Salt and marine products in the Classic Maya economy from use-wear study of stone tools

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Microscopic study of the edges of Late to Terminal Classic Maya (AD 600–900) chert stone tools from the Paynes Creek Salt Works, Belize, indicates most tools were used for cutting fish or meat or working hide, which was unexpected, given the virtual absence of fish or other animal remains at this large salt-production complex. Use-wear study shows that a minority of stone tools have edge-wear from woodworking. Our study suggests that salting fish was a significant activity at the salt works, which corresponds to Roman, Chinese, and other East Asian civilizations, where salt and salted fish were critical components of food storage, trade, and state finance. Based on analogy with modern Maya salt producers at Sacapulas, Guatemala, we provide estimates of the amounts of salt and salted fish produced at the Paynes Creek Salt Works and the implications for the Classic Maya economy. Salt cakes and salted fish were preserved commodities that could be stored and traded in the marketplace.

Classic Maya | salting fish | marketplace trade | stone tool use-wear | salt archaeology

Salt production at the Paynes Creek Salt Works, Belize, was clear from the abundant briquetage—the pottery vessels used to boil brine over fires to make salt associated with wooden structures (Fig. 1) (1, 2). Excavations inside the salt kitchens indicated 90–98% of the artifacts were briquetage, underscoring the focus on making salt—a basic biological necessity that was transported inland to Classic Maya cities (3). Salt making likely was carried out as surplus household production, which was the fundamental economic unit for production of goods and resources by elites and commoners by the Late Classic period (AD 600–800) (4–8). Surplus household products were taken to marketplaces within large cities such as Caracol and Tikal and to marketplaces at other communities (4, 5, 8, 9). Marketplaces have been identified by the presence of market stalls, soil chemistry, and artifact patterns (5).

The Paynes Creek Salt Works were located on the shores of a coastal lagoon for access to seasonally, hypersaline water from solar evaporation. Salt production was similar to other places, including Sacapulas, Guatemala, where brine from a salt spring is boiled in salt kitchens located near residences (pp 56–61 and 89–93 in ref. 10; figure 5.13 in ref. 11; 12; 13). The locations of the Paynes Creek salt-workers' residences are unknown, but were seasonal or permanent buildings near the salt kitchens or at a nearby coastal community such as Wild Cane Cay (Fig. 1). After their abandonment, the salt works were flooded by sea-level rise recorded in red mangrove peat (*Rhizophora mangle*), a proxy for sea-level rise (14–16). The peat preserved wooden building posts that had been driven into the ground. The acidic peat dissolved limestone temper in pottery and calcium carbonate in mangrove oyster shells and would not have preserved fish or other bones (2, 17).

The salt works include 110 known underwater sites concentrated within a 5 km^2 area. Each site is defined by a cluster of wooden posts and artifacts embedded in the sea floor separated from other sites by at least 10 m. Although mangroves cover parts of many sites, posts demarcate outlines of rectangular pole and thatch structures at some sites (figure 2 in ref. 18). The structures may have been open on the sides, but walls would have provided better protection from rain for brine boiling and for storing pots of brine, salt, and wood fuel, as at Sacapulas. Modern Maya pole and thatch structures in southern Belize and elsewhere have supporting posts dug into the ground, with additional wall posts resting on the ground surface (pp 62 and 65 and plate 17 in ref. 19). The number of wooden structures at each site varies from 1 to 10. Sea-floor survey and excavations yielded Late and Terminal Classic (AD 600–900) pottery (1–3, 17, 18). Some sites have multiple buildings, with wooden posts mapped at 70 sites and known for 30 more sites.

Materials and Methods

We report a study of use-wear on 20 chert stone tools mapped during sea-floor survey. Diagnostic Late to Terminal Classic Belize Red incised dishes and Warrie Red unit-stamped jars (figures 3.28–3.29 and 3.35 in ref. 1) were mapped at the sites. Radiocarbon dates confirm the ages of the sites (Table 1). Posts mark the outlines of rectangular structures at site 77 (5 × 6 m and 2.5 × 4 m), including a chert tool from structure 77B (table 1 and figure 2 in ref. 18).

The artifacts were examined under high-power microscopy to identify patterns of striations and polish that indicate a variety of activities, based on previous use-wear experiments using a range of worked materials on replicas of Maya stone tools (20–22; *SI Appendix*, Figs. S1 and S2). The instrument used in the study was a metallurgical microscope (Olympus BX60M) with 50–500× magnification and an incident-light attachment. Magnification of 200× was most frequently used. Use-wear patterns were documented with an Olympus photomicrographic system PD-20 attached to a digital camera.

