects made from locally available clay and temper materials not directly used in salt making were found at the Ch'ok Ayin site, including small incense burners or “*candeleros*” (Q, WW, DDD, and SS) and a burner lid (VV) from Building B (Figure 6).

Containers used to store brine and salt used in the brine-enrichment and boiling process include plain and decorated

jars (Figures 8, 10). Warrie Red water jars are red-slipped, with some having incised, impressed, and “unit-stamped” decoration (using a tool to stamp a decoration) on the vessel shoulder. Defined for the Paynes Creek Salt Works (McKillop 2002:77–86, Figures 3.27–3.31), the technique of impressing designs from a stamp on Warrie Red resembles Remate Red from Lubaantun (Hammond 1975), Tinaja Red from Seibal and Altar de Sacrificios, and elsewhere (McKillop 2002:82–83). Warrie Red jars are found in Buildings A and B at the Ch'ok Ayin site and include the reverse “S” unit-stamp motif (L, Figure 10H) and horizontal incised lines (H, BBB2, Figure 10a and 10d). Mangrove Unslipped pottery, defined for the Paynes Creek Salt Works (McKillop 2002:72–77, Figures 3.22–3.24), is an undecorated water storage jar, typically much larger than Warrie Red jars. There are several other jars (Figure 8a–d), including two in Building A (BBB1 and OOO), one in Building

Table 2. Sea-floor artifacts from the Ch'ok Ayin residential household group (Site 83). Artifacts A-MM were mapped in 2008. Artifacts NN-LLLL were mapped in 2023.

Site	Artifact	Type	Description	Year
83	A	obsidian	obsidian distal blade	2008
83	AA	Punta Ycacos	bowl	2008
83	B	obsidian	midsection blade	2008
83	BB	Punta Ycacos	funnel	2008
83	C	chert	large flake	2008
83	CC	wood artifact	pencil with hole	2008
83	D	wood artifact	pointed stick	2008
83	DD	chert	adze	2008
83	E	obsidian	complete blade	2008
83	EE	Punta Ycacos	base	2008
83	F	unknown	jar rim, striated	2008
83	FF	chert	biface	2008
83	G	wood artifact	canoe paddle blade	2008
83	GG	ocarina	ocarina	2008
83	H, HH	Warrie Red, Punta Ycacos	jar, cup	2008
83	I	Punta Ycacos	spout	2008
83	II	Punta Ycacos	funnel	2008
83	J	chert	adze	2008
83	JJ	Punta Ycacos	basin rim	2008
83	K	chert	chopper pounder	2008
83	KK	Punta Ycacos	bowl	2008
83	L	Warrie Red	jar, reverse S	2008
83	LL	Punta Ycacos	handle	2008
83	M	chert	adze	2008
83	MM	pottery	sherd	2008
83	N	Belize Red	potsherd disk	2008
83	O	Belize Red	pedestal base	2008
83	P	chert	chopper pounder	2008

(Continued)

Table 2. (Continued.)

Site	Artifact	Type	Description	Year
83	Q	Punta Ycacos	candelero, flat base	2008
83	R	Belize Red	bowl	2008
83	S	Punta Ycacos	funnel	2008
83	T	Mangrove	jar	2008
83	U	Belize Red	pedestal base	2008
83	V	metate leg	leg	2008
83	W	Mangrove	jar	2008
83	X	chert	large blade	2008
83	Y	Punta Ycacos	funnel	2008
83	Z	Punta Ycacos	bowl	2008
83	NN	chert	stem point	2023
83	OO	Warrie Red	Warrie rim, circle stamp	2023
83	PP	wood artifact	paddle blade	2023
83	QQ	Punta Ycacos	small bowl	2023
83	RR	Warrie Red	jar, tear drop punctate	2023
83	SS	Punta Ycacos	candelero	2023
83	TT	wood artifact	small pendant	2023
83	UU	perforated pebble	drilled pebble	2023
83	VV	Punta Ycacos	basin	2023
83	WW	Punta Ycacos	candelero, flat base	2023
83	XX	unknown jar	large, square lip	2023
83	YY	Punta Ycacos	shallow bowl	2023
83	ZZ	Punta Ycacos	base with cylinder	2023
83	AAA	Belize Red	base	2023
83	BBB1, BBB2	unknown Warrie Red	grooved square lip, incised	2023
83	CCC	Belize Red	base	2023

(Continued)

Table 2. (Continued.)

Site	Artifact	Type	Description	Year
83	DDD	Punta Ycacos	candelero, flat base	2023
83	EEE	wood artifact	wooden stick	2023
83	FFF	Punta Ycacos	funnel	2023
83	GGG	Punta Ycacos	small jar with spout	2023
83	HHH	Belize Red	bowl	2023
83	III	unknown jar	with mangrove oysters	2023
83	JJJ	pumice float	worked pumice	2023
83	LLL	ocarina	ocarina	2023
83	MMM	Warrie Red	circle punctate	2023
83	NNN	unknown bowl	slipped, outflared square lip	2023
83	OOO	unknown jar	large square lip	2023
83	PPP	Punta Ycacos	funnel	2023
83	QQQ	Punta Ycacos	candelero, flat base	2023
83	RRR I	Belize Red	outflared bowl	2023
83	SSS	chert	distal unifacial stem point	2023
83	TTT	unknown jar	applique fillet, square lip	2023
83	UUU	chert	reworked chopper	2023
83	VVV	Punta Ycacos	funnel	2023
83	WWW	ocarina	ocarina	2023
83	XXX	chert	unifacial stem point	2023
83	YYY	chert	broken chopper pounder	2023
83	ZZZ	Punta Ycacos	incurved bowl	2023
83	AAAA	Punta Ycacos	base with cylinder	2023
83	BBBB	unknown jar	slipped neck, hard surface	2023
83	CCCC	Warrie Red	lines, tear drop punctate	2023

(Continued)

Table 2. (Continued.)

Site	Artifact	Type	Description	Year
83	DDDD	chert	flake with cortex	2023
83	EEEE	Warrie Red	jar rim, punctate	2023
83	FFFF	Belize Red	notched ridge slipped bowl	2023
83	GGGG	chert	flake with cortex	2023
83	HHHH	Punta Ycacos	shallow bowl, near post 40	2023
83	IIII	jadeite	axe fragment, near post 45	2023
83	JJJJ	Punta Ycacos	shallow bowl, posts 31 + 41	2023
83	KKKK	ground-stone	metate leg, near post 45	2023
83	LLLL	chert	flake NW of artifact N	2023

B (XX), and two in Building C (T and W). Artifacts T and W have square lips, which is a Terminal Classic trait. Another water storage vessel at the Ch'ok Ayin site is a large, striated jar with a square lip and outflared rim (F).

