The cultural and chronological context of early Holocene maize and squash domestication in the Central Balsas River Valley, Mexico

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Molecular evidence indicates that the wild ancestor of maize is presently native to the seasonally dry tropical forest of the Central Balsas watershed in southwestern Mexico. We report here on archaeological investigations in a region of the Central Balsas located near the Iguala Valley in Guerrero state that show for the first time a long sequence of human occupation and plant exploitation reaching back to the early Holocene. One of the sites excavated, the Xihuatoxtla Shelter, contains well-stratified deposits and a stone tool assemblage of bifacially flaked points, simple flake tools, and numerous handstones and milling stone bases radiocarbon dated to at least 8700 calendrical years B.P. As reported in a companion paper (Piperno DR, et al., in this issue of PNAS), starch grain and phytolith residues from the ground and chipped stone tools, plus phytoliths from directly associated sediments, provide evidence for maize (*Zea mays* L.) and domesticated squash (*Cucurbita* spp.) in contexts contemporaneous with and stratigraphically below the 8700 calendrical years B.P. date. The radiocarbon determinations, stratigraphic integrity of Xihuatoxtla's deposits, and characteristics of the stone tool assemblages associated with the maize and squash remains all indicate that these plants were early Holocene domesticates. Early agriculture in this region of Mexico appears to have involved small groups of cultivators who were shifting their settlements seasonally and engaging in a variety of subsistence pursuits.

agricultural origins | Mesoamerican preceramic | maize domestication

Mexico was one of the world's great centers for the independent development of agriculture beginning 10,000 calendrical years B.P. (cal B.P.) (1–3). Among the many plants that were domesticated there during the pre-Columbian era, none has received as much attention and been subject to as much debate as corn, or maize (*Zea mays* L.), the most important crop of the Americas (4–12). Once thought to be a cultivar of the arid Mexican highlands, molecular data now indicate that maize was domesticated a single time and that a subspecies of teosinte classified as *Zea mays* ssp. *parviglumis* (Iltis and Doebley) native to the tropical Central Balsas River Valley, Mexico, is its wild ancestor (Fig. 1) (7, 13). Other crop plants that have close wild relatives native to the Central Balsas region, and may thus have been domesticated there, include the silverseeded squash (*Cucurbita argyrosperma* Huber) and important tree crops (e.g., *Leucaena* spp., *Spondias purpurea* L.) (14–16). However, previous archaeological research there has focused on ceramic era occupations, those dating no earlier than 4,000 years ago, long after maize and squash were domesticated and dispersed (17, 18). Moreover, since the seminal studies of Flannery and MacNeish (1, 2, 19) in the central and southern Mexican highlands, there has been little systematic fieldwork on early human settlement and agricultural origins elsewhere in Mesoamerica.

Currently, the earliest evidence for Mexican maize consists of maize cobs from Guilá Naquitz Cave, Oaxaca, dated to 6200 cal B.P. (20, 21), and maize phytoliths and pollen dated to 7300 cal B.P. from San Andres, Tabasco, on the Caribbean coast (10, 22). These regions are well outside the present distributional range of the wild ancestor of maize, which, indeed, was not present in their premaize records. Furthermore, a large corpus of archaeological and paleoecological microfossil (phytolith, starch grain, and pollen) research indicates that maize had spread south out of Mexico earlier—arriving in Panama by 7600 cal B.P.—and by 6000 cal B.P. was well established in northwestern South America (e.g., 9, 12, 23–26). This time frame accords with the estimated ≈9000 cal B.P. divergence of maize from teosinte based on a molecular clock (7). It seems clear that documenting the earliest history and cultural context of maize domestication, together with the role more generally that tropical southwest Mexico played in agricultural origins, requires investigation of archaeological deposits in the Central Balsas watershed that date back at least 9,000 years.

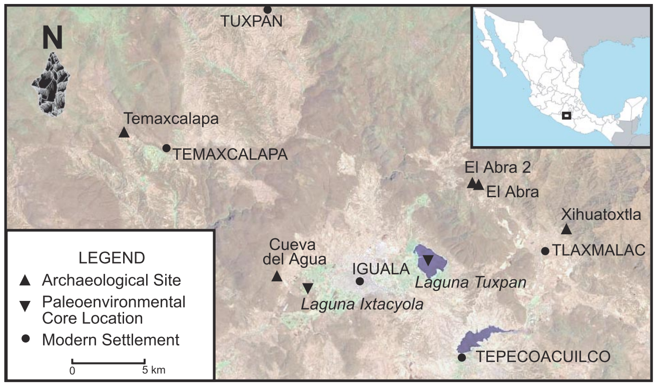

Fig. 1. The study area in northern Guerrero.