All data are available in the manuscript or the *SI Appendix*. The artifacts are housed at Louisiana State University.

Significance

The Classic Maya (AD 300–900) technology of producing salt by boiling brine in pots over fires in wooden buildings at the Paynes Creek Salt Works, Belize, is consistent with this common and productive method elsewhere in the world in antiquity, historic, and modern times. We report the surprising results of a use-wear study of the edges of chert stone tools that indicates most were used for cutting fish or meat or scraping hides. Like the ancient Roman, Asian, and other civilizations, the Classic Maya evidently produced salt and salted fish—storable commodities for marketplace trade.

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Fig. 1. Map of the Maya area with sites mentioned in the text.

Results

Microscopic use-wear was observed on all artifacts (Table 2). Fourteen artifacts were used to cut fish or meat, six to scrape hides, four to cut wood, and six to whittle wood (Figs. 2–4 and Table 3). Following Vaughan (23), each portion of an artifact with interpretable use-wear was counted as an independent use zone (IUZ), for a total of 54 (Figs. 2–4 and *SI Appendix*, Table S1). The number of IUZ per artifact ranges from one to five, including one to four different activities per tool. Single-use artifacts include seven for cutting fish or meat (Fig. 2), two for scraping hides (Fig. 3 *A* and *B*), and one for whittling wood (Fig. 4*B*). The three stemmed bifaces and the oval biface were used only for cutting fish or meat, as were two of the three stemmed macroblades (Table 3). Other tools were multipurpose. Evidence of two activities was noted on three artifacts used to cut fish or meat and scrape hides (Fig. 3 *C*–*E*), one artifact to cut and whittle wood (Fig. 4*A*), and one artifact to cut fish or meat and whittle wood (Fig. 4*C*). Evidence for three activities was noted on two artifacts used to whittle and cut wood and to cut fish or meat (Fig. 4 *C*–*E*). One artifact was used for all four activities (Fig. 4*F*). Chert tools were used for a limited number of activities, in contrast to the many uses of chert tools at the inland Maya city of Aguateca, Guatemala (24–26).

Comparing tool use by site, there is no woodworking at site 72 where five tools were used to cut fish or meat and/or scrape hides (Table 4). In contrast, the three tools from site 70 were used for woodworking. Some activities were focused in particular structures (Tables 2 and 4). The four artifacts from structure B at site 72 were used to cut fish or meat, with two also used to scrape hides. At site 60, structure A artifacts were used to cut fish or meat, structure B to cut and whittle wood, and structure C to cut fish or meat and scrape hides.

Discussion

Surplus household production of commodities for marketplace trade was an important means for the distribution of goods and resources in the Maya area from the Late Classic period (4–6, 8) through the Postclassic (27). Marketplaces made nonlocal goods and resources, including highly crafted goods, widely available to Classic Maya householders (4). Stone tools, pottery, and other goods produced at local workshops were available at marketplaces, as were obsidian, marine shell, and other resources from farther away (28). Marketplaces included salt in the repertoire of commodities as indicated by a depiction of a salt vendor accompanied by the glyph for salt, along with depictions of other vendors and their wares, painted on the exterior of a building at Calakmul, Mexico (29). Transport of coastal salt inland to Maya cities is suggested by chemical analysis of human bones from Tikal (30).

Salt cakes may have been used to facilitate trade transactions by the Classic Maya, who used textiles and cacao beans as currency equivalencies (7, 31–33). Production of standardized salt cakes for trade at marketplaces in different communities has a long antiquity in the Maya highlands and elsewhere (10, 12, 13). Salt pots from three of the Paynes Creek sites were standardized in their dimensions, suggesting salt cakes were made for trade (1: 129–133). Statistically significant differences in measurements of pots among the sites suggested that different households or work parties were making salt pots for each site.

In addition to salt, salted fish was an important food and trade item in other ancient civilizations. Salted fish was a major product at the Zhongba salt works in China, as indicated by selection of high–meat-yield fish species (34). Changes in the quantity of fish remains showed more fish than needed for a local population. In Thailand, China, and the Philippines, salted fish was stored and traded near and far (11, 13, 34, 35). Salt drying fish is preferable to sun drying, since salted fish last longer, especially if they are fermented (35). Fish products may have been the most important trade commodity after wine, olive oil, and grain in Roman times (36–38).