Belize Red pottery and ocarinas

Commonly found in residential households at Caracol and sites in the upper Belize River valley where it was made, Belize Red pottery was also found at the Ch'ok Ayin site and elsewhere at the Paynes Creek Salt Works (McKillop 2019:Table 7.2). Belize Red is easy to identify from the volcanic ash temper that creates a smooth and powdery surface, even with small fragments and weathered surfaces so that there were only traces of red slip (McKillop 2002:86–90, Figures 3.35–3.36). Belize Red is found outside Buildings A and B and in the open area between them (Figures 9, 11, Table 2). The vessels include a flat-bottomed bowl (HHH, Figure 11a), a sag-bottomed bowl with basal notching (FFFF, Figure 11c), a bowl (RRR1, Figure 11d), a pedestal base (O, Figure 11b), and a perforated potsherd disk with incised lines (location O, Figure 11e) near Building A. There is a Belize Red bowl with a plain basal angle (R) and another pedestal base (U) from the open area between Buildings A and B (Figure 9). There are a Belize Red body sherd with traces of red slip (AAA) and a Belize Red base (CCC) near Building B. Belize Red dates from the Late to the Terminal Classic at Caracol, with some traits temporally distinctive (Chase and Chase 2012:8, Figures 2, 3). The large footed plate with outflaring sides, a sag bottom, is standard for the later part of the Late Classic (A.D. 550–800) at Caracol (Chase and Chase 2012:Figure 2g). Toward the end of the Terminal Classic, small footed plates or bowls, including some with notched flanges and incised decoration, along with pedestal base bowls, come into use and were found at Caracol (Chase and Chase 2012:8). The small collection of Belize Red sherds from the Ch'ok Ayin residential group includes forms



Figure 8. Miscellaneous jars, briquetage, and ocarina. For map locations, see Figure 6 for 83 QQ and 83 AAAA. See Figure 9 for 83 WWW. Others not on map. For descriptions, see Table 2. (a) 83 F, (b) 83 V, (c) BBBI, (d) 83 OOO, (e) 83 QQ, (f) 83 AAAA, (g) 83 WWW.

that are generally Late Classic and that may continue into the Terminal Classic.

Ocarinas are figurine whistles found in household deposits for domestic ritual during the Classic period (Halperin 2014). They are common at some sites at the Paynes Creek Salt Works, notably Stingray Lagoon (McKillop 2002:Figure 3.39–3.40) and at Ek Way Nal where most are helmeted male figures or women with children (McKillop and Sills 2022:Figure 16). They resemble mold-made ocarinas produced at Lubaantun, where there are ocarina molds (Hammond 1975, 2017). There are four fragmentary ocarinas at the Ch'ok Ayin site. There are two ocarina fragments (MM and GG) in Building B, a fragment in Building A showing kneeling legs and a shield (LLL), and an elaborately dressed male figure (WWW) from Building A (Figures 8g, 9).

Stone objects

There are many stone tools, mainly associated with Building A and most made from chert (Figures 12, 13, Table 2). They include formal tools made from high-quality material with characteristic banding of the northern Belize chert-bearing region. The formal tools resemble artifacts from Colha (Shafer and Hester 1983). There are 11 chert objects associated with Building A. Most are along the exterior building wall, with two outside. J (Figure 13c) is to the northwest and SSS is to the southeast of the building. The Building A chert objects include three unifacial stemmed points (SSS, NN, and XXX, Figure 13a), two chert adzes (J and M), three chopper pounders (K, P, and YYY, Figure 13e), and flakes (C, DDDD, and GGGG, Figure 13f). A biface (FF, Figure 13b) is associated with Building B, a large blade likely part of a unifacial stemmed

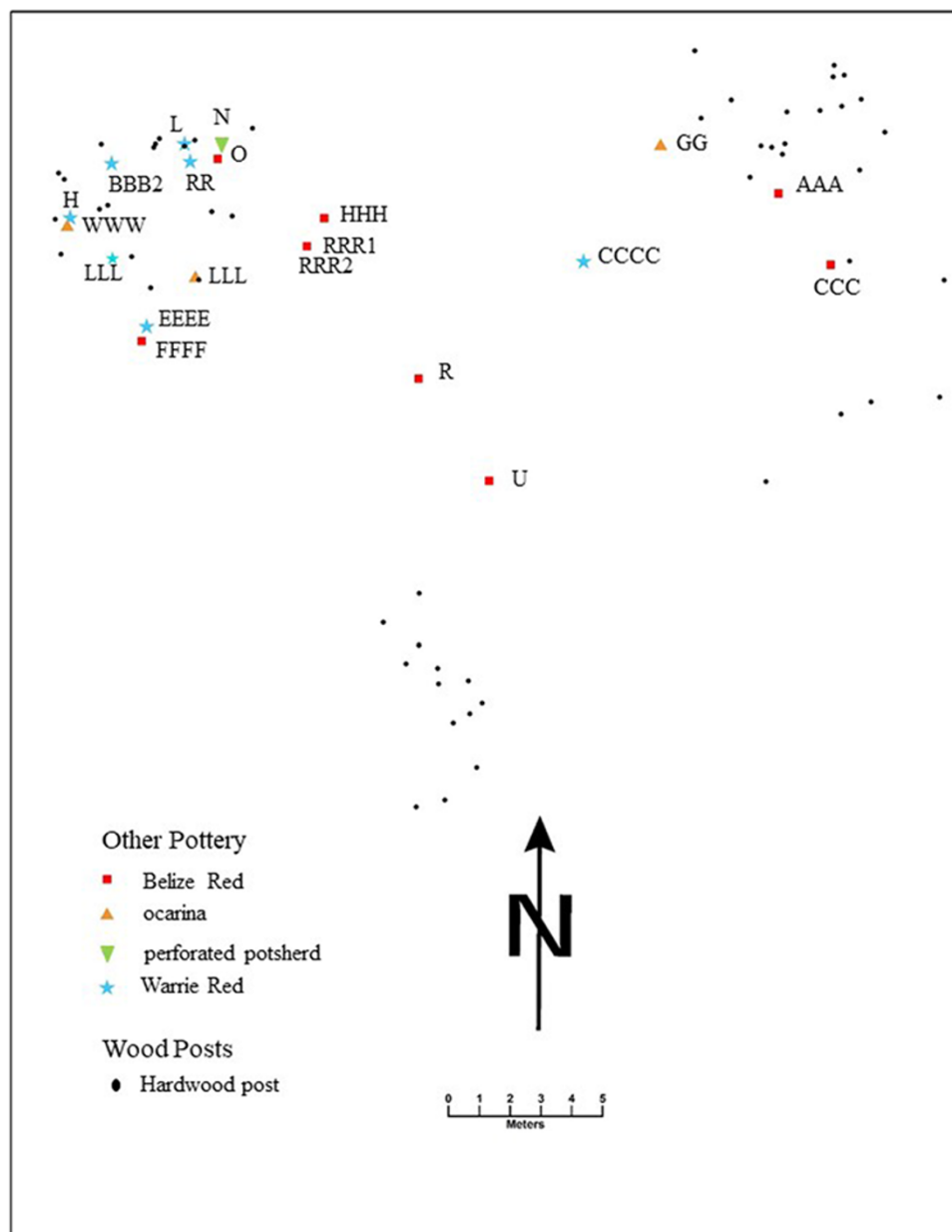


Figure 9. Map showing locations of Warrie Red and Belize Red ceramics. (Map includes LLL ocarina and LLL Warrie Red distinguished by symbols).

point (X) with Building C, and a chert adze (DD, Figure 13d) with Building D.