Our field research was carried out within the Central Balsas watershed of northern Guerrero near the modern town of Iguala in an area drained by northern tributaries of the Balsas River (Fig. 1). Elevations vary from 700 to 900 m above sea level (asl) in the valley bottoms to 1,500–1,800 m asl at the summits of small ranges that separate the valleys. Rainfall varies from ≈1,000 to

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Fig. 2. A view of the enormous boulder that formed the Xihuatoxtla Shelter.

1,400 mm annually with over 90% falling during the June-to-October rainy season. The potential vegetation of the region is tropical deciduous forest, seen today in remnants scattered throughout the region. Vegetational reconstructions indicate that a species-diverse seasonal tropical forest flourished there after the Pleistocene ended and until systematic human disturbance began (27). The native vegetation contains legumes and many other plants that would have been important subsistence resources, such as *Pithecolobium dulce*, *Prosopis* spp, *Leucaena* spp., *Spondias* spp., palms, *Dioscorea* spp., and others (27). Bedrock in the study area is predominantly limestone, although extrusive igneous formations are found in the eastern portion of the area. Both limestone and igneous formations provide caves and overhangs that early occupants of the region used as shelters. The karstic landscape also resulted in the formation of a number of permanent lakes near the shelters that offered a stable and abundant supply of animal protein as well as diverse plant foods (27).

Our survey focused on caves and rock shelters because they were commonly used by ancient peoples and because they provide better protection for perishable materials, such as plant remains, than open-air sites. We located 15 caves and rock shelters that had been occupied sometime in prehistory, based on the stone and ceramic artifacts recovered from the site surfaces, and carried out excavations in 4 of these sites (Fig. 1). Two of the sites, Cueva del Agua and El Abra 2, contained only ceramic-aged deposits. A third site, El Abra, was occupied at least as early as 8330–8160 cal B.P. (^{14}C AMS date of 7400 ± 40 B.P.), but the reworking of the rock shelter deposits in the early 20th century has left them thoroughly mixed over most of the site. At a fourth site, the Temaxcalapa Shelter, we recovered a large number of chipped stone artifacts from the eroded slope in front of the shelter, including preceramic-aged spear points. We were unable to excavate this site (see *SI Text*, *Site Descriptions* for additional information on these 4 sites). In a fifth site, the Xihuatoxtla Shelter, our excavations encountered undisturbed preceramic and ceramic deposits containing both chipped and ground stone tools, plant remains, and ceramics (see Table S1 for ^{14}C dates from these sites).

Results

The Xihuatoxtla Shelter (964 m asl) is formed by the overhang of an enormous boulder (17 × 16 × 14 m) and contains ≈75 m^2 of protected floor space inside the dripline (Fig. 2 and Fig. S1). It is located 260 m from Barranca Xihuatoxtla near the point where the now-seasonal stream opens out onto a flat basin. The nearly 1-m-deep stratigraphic sequence (Fig. 3) is anchored by 4 radiocarbon dates on charcoal: (1) 1200 ± 40 B.P. (1240–1000 cal B.P.) from layer B, 20–30 cm below surface, (2) 2790 ± 40 B.P. (2970–2780 cal B.P.) from layer B, 30–40 cm below surface, (3) 4730 ± 40 B.P. (5590–5320 cal B.P.) from layer C, 49 cm below surface, and (4) 7920 ± 40 B.P. (8990–8610 cal B.P.) from layer D, 65 cm below surface. The cultural deposits extended another 35 cm below the 8990–8610 cal B.P. level, but we were unable to date any of the samples recovered from these earlier deposits. Though starch grains and phytoliths were well pre-

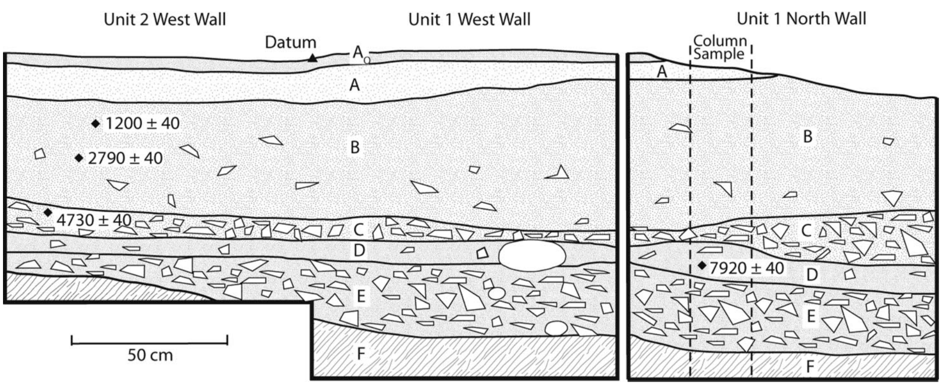

Fig. 3. Stratigraphy of units 1 and 2 in the Xihuatoxtla Shelter.