Salt may have been used to preserve fish, animal meat, and hide that were processed using chert tools at the Paynes Creek Salt Works. The striations and polish damage on the edges of the stone tools identify that fish or meat were cut and also distinguish those activities from scraping hides (*SI Appendix*). Even though the acidic mangrove peat would not have preserved bones, fish may have been cleaned, salted, and transported whole to inland markets, leaving no skeletal evidence. Cutting fish may refer to removing the intestines of fish. Cut marks on the ventral side of tuna vertebrae indicate the fish were cut and splayed

Table 1. Radiocarbon dates for sites in this study

Site	Post	Date	Beta analytic no.
46	44	Cal AD 610–690	258739
52	12	Cal AD 670–890	259517
60	255	Cal AD 680–970	258747
70	61 A	Cal AD 550–690	259520
72	67	Cal AD 640–780	258742
77	53	Cal AD 690–900	264870

Radiocarbon dates are on wood posts, calibrated, 2 Sigma (2 SDs), by Beta Analytic.

Table 2. Chert artifact use-wear and descriptive data, Paynes Creek Salt Works

Site item no.	Type	Cut wood	Whittle wood	Cut fish/meat	Scrape hide	Structure	Figs.
6 E1	Stemmed biface			X		A	2*E*
6 E2	Trimmed macroblade		X	X		A	4*E*
46 B	Stemmed macroblade			X		A	2*B*
46 C	Stemmed macroblade			X		A	2*C*
46 D	Recycled biface	X	X	X	X	A	4*F*
52 A	Recycled biface		?			A	–
60 F	Lenticular biface	X	X			B	4*A*
60 T	Recycled biface				X	C	3*A*
60 X	Stemmed biface			X		C	2*D*
60 ZZ	Stemmed biface			X		A	2*A*
70 D	Stemmed macroblade	X	X	X		A	4*C*
70 I	Recycled biface		X			A	4*B*
70 K	Tranchet bit biface	X	X	X		A	4*D*
72 B	Lenticular biface			X	X	B	3*C*
72 BBB	Bifacial pick			X	X	B	3*E*
72 GG	Recycled biface			X		B	2*G*
72 LLL	Recycled biface			X	X	C	3*D*
72 ZZ	Oval biface			X		B	2*F*
77 C	Recycled biface		?			B	–
78 L	Recycled biface				X	–	3*B*

for drying at Colson Point (39). Valdez and Mock (40) suggest fish were salted for inland transport at Northern River Lagoon. Limited evidence of fishing at the Paynes Creek Salt Works includes a fragmentary, solid manatee (*Trichechus manatus*) rib bone and a fish vertebra preserved in deep silt, one side-notched stone fishing weight, and a pumice fishing float (17).

Edible marine resources as well as conch shells, coral, stingray spines, and other ritual or ceremonial marine items have been found in caches and burials as well as depicted in art at inland Maya sites (41–43). There was inland demand for manatee and marine fishes, as well as other animals such as jaguars (*Panthera onca*), peccaries (*Tayassu pecari*), and crocodiles (*Crocodylus acutus*) available near the Paynes Creek Salt Works. Manatee and peccary were desired meats by the coastal and inland Maya, respectively (41–44). Scraping hides at the salt works may refer to manatee, which are common locally, and there are historic references to tanning manatee hides (42). Manatee were hunted by the Classic Maya along the Caribbean coast, with bones recovered from coastal middens and inland caches (41–43). Alternatively, scraping hides may also refer to scraping off fish scales.

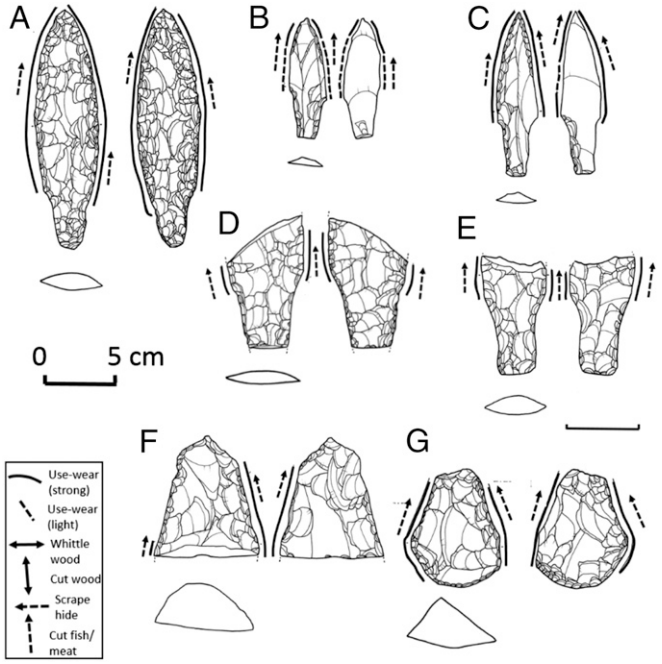

Fig. 2. Chert stone tools used to cut fish or meat. (*A*) 60 ZZ, (*B*) 46 B, (*C*) 46 C, (*D*) 60 X, (*E*) 6 E1, (*F*) 72 ZZ, (*G*) 72 GG. Arrows parallel to the artifact indicate cutting action. Arrows perpendicular to the artifact indicate scraping or whittling.