Use-wear analysis of chert tools from other sites at the Paynes Creek Salt Works indicates most were used to process fish and/or meat and a minority to cut or whittle wood (McKillop and Aoyama 2018). The use-wear study also indicated that the morphology of the tools did not identify their use: for example, the pointed ends of unifacial stemmed points were unused, but the sides showed multiple use areas for cutting or scraping. More than salt making took place in Building A, which has evidence for woodworking and/or fish processing as well as use as a residence.

There are three obsidian blades, including two in Building A (object A and object E) and one in Building B (object B). E is a complete blade, visually identified to the El Chayal source in highland Guatemala. Object A is the distal end of

a blade, visually identified to the Ixtepeque source. B is a mid-section of an obsidian blade, visually identified to the Ixtepeque source.

Other objects indicate fishing and domestic activities. Ground stone objects include a broken pumice fishing float (object JJJ), located just outside Building A to the south-east. There is a drilled pebble fishing weight (UU) outside Building C to the southeast. There is a fragmentary jadeite axe (IIII) from Building A. There is a metate leg (V) in the open area between the buildings. Metates are common in households at Maya sites, but they are also associated with salt production at Sacapulas (Reina and Monaghan 1981), so their presence may support one or both uses at the Ch'ok Ayin site. At Sacapulas, corn was used in brine enrichment and in brine boiling. During the brine-enrichment process, when a drop of corn dough floated in



Figure 10. Warrie Red jars and other incised jars. For map locations, see Figure 9, except for 83 MMM and 83 OO which are not on the map. For descriptions, see Table 2. (a) 83 BBB2, (b) 83 CCCC, (c) 83 MMM, (d) 83 H, (e) 83 OO, (f) 83 EEEE, (g) 83 RR, (h) 83 L.

the brine it was deemed sufficiently salty. Corn dough was added to the brine before pouring into the bowls to prevent the salt from sticking to the walls and to make the salt fine-grained.

Wood objects

Wood objects and building posts were preserved in the red mangrove peat matrix of the Elon site below the sea floor (Figure 14, Table 2). Parts of two wooden canoe paddle blades were discovered nearby one another on the west side of Building A (G) (McKillop 2019:Figure 6.15) and outside the same building (PP). A small carved wood pendant with a hole drilled at one end was discovered on the north side of Building A (TT). A small wood object shaped like pencil, with a hole drilled in the center (CC) was found near Building D.

Discussion

The type and distribution of objects associated with the wooden buildings at the Ch'ok Ayin site indicate that a variety of activities took place. The artifacts mapped on the sea floor were likely moved from their original use locations (see Binford 1981; Schiffer 1975). Sweeping material to the edge of rooms or outside may explain the concentration of artifacts in those areas in contrast to the center of buildings, especially for Building A. Artifacts may have been cached in the rafters along walls and then fallen to the floor, as described for the Ceren site that was covered by volcanic tephra (Sheets et al. 2015). The concentration of artifacts with buildings in contrast to the paucity of material outside supports the interpretation that the activities that resulted in the artifact distributions took place nearby. The construction of the buildings and their use was at the same time, supporting the

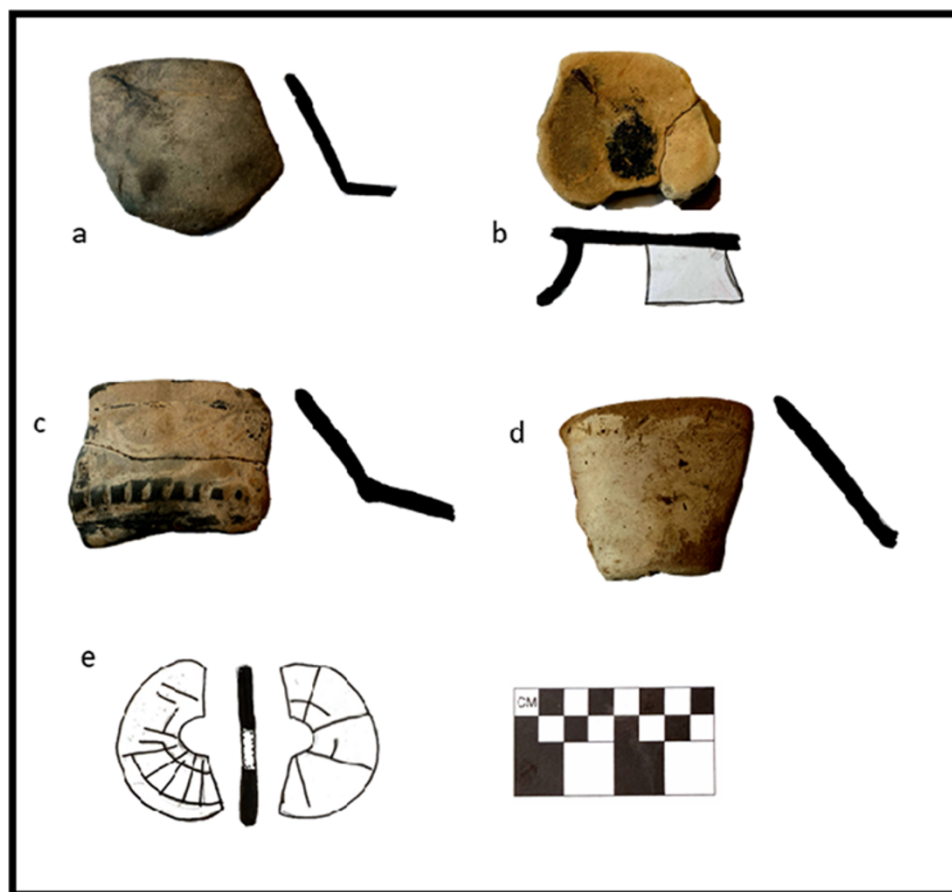


Figure 11. Belize Red pottery. For map locations, see [Figure 9](#). For descriptions, see [Table 2](#). (a) HHH, (b) O, (c) FFFF, (d) RRR1, (e) N.

interpretation that the buildings were not used for refuse from earlier times.

The objects found in the buildings most likely reflect the activities that took place in and around those buildings, for several reasons: The diagnostic artifacts are similar. There are different types of artifacts associated with the different buildings that reflect different activities, supported by ethnographic models of salt production at Sacapulas and elsewhere (Reina and Monaghan 1981). The Ch'ok Ayin site is isolated from other residential plaza groups and there are no artifacts in the intervening areas. Distinct patterns of artifacts on the sea floor at other lagoon sites also have defined building uses, including examples at Tab Nuk Na, Pok Tot, and Ek Way Nal. Excavations in building A at Pok Tot revealed 89 percent of the artifacts were briquetage from brine boiling, suggesting the activity took place in the building (McKillop and Sills 2016), supported by the model of Sacapulas salt kitchens with separate residences.