served in stone tool residues, and phytoliths commonly occurred in the shelter sediments, pollen grains and plant macrofossils other than wood charcoal were scarce (28). No faunal remains were preserved. The sedimentary sequence at Xihuatoxtla can be divided into 5 major and discrete stratigraphic units (Fig. 3).

Layer A (≈0–10/15 cm below surface) is a 10- to 15-cm-thick deposit of very compact tan silt that contained numerous pre-Columbian potsherds ($n = 414$) and a modest number ($n = 26$) of lithic artifacts, primarily debitage but including a small tanged obsidian point and an obsidian blade fragment. A small number of bottle glass fragments ($n = 3$) are the only indication of recent disturbance (all counts given here and below are for units 1 and 2, contiguous 1 m^2 blocks).

Layer B (≈10/15–45/50 cm b.s.) is a 30- to 40-cm-thick deposit of clayey silt with small amounts of angular roof-fall that changes from gray/brown to brown in color with depth. Sherd densities vary from 110 sherds per 5-cm level per square meter at the top of the layer to 25 sherds per 5-cm level per square meter at the bottom. Lithic densities averaged 27 specimens per 5-cm level per square meter. Obsidian artifacts included 12 prismatic blade fragments, 1 tanged point, 1 tabular wedge (*piece esquillée*), and 9 flakes. Other chipped stone artifacts of local materials included 1 steep scraper, 1 flake knife, 1 graver, 1 chopper, and 1 small bipolar core. Also recovered from the layer were 3 handstones (*manos*, small implements used for grinding plant and possibly other kinds of materials), 2 milling stone base fragments, and 1 shaped *metate* fragment.

Layer C (≈45/50–60 cm b.s.) is an 8- to 12-cm-thick deposit of large angular roof-fall blocks (cobble sized) in a matrix of gray/brown clayey silt. The density of lithic artifacts (119 per 5-cm level per square meter), absence of obsidian blades, and the AMS ^{14}C date of 4730 ± 40 B.P. (5590–5320 cal B.P.) indicate that this layer dates to the preceramic, although there is some intrusion of sherds from the ceramic occupation above ($n = 36$). The chipped stone tools recovered from layer C include 2 scraper planes, 1 borer, 1 flake knife, 1 bifacial core, 2 bipolar cores, 1 small obsidian biface fragment, and 4 used flakes. There were also 6 handstones (see Fig. 4 and Fig. S2*A*) and 1 possible milling stone base fragment recovered from layer C.

Layer D (≈60–70 cm b.s.) is an 8- to 10-cm-thick deposit of brown clayey silt with some angular roof-fall blocks. There were 251 chipped stone artifacts recovered (63 per 5-cm level per m^2) and no ceramics. The chipped stone tools recovered from layer D include 1 cobble spall chopper, 1 concave scraper, 2 gravers, 5 flake knives, and 1 biface fragment. Also recovered were 2 handstones, and 1 complete and 2 fragmentary milling stone bases (see Fig. 4 and Fig. S2 *B* and *C*).

Layer E (≈70–95 cm b.s.) is an 8- to 25-cm-thick deposit of brown clayey silt with more angular roof-fall blocks than layer D. It rests on eroded bedrock (layer F) that slopes from 78 to 95 cm below surface moving from south to north (see Fig. 3). There were 179 chipped stone artifacts recovered (30 per 5-cm level per square meter), including the base of a stemmed, indented base point, the distal end of a thick lanceolate point (Fig. 5), 1 graver, 1 spokeshave, 1 flake knife, 9 used flakes, 5 thinning flakes with ground platforms, 2 core fragments, and 3 bipolar cores. Four handstones were recovered from this earliest occupation layer (Fig. 4 and Figs. S2*D* and S3).