The presence of marine food resources at inland Maya communities argues for their preservation by sun and/or salt drying. Near-coastal communities including Lubaantun, Altun Ha, and Dzibilchaltun had marine resources as a common component of the diet (41, 42). Marine fish bones are found in smaller quantities in middens farther inland, as well as in ceremonial contexts (41, 42, 45–47).

Marine fish comprise 39% of the faunal material at Lubaantun, a nearby inland city contemporary with the salt works. Most of the nonbriquetage ceramics from the salt works resembles pottery from Lubaantun (1). The marine fish include species available near the salt works, notably jack (*Caranx* sp.), grouper (Serranidae), and snook (*Centropomus* sp.) (48). These fish would have been preserved before inland transport. These and additional species were abundant in Late to Terminal Classic middens at Wild Cane Cay (pp 36 and 37 in ref. 44). Preservation of wooden canoe paddles and a canoe at the salt works underscores the use of canoe transport (2, 49). Salt makers or traders who transported marine resources up river to Lubaantun and other inland communities may have returned from marketplaces with Belize Red and Warrie Red pottery, ocarinas, and other goods and resources (50).

Salting fish would have reduced the amount of dietary salt available for inland trade to nearby Classic period cities. Estimates of salt production in the 4-mo dry season (March–June) for 100 of the 110 salt sites at the Paynes Creek Salt Works are 37.5 tons of salt per week or 600 tons over 4 mo, or 300 tons if 50% of the salt produced was used for salting fish. The estimates are based on salt production at Sacapulas, where two people working 6 d/wk produce 56.7 kg of salt per day in a 6 × 8 m salt kitchen near the brine springs (12), yielding six tons of

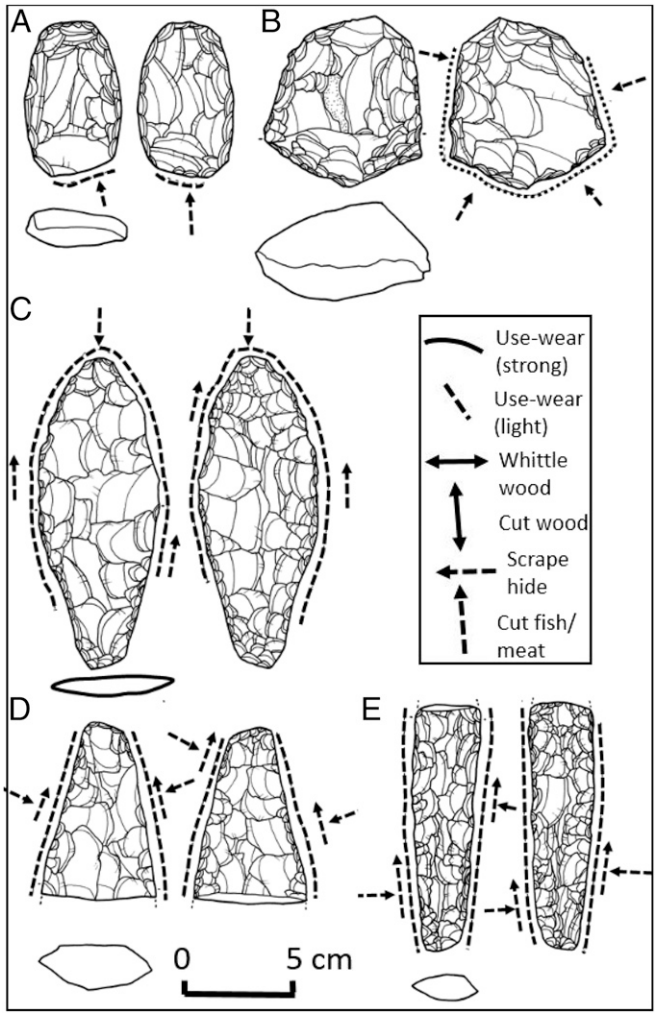

Fig. 3. Chert stone tools used to scrape hides (*A* and *B*) and cut fish/meat (*C*–*E*). (*A*) 60 T, (*B*) 78 L, (*C*) 72 B, (*D*) 72 LLL, (*E*) 72 BBB.