The Belize Red serving bowls and ocarinas in Building A, along with other items typically found in Maya households, point to this building being a residence for the salt makers. Additional evidence for residential use is the perforated potsherd disk in Building A (N). The spindle whorl has incisions from spinning on the red slip ([Figures 9, 11](#)). The interior of Building A is empty, with objects along the exterior wall and under the roof overhang area 1–2 m outside the building. The residents of Building A kept the interior

of the structure clean, since it was a living area. Any items stored in the rafters, on building posts, or on the wall fell when the building collapsed, resulting in the distribution of objects along the exterior walls, as described for the Ceren site (Sheets et al. 2015). Broken bowls from fire-hardening salt at Sacapulas are stored inside the salt kitchens and then dumped outside the building (Reina and Monaghan 1981). This may have been the case at the Ch'ok Ayin site. Most of the chert tools are outside Building A, suggesting their use outdoors, perhaps for fish or meat processing or for wood-working as indicated by use-wear study of other similar chert tools elsewhere at the Paynes Creek Salt Works (McKillop and Aoyama 2018).

Salt production was associated with the other buildings. Building C and Area D, lacking ocarinas and Belize Red pottery, were involved in salt production. Building C may have been a salt kitchen. The distribution of wooden posts and the occurrence of funnels in Area D suggest the area may have been used for brine enrichment. The number of funnels indicates that brine enrichment was a frequent activity at the Ch'ok Ayin site. The variety of Punta Ycacos vessels include large jars, bowls, and basins suitable for brine boiling. In addition, there are smaller bowls suitable for hardening wet salt into fire-hardened cakes for storage and trade.

The Late Classic Maya household at the Ch'ok Ayin site enriched the salinity of lagoon water, boiled the brine to make salt, and were engaged in other activities related to

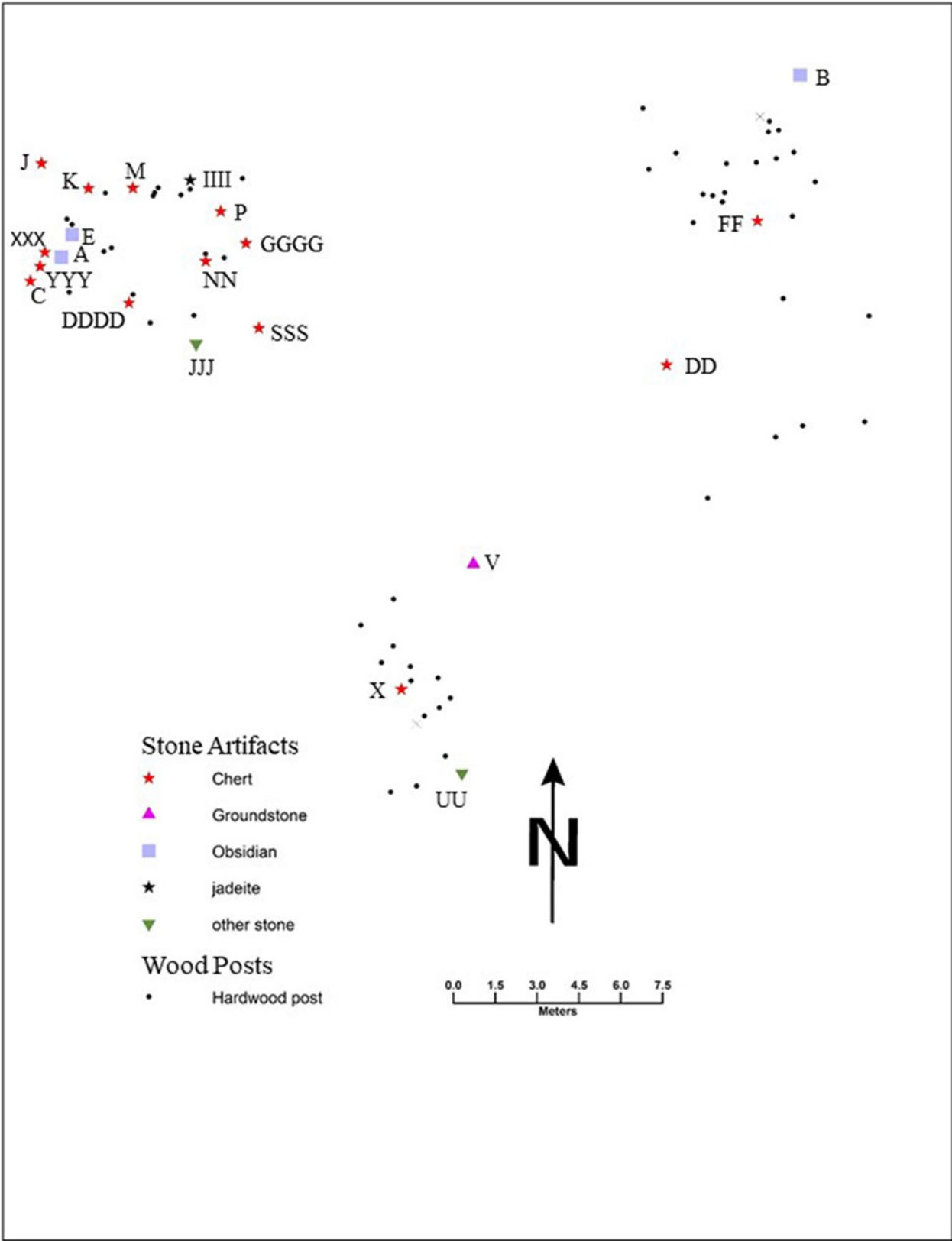


Figure 12. Map showing locations of stone artifacts.

salt production and subsistence. The salt pots may have been made at Site 103, about 37 m to the north, where a wooden pottery-making paddle was found (McKillop 2019:Figure 6.5).

The Maya at the Ch’ok Ayin site certainly communicated with salt makers at other household salt works, with a residence dated to the Late Classic at Ta’ab Nuk Na 330 m to