Nearly all of the handstones and milling stone bases (Fig. 4) used for plant processing consisted of river cobbles and boulders that were modified only by use. One milling stone base fragment came from a stone slab (Fig. S2*C*) rather than a river boulder that was also modified only by use. Wear polish can occur on one or both faces of a handstone and on the tool edges as well. One handstone from layer E (318e) appears to have seen considerable use as a pestle. A number of the milling stone fragments exhibit polish on their flat or slightly concave surfaces as well. Striations are rare on both handstones and milling stone fragments but where they occur they are aligned in parallel to each other, suggesting a back and forth motion. An exception is the complete milling stone recovered from layer D (316d) that exhibited randomly oriented striations near the edges of a shallow depression 11 cm in diameter. The use of unmodified river cobbles as handstones and unmodified river boulders or stone slabs as milling stone bases is a common pattern observed in early Holocene sites in the semiarid Mexican highlands in the Tehuacan Valley (29) and at Guilá Naquitz in Oaxaca (1). Similar ground stone tools were also recovered in early Holocene contexts at the Santa Marta Rock Shelter (30), a site in the Central Chiapas Depression that sits at an elevation of 860 m in a zone of tropical deciduous forest.

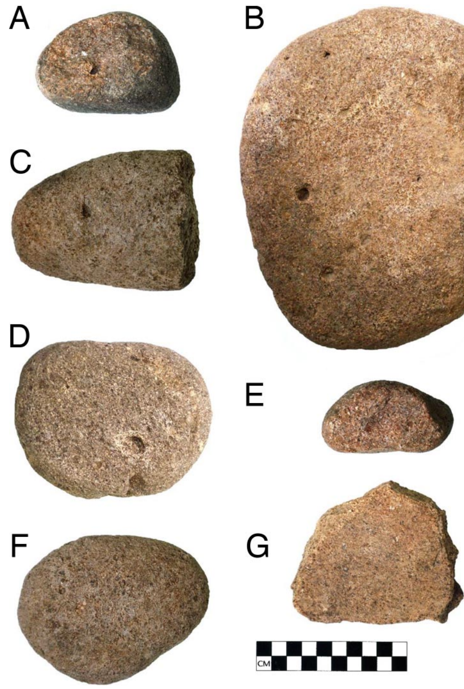

Fig. 4. Handstones and milling stone bases from the preceramic layers in the Xihuatoxtla Shelter. (*A*) Small handstone (318e) from layer E that yielded 80 maize starch grains, maize cob phytoliths, and 29 squash phytoliths. (*B*) Complete milling stone base (316d) from layer D that yielded 68 maize starch grains as well as 4 yam (*Dioscorea* sp.), 3 legume, and 1 Marantaceae starch grains. (*C*) Handstone fragment (318d) from layer E that yielded 22 maize starch grains, maize cob phytoliths, and 28 squash phytoliths. (D) Handstone (322c) from layer E that yielded 11 maize starch grains, maize cob phytoliths, and 7 squash phytoliths. (*E*) Small handstone (365a) from layer C that yielded 24 maize starch grains and maize cob phytoliths. (*F*) Handstone (319d) from layer E that yielded 8 maize starch grains, maize cob phytoliths, and 37 squash phytoliths. (*G*) Slab milling stone fragment (316c) from layer D that yielded 2 maize starch grains, maize cob phytoliths, and 29 squash phytoliths.

Chipped stone tool manufacturing at Xihuatoxtla was an important activity during the preceramic period and continued into the ceramic period, albeit with less intensity (Table S2). A wide range of raw materials was used, including chalcedony, chert, quartzite, rhyolite, basalt, sandstone, and obsidian. All but the obsidian appear to be locally available. At the base of the sequence in layer E (≈75–95 cm below surface), evidence for bifacial reduction in the production of projectile points is indicated by thinning flakes oftentimes containing ground platforms. The preparation of the edge of a spear point preform by grinding is a way of increasing platform strength and allowing larger thinning flakes to be removed. Bifacial thinning flakes with ground platforms are characteristic of Paleoindian and Early Archaic periods (before ≈8000 cal years B.P.) (31), and their appearance in layer E is consistent with its estimated age