salt over a 4-mo dry season, per salt kitchen. Sacapulas and Paynes Creek structures are similar in size (table 1 and figure 2 in ref. 18). At the height of Late and Terminal Classic period population at nearby inland Maya communities such as Lubaantun, Nim li punit, and Pusilha, perhaps only 25 sites were used in a given year, with salt production 125 tons over 4 mo. Half that amount used to salt fish leaves 62.5 tons of dietary salt. Using an estimate of 8 g per person of daily salt (1, 10), one salt kitchen provided salt for 7,087 people per day, or 3,444 people if half the salt was used to salt fish. Twenty-five salt kitchens provide dietary salt for 88,594 people per day, or 44,297 people if half was used to salt fish. This model can be expanded to include other coastal Maya salt works: Coastal production of salt cakes and salted fish for trade at nearby inland marketplaces provided dietary salt and salted fish or meat in the form of storable commodities that had additional value for further trading.

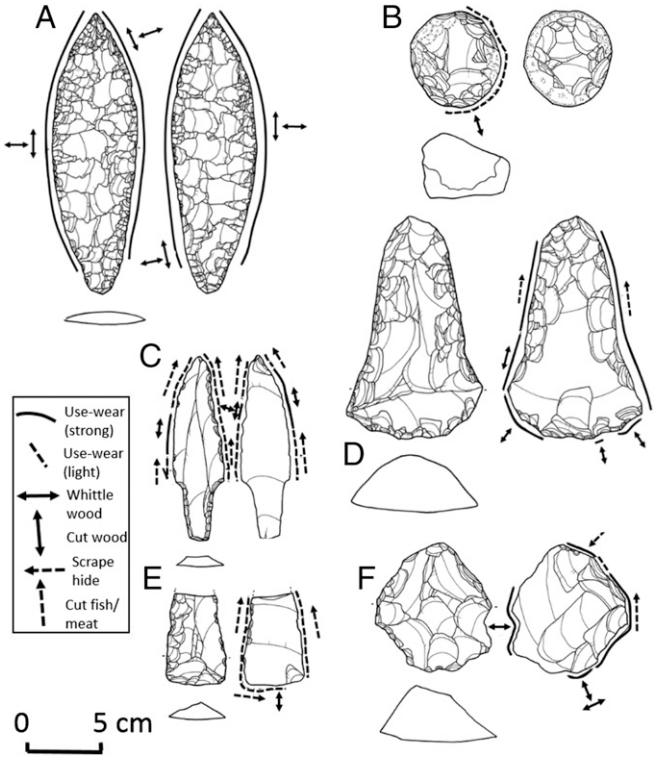

Fig. 4. Chert stone tools used for woodworking (*A* and *B*) and also to cut fish/meat/scrape hides (*C*–*F*). (*A*) 60 F, (*B*) 70 I, (*C*) 70 D, (*D*) 70 K, (*E*) 6 E2, (*F*) 46 D.

Conclusions

Surplus household production by commoners and elites, along with trade of surplus commodities at marketplaces within cities and regionally at marketplaces in various communities, created a network for trade of staple commodities and other goods and resources from nearby and from more distant origins. Householders were integrated into regional economic networks that included commodities from beyond the region, as well as from beyond the lowlands, such as obsidian and jadeite. Although seafood was previously touted as a possible subsistence alternative to the inland Maya (51), the real importance of marine resources was production of dietary salt as well as salted fish that allowed storage and trade of salt cakes, salted fish, and meat, as well as hides, which circulated in the market economy and may have helped mediate periodic food shortages.

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Table 3. Chert tool type and use

Tool type	Cut wood	Whittle wood	Cut fish/meat	Scrape hide
Tranchet bit biface	1	1	1	0
Oval biface	0	0	1	0
Lenticular biface	1	1	1	1
Stemmed biface	0	0	3	0
Bifacial pick	0	0	1	1
Recycled biface	1	2	3	4
Stemmed macroblade	1	1	3	0
Trimmed macroblade	0	1	1	0
Total	4	6	14	6

Excludes artifacts from sites 52 and 77 of unknown use.

Table 4. Use-wear on chert tools by site

Site	No. items	Cut/whittle wood	Cut fish/meat	Scrape hides
6	2	1	2	0
46	3	1	3	1
52	1	–	–	–
60	4	1	2	1
70	3	3	2	0
72	5	0	5	3
77	1	–	–	–
78	1	0	0	1
Total	20	6	14	6

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