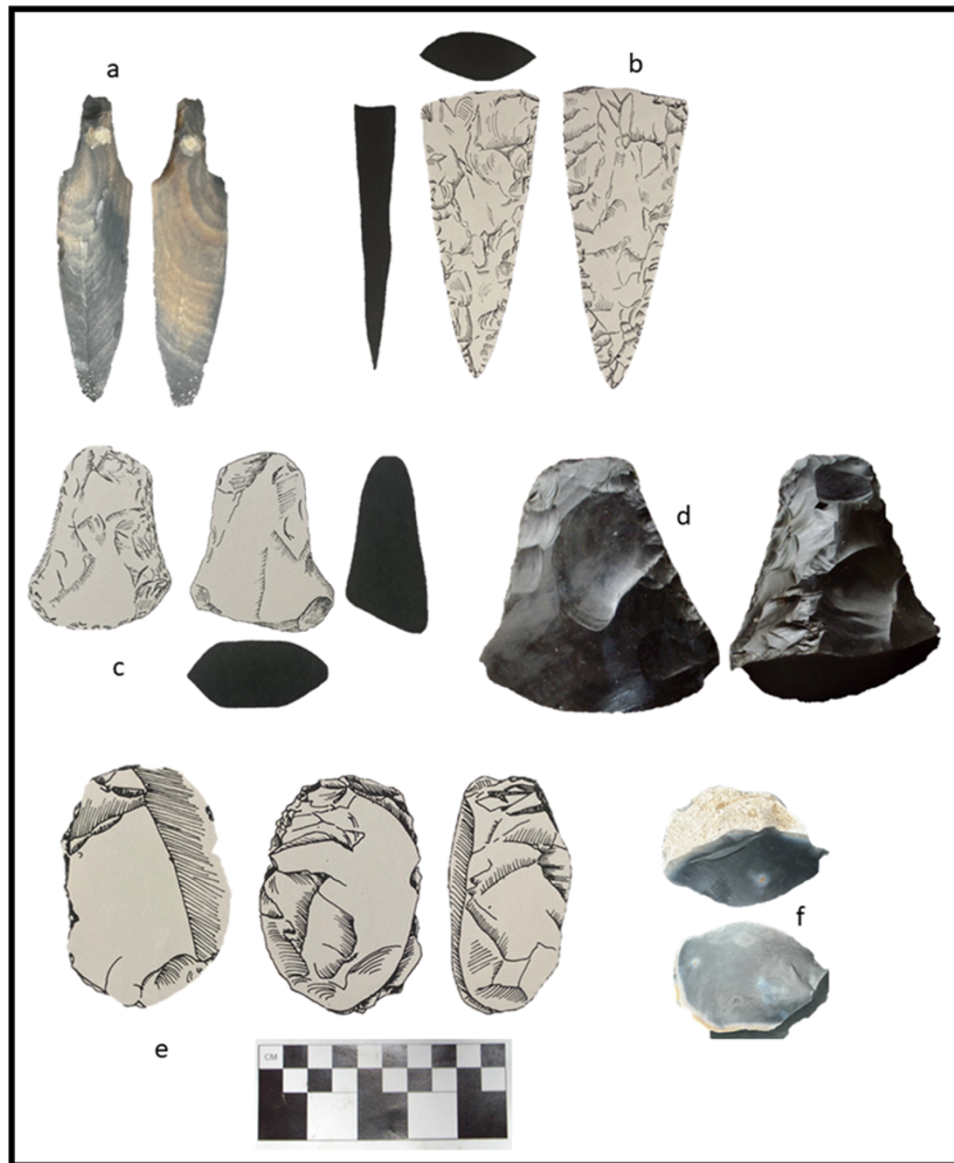


Figure 13. Chert artifacts. For map locations, see [Figure 12](#). For descriptions, see [Table 2](#). (a) 83 XXX, (b) 83 FF, (c) 83 J, (d) 83 DD, (e) 83 P, (f) 83 DDDD.

the north. Sites 8, 69, and 70 have Late Classic Warrie Red and Belize Red pottery from the sea floor. The abundance of formal chert stone tools sets Ch'ok Ayin apart from the other household salt works in the area, with most of the chert from the residence, Building A. Although it is tempting to suggest the stone tools were used for processing fish, as elsewhere (McKillop and Aoyama 2018) and the spindle whorl from Building A used to spin cotton for fishing nets or lines, the stone tools may have been used for cutting wood and the spindle whorl for making cotton clothes. In any case, the number of formal chert tools in Building A indicates a focused activity using stone tools that did not occur elsewhere at the site.

The Maya at the Ch'ok Ayin site were able to obtain pottery and stone objects from diverse origins, indicating that the people were integrated into several economic production and distribution networks through regional marketplace

trade. This was similar to the small Maya communities of Ceren in El Salvador (Sheets et al. 2015), San Lorenzo and Chan No'ohol (Yaeger and Robin 2004), Uxbenka and Ixkuku'il (Thompson and Prufer 2021), or outlying areas of Caracol (Chase et al. 2015). The Maya at the Ch'ok Ayin site had access to a wide variety of local and imported goods and resources, despite their low economic status as represented by the pole-and-thatch buildings constructed directly on the ground surface—buildings that would be “invisible” in the modern landscape of mounded remains of house mounds visible on lidar or traditional field survey. They extended to the south in the Guatemala highlands (for obsidian) and the Motagua River valley (for jadeite and greenstones). Economic ties extended north to the upper Belize River valley (for Belize Red pottery) and to the northern Belize chert-bearing zone with its main production locale at Colha (for formal chert tools). Economic ties also extended to inland locations in

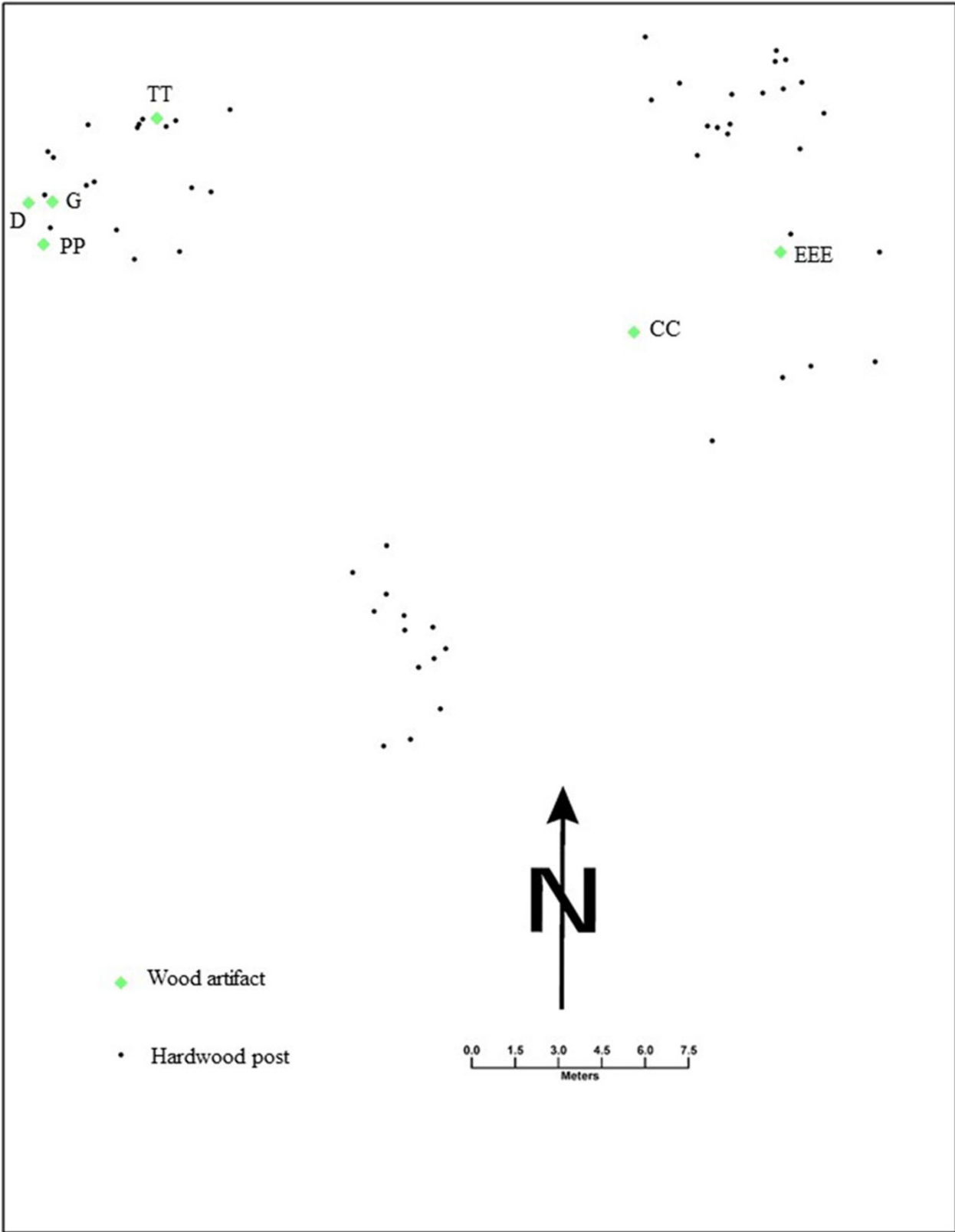


Figure 14. Map showing locations of wooden artifacts. For descriptions, see [Table 2](#).

southern Belize for ocarinas, and perhaps farther inland to the Pasion and Petexbatun regions of Guatemala (for Warrie Red “unit-stamped” jars).

Radiocarbon dating places building construction at Ch’ok Ayin in the Late Classic, although the ceramics span a longer time, and extend into the Terminal Classic. The diverse forms

of Belize Red are comparable to those dated throughout the Late and Terminal Classic at Caracol (Chase and Chase 2012) and resemble forms found at Ek Way Nal in the East Lagoon at the Paynes Creek Salt Works (McKillop and Sills 2023). Shared unit-stamping motifs on Warrie Red and the presence of ocarinas also link the two sites. The presence of square lips and spouted jars at the Ch'ok Ayin site are Terminal Classic traits elsewhere.

Using the pole-and-thatch buildings provides an alternative for estimating population based on mound counts or residential groups, for which the Ch'ok Ayin site would have zero people. The Ch'ok Ayin site was a single-component residential household group with several buildings, including the Building A residence and other structures. They represented a household involved in surplus production of salt and related activities of an estimated five people. Using mound counts for the 100 sites with wooden architecture at the salt works (McKillop 2019) would indicate a population of zero. However, some sites have multiple wooden structures and not all buildings were constructed at the same time. Radiocarbon dating each of the 10 pole-and-thatch building at Ek Way Nal and Ta'ab Nuk Na sites indicated that different buildings were constructed at different times from the end of the Early Classic to the Terminal Classic (McKillop and Sills 2022, 2023). The type and variability of associated objects indicated the use of each building at these sites, which includes residences and workshops dated to different times. Future radiocarbon dating of each building at the Paynes Creek Salt Works would provide a better estimate of building construction dates upon which to base population estimates.

Conclusions

The Ch'ok Ayin residential group at the Paynes Creek Salt Works provides information on the Late Classic Maya domestic economy of what is regarded the lowest rank of Maya architecture—pole-and-thatch structures built directly on the ground surface. The outstanding preservation of wooden building posts at the salt works provides the only examples of Classic Maya pole-and-thatch architecture. The associated objects indicate one building was a residence, along with other structures used as salt kitchens, and outdoor activities. Far from being impoverished, the Ch'ok Ayin householders participated in the marketplace economy of the Late Classic southern lowlands, obtaining goods and resources from nearby and distant locations, including painted pottery, jadeite, and obsidian.

Sea-level rise during the Holocene flooded what was land between the current coast of Belize and the barrier reef. Hundreds of mangrove and sand cays developed in shallow water in the inshore lagoon. Maya settlement along the coast began by the Middle Preclassic (600 B.C.) at Ich'ak'tun, a shell midden at the mouth of the Deep River (McKillop and Robertson 2019). Settlement and salt production at Cerros (Robertson 2016) began in the Late Preclassic (300 B.C.–A.D. 250), with the major stone architecture constructed later during the Late Preclassic. Moho Cay, a Late Classic trading port at the mouth of the Belize River, was inundated (McKillop 2004). Island sites with coral rock foundations of

buildings in the Port Honduras in southern Belize flooded by sea-level rise include Wild Cane Cay, Frenchman's Cay, Green Vine Snake, and Pelican (McKillop 2002:Table 5.3, 2005b, 2024). Settlement elsewhere along the coast of Belize and the Yucatan peninsula of Mexico impacted by rising seas includes Canbalam (Dahlin et al. 1998) and sites on the south coast of Belize that are hidden in the modern landscape (McKillop 2024). Only at the Paynes Creek Salt Works were the wooden posts from pole-and-thatch buildings preserved. Flooded coasts hold sites that are underrepresented in settlement studies, population estimates, and considerations of household livelihood. As sea levels continue to rise, low-lying coastal areas in the Maya area and beyond, worldwide, will disappear from the visible landscape.

Data availability statement. Data are available in the manuscript and by contacting the corresponding author.

Acknowledgements. The research is based on field research carried out in 2023, supported by NSF Grant 826653, with permits from the Belize Institute of Archaeology, and field assistance from Cher Foster and John Young.

Funding statement. The research was funded by NSF grant 826653.

Competing interests. The authors have no competing interests.

References

- Andrews, Anthony P.
1983 *Maya Salt Production and Trade*. University of Arizona Press, Tucson.
- Binford, Lewis R.
1981 Behavioral Archaeology and the Pompeii Premise *Journal of Anthropological Research* 37 195–208
- Cameron, Cornelia C., and Curtis A. Palmer
1995 The Mangrove Peat of the Tobacco Range Islands, Belize. *Atoll Research Bulletin* 431:1–32.
- Canuto, Marcello A., Francisco Estrada-Belli, Thomas G. Garrison, Stephen D. Houston, Mary Jane Acuña, Milan Kováč, Damien Marken, Philippe Nondédéo, Luke Auld-Thomas, Cyril Castanet, David Chatelain, Carlos R. Chiriboga, Tomáš Drápela, Tibor Lieskovský, Alexandre Tokovinine, Antolín Velasquez, Juan C. Fernández-Díaz, and Ramesh Shrestha
2018 Ancient Lowland Maya Complexity as Revealed by Airborne Laser Scanning of Northern Guatemala. *Science* 361:eaau0137.
- Chase, Adrian S. Z.
2017 Residential Inequality among the Ancient Maya: Operationalizing Household Architectural Value at Caracol, Belize. *Research Reports in Belizean Archaeology* 14:31–39.
- Chase, Adrian S. Z., Elyse D. Z. Chase, Diane Z. Chase, and Arlen F. Chase
2024 Population History for Caracol, Belize: Numbers, Complexity, and Urbanism. In *Ancient Mesoamerican Population History: Urbanism, Social Complexity, and Change*, edited by Adrian S. Z. Chase, Arlen F. Chase, and Diane Z. Chase, pp. 67–88. University Press of Florida, Gainesville.
- Chase, Arlen F., and Diane Z. Chase
2012 Belize Red Ceramics and Their Implications for Trade and Exchange in the Eastern Maya Lowlands. *Research Reports in Belizean Archaeology* 9:3–14.
- Chase, Arlen F., and Diane Z. Chase
2014 Ancient Maya Houses, Households, and Residential Groups at Caracol, Belize. *Research Reports in Belizean Archaeology* 11:3–17.
- Chase, Arlen F., Diane Z. Chase, and Adrian S. Z. Chase
2024 Archaeological Population Studies in Mesoamerica. In *Ancient Mesoamerican Population History: Urbanism, Social Complexity,*

- and Change, edited by Adrian S. Z. Chase, Arlen F. Chase, and Diane Z. Chase, pp. 5–41. University Press of Florida, Gainesville.
- Chase, Arlen F., Diane Z. Chase, Richard E. Terry, Jacob M. Horlacher, and Adrian S. Z. Chase
2015 Markets among the Ancient Maya: The Case of Caracol, Belize. In *The Ancient Maya Marketplace: The Archaeology of Transient Space*, edited by Eleanor King, pp. 226–250. University of Arizona Press, Tucson.
- Chase, Diane Z.
1990 The Invisible Maya: Population History and Archaeology at Santa Rita Corozal. In *Precolumbian Population History in the Maya Lowlands*, edited by T. Patrick Culbert and Don S. Rice, pp. 199–214. University of New Mexico Press, Albuquerque.
- Culbert, T. Patrick, and Don S. Rice
(editors) 1990 *Precolumbian Population History in the Maya Lowlands*. University of New Mexico Press, Albuquerque.
- Dahlin, Bruce H., Anthony P. Andrews, Timothy Beach, Clara Bezanilla, Patrice Farrell, Sheryl Luzzadder-Beach, and Valerie McCormick
1998 Punta Canbalam in Context: A Peripatetic Coastal Site in Northwest Campeche, Mexico. *Ancient Mesoamerica* 9:1–15. <https://doi.org/10.1017/S0956536100001814>
- Estrada-Belli, Francisco, Laura Gilibert-Sansalvador, Marcello A. Canuto, Ivan Sprajc, and Juan Carlos Fernandez-Díaz
2023 Architecture, Wealth and Status in Classic Maya Urbanism Revealed by Airborne Lidar Mapping. *Journal of Archaeological Science* 157:105835. <https://doi.org/10.1016/j.jas.2023.105835>
- Foster, Cheryl, Heather McKillop, and E. Cory Sills
2023 Human-Environment Interactions at Ta'ab Nuk Na, a Submerged Maya Salt Works Site in Belize. *Ancient Mesoamerica* 35: 388–400. <https://doi.org/10.1017/S0956536123000196>
- Gonlin, Nancy
2007 Ritual and Ideology Among Classic Maya Rural Commoners at Copán, Honduras. In *Commoner Ritual and Ideology in Ancient Mesoamerica*, edited by Nancy Gonlin and Jon C. Lohse, pp. 83–121. University Press of Colorado, Boulder.
- Halperin, Christina
2014 *Maya Figurines: Intersections between State and Household*. University of Texas, Austin.
- Hammond, Norman D.
1975 *Lubaantun: a Classic Maya Realm*. Monographs of the Peabody Museum of Archaeology and Ethnology 2. Harvard University, Cambridge.
- Hammond, Norman D.
2017 Boxing Day: A Maya Polychrome Pot from Southern Belize. *Antiquity* 91:e6.
- Haviland, William A.
1970 Tikal, Guatemala, and Mesoamerican Urbanism. *World Archaeology* 2:186–198.
- Haviland, William A.
1972 Estimates of Maya Population. Comments on Thompson's Comments. *American Antiquity* 37:261–262.
- Haviland, William A.
1982 Where the Rich Folks Lived: Deranging Factors in the Statistical Analysis of Tikal Settlement. *American Antiquity* 47:427–429.
- Haviland, William A.
1985 *Excavations in Small Residential Groups of Tikal, Groups 4F-1 and 4F-2*. Tikal Report 19. University Museum, University of Pennsylvania, Philadelphia.
- Hiquet, Julien
2024 Estimation of Early Classic Maya population: Methodological challenges and modeling at Naachtun, Guatemala. *Latin American Antiquity* 35:91–110.
- Inomata, Takeshi, Daniela Triadan, Flory Pinzón, Melissa Burham, José Luis Ranchos, Kazuo Aoyama, and Tsuyoshi Haraguchi
2018 Archaeological Application of Airborne LiDAR to Examine Social Changes in the Ceibal Region of the Maya Lowlands. *PLOS One* 13(2):e0191619.
- Johnston, Kevin J.
2004 The “Invisible” Maya: Minimally Mounded Residential Settlement at Itzán, Petén, Guatemala. *Latin American Antiquity* 15:145–175.
- Kepecs, Susan M.
2005 Mayas, Spaniards, and Salt: World Systems Shifts in Sixteenth-Century Yucatán. In *The Postclassic to Spanish-Era Transition in Mesoamerica: Archaeological Perspectives*, edited by Susan Kepecs and Rani T. Alexander, pp. 117–137. University of New Mexico Press, Albuquerque.
- McKillop, Heather
2002 *Salt: White Gold of the Ancient Maya*. Gainesville: University Press of Florida.
- McKillop, Heather
2004 The Classic Maya Trading Port of Moho Cay. In *Archaeology of the Upper Belize Valley*, edited by James Garber, pp. 257–272. University Press of Florida, Gainesville.
- McKillop, Heather
2005a Finds in Belize Document Late Classic Maya Salt Making and Canoe Transport. *Proceedings of the National Academy of Sciences* 102:5630–5634.
- McKillop, Heather
2005b *In Search of Maya Sea Traders*. Texas A&M University Press, College Station.
- McKillop, Heather
2019 *Maya Salt Works*. University Press of Florida, Gainesville.
- McKillop, Heather
2021 Salt as a Commodity or Money in the Classic Maya Economy. *Journal of Anthropological Archaeology* 62:101277.
- McKillop, Heather
2024 Flooded Mangrove Landscapes Hide Ancient Maya Coastal Sites in Belize. *The Journal of Island and Coastal Archaeology* 19:484–504. <https://doi.org/10.1080/15564894.2022.2163323>
- McKillop, Heather, and Kazuo Aoyama
2018 Salt and Marine Products in the Classic Maya Economy from Use-Wear Study of Stone Tools. *Proceedings of the National Academy of Sciences* 115:10948–10952.
- McKillop, Heather, George Harlow, April Sievert, C. Wayne Smith, and Michael C. Wiemann
2019 Demystifying Jadeite: Underwater Maya Discovery at Ek Way Nal, Belize. *Antiquity* 93:502–518.
- McKillop, Heather, and Robin Robertson
2019 Ich'ak'tun: An Early Maritime Shell Midden Site on the South Coast of Belize. *Research Reports in Belizean Archaeology* 16:323–332.
- McKillop, Heather, and E. Cory Sills
2016 Spatial Patterning of Salt Production and Wooden Buildings Evaluated by Underwater Excavations at Paynes Creek Salt Work 74. *Research Reports in Belizean Archaeology* 13:229–237.
- McKillop, Heather, and E. Cory Sills
2022 Household Salt Production by the Late Classic Maya: Underwater Excavations at Ta'ab Nuk Na. *Antiquity* 389:1232–1250. <https://doi.org/10.15184/aqy.2022.106>
- McKillop, Heather, and E. Cory Sills
2023 Briquetage and Brine: Living and Working at the Classic Maya Salt Works of Ek Way Nal, Belize. *Ancient Mesoamerica* 34:24–46. <https://doi.org/10.1017/S0956536121000341>
- McKillop, Heather, and E. Cory Sills
2025 Earliest Ancient Maya Salt Production in Southern Belize: Excavations at Jay-yi Nah. *Antiquity* 99:187–202. <https://doi.org/10.15184/aqy.2024.186>
- McKillop, Heather, E. Cory Sills, and Vincent Cellucci
2014 The Ancient Maya Canoe Paddle and the Canoe from Paynes Creek National Park, Belize. *Research Reports in Belizean Archaeology* 11:297–306.
- McKillop, Heather, E. Cory Sills, and Jessica Harrison
2010 A Late Holocene Record of Sea-Level Rise: The K'ak' Naab' Underwater Maya Site Sediment Record, Belize. *ACUA Underwater Archaeology Proceedings* 2010:200–207.
- Prufer, Keith M., Moyes, Holley, Culleton, Brandon, Kindon, Andrew, and Kennet, Douglas J.

- 2011 Formation of a Complex Polity on the Eastern Periphery of the Maya Lowlands. *Latin American Antiquity* 22 199–223
- Pyburn, K. Anne
1990 Settlement Patterns at Nohmul: Preliminary Results of Four Excavation Seasons. In *Precolumbian Population History in the Maya Lowlands*, edited by T. Patrick Culbert and Don S. Rice, pp. 183–198. University of New Mexico Press, Albuquerque.
- Reina, Robert E., and John Monaghan
1981 The Ways of the Maya: Salt Production in Sacapulas, Guatemala. *Expedition* 23:13–33. <https://www.penn.museum/sites/expedition/the-ways-of-the-maya/>, accessed 2 May 2025.
- Ringle, William M., and E. Wyllys Andrews IV
1988 Formative Residences at Komchen, Yucatan, Mexico. In *House and Household in the Mesoamerican Past*, edited by Richard R. Wilk and Wendy Ashmore, pp. 171–197. University of New Mexico Press, Albuquerque.
- Robertson, Robin
2016 Red Wares, Zapatista, Drinking Vessels, Colonists, and Exchange at Cerro Maya. In *Perspectives on the Ancient Maya of Chetumal Bay*, edited by Debra S. Walker, pp. 125–148. University Press of Florida, Gainesville.
- Robin, Cynthia
(editor) 2012 *Chan: An Ancient Maya Farming Community*. University Press of Florida, Gainesville.
- Robinson, Mark, and Heather McKillop
2013 Ancient Maya Wood Selection and Forest Exploitation: A View from the Paynes Creek Salt Works, Belize. *Journal of Archaeological Science* 40:3584–3595.
- Robinson, Mark, and Heather McKillop
2014 Fueling the Ancient Maya Salt Industry. *Economic Botany* 68:96–108.
- Schiffer, Michael B
1975 Archaeology as Behavioral Science *American Anthropologist* 77 836–848
- Shafer, Harry J., and Thomas R. Hester
1983 Ancient Maya Chert Workshops in Northern Belize. *American Antiquity* 48:519–543.
- Sheets, Payson, Christine Dixon, David Lentz, Rachael Egan, Alexandria Halmacher, Venicia Slotten, Rocio Herrera, and Celine Lamb
2015 The Sociopolitical Economy of an Ancient Maya Village: Cerén and Its Sacbe. *Latin American Antiquity* 26:341–361.
- Sills, E. Cory
2016 Re-evaluating the Ancient Maya Salt Works at Placencia Lagoon, Belize. *Mexicon* 38:69–74.
- Thompson, Amy E., and Prufer, Keith M.
2021 Household Inequality, Community Formation, and Land Tenure in Classic Period Lowland Society. *Journal of Anthropological Method and Theory* 28 1276–1313.
- Thompson, Amy E., John P. Walden, Adrian S. Z. Chase, Scott R. Hutson, Damien B. Marken, Bernadette Cap, Eric C. Fries, M. Rodrigo Guzman Piedrasanta, Timothy S. Hare, Sherman W. Horn III George J. Micheletti, Shange M. Montgomery, Jessica Munson, Heather Richards-Rissetto, Kyle Shaw-Müller, Traci Ardren, Jaime J. Awe, M. Kathryn Brown, Michael Callaghan, Claire E. Ebert, Anabel Ford, Rafael A. Guerra, Julie A. Hoggarth, Brigitte Kovacevich, John M. Morris, Holley Moyes, Terry G. Powis, Jason Yaeger, Brett Houk, Keith M. Prufer, Arlen F. Chase, and Diane Z. Chase
2022 Ancient Lowland Maya Neighborhoods: Average Nearest Neighbor Analysis and Kernel Density Models, Environments, and Urban Scale. *PLOS One* 17(11):eD275916.
- Watson, Rachel, and Heather McKillop
2019 A Filtered Past: Interpreting Salt Production and Trade Models from Two Remnant Brine-Enrichment Mounds at the Ancient Maya Paynes Creek Salt Works, Belize. *Journal of Field Archaeology* 44:40–51.
- Wauchope, Robert
1938 *Modern Maya Houses*. Carnegie Institution of Washington Publication 502. Washington, DC: Carnegie Institution.
- Wilk, Richard R.
1988 Maya Household Organization: Evidence and Analogies. In *Household and Community in the Mesoamerican Past*, edited by Richard R. Wilk and Wendy Ashmore, pp. 135–152. University of New Mexico Press, Albuquerque.
- Williams, Eduardo
2023 Salt-Making in Mesoamerica: Production Sites and Tool Assemblages. *Ancient Mesoamerica* 34:1–23. <https://doi.org/10.1017/S0956536121000031>
- Yaeger, Jason, and Robin, Cynthia
2004 Heterogeneous Hinterlands: The Social and Political Organization of Commoner Settlements near Xunantunich, Belize. *Ancient Maya Commoners* Lohse, John G., and Valdez, Jr, Fred 147–173 Tucson: University of Arizona Press
- Yankowski, Andrea
2019 Salt Making and Pottery Production: Community Craft Specialization in Albuquerque, Bohol, Philippines. *Ethnoarchaeology: Journal of Archaeological, Ethnographic, and Experimental Studies* 11:134–154.