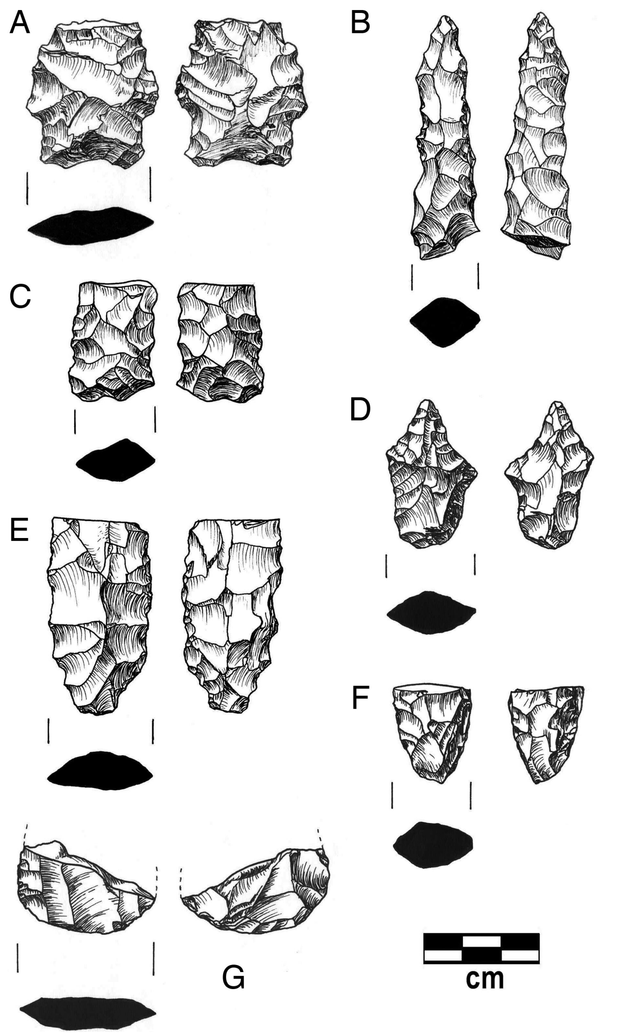

Fig. 5. Bifacial points and preforms from north central Balsas Valley sites. (*A*) ''Pedernales'' point base from Xihuatoxtla, layer E. (*B*) Point from Xihuatoxtla, layer E (distal end). (*C*) Point base from El Abra. (*D*) Reworked stemmed point from Temaxcalapa. (*E*) Preform fragment from Temaxcalapa. (*F*) Point base from Temaxcalapa. (*G*) Preform base from Temaxcalapa.

(older than ≈9000 cal years B.P.) The basal half of a stemmed, indented base point and the distal end of a diamond cross-sectioned point were also recovered from this layer (Fig. 5). The point base is similar to single examples classified as Pedernales points from the Guilá Naquitz site in Oaxaca and from the Tehuacan Valley in contexts dated between ≈9510 and 7742 cal years B.P. (1, 29). Evidence of bifacial reduction continued in layer D (≈60–75 cm below surface) with the recovery of additional thinning flakes and also one biface preform fragment. Bifacial flaking occurred in layer C and in layer B associated with ceramics, albeit at reduced levels and with no platform preparation by grinding.

Of equal or greater importance in stone tool manufacturing was core reduction for flakes that could be used with little or no modification. Cores were reduced opportunistically or by bipolar methods. The resulting flakes were used as knives, scrapers, borers, spokeshaves, and gravers and represented the majority of the tools recovered in the preceramic deposits. Tools recovered from ceramic-aged deposits were mainly made on obsidian prismatic blades, although some tools and the bulk of the chipping debris were of local nonobsidian materials.

As reported in a companion paper (28), starch grains identified as maize were recovered, often in large numbers, from most artifacts identified as grinding stones found throughout the Xihuatoxtla stratigraphic sequence. All 8 of the grinding tools and both of the chipped stone tools examined for starch grains in levels contemporary with or below the ^{14}C date of 7920 ± 40 B.P. (8990–8610 cal years B.P.) yielded maize starch. Maize phytoliths were recovered from both sediments and stone tools throughout the sequence, including those beneath and from the level that produced the 7920 ± 40 ^{14}C B.P. date. Phytoliths identified as domesticated *Cucurbita*, possibly *C. argyrosperma*, were also found in direct association with the 7920 ± 40 ^{14}C B.P. date at Xihuatoxtla and in levels below (see ref. 28 for details on starch grain and phytolith recovery and identification). Thus, the evidence firmly indicates that maize and squash were domesticated by 8990–8610 cal years B.P., the earliest date yet recorded for maize.

Discussion

Although Mexico played a central role in New World agricultural origins, contributing a large number of important crop plants in addition to maize (9), little research directed toward understanding early human occupation and agricultural evolution has been carried out in its lowland tropical regions. Our investigations in northern Guerrero show that this region of tropical southwest Mexico supported persistent human occupation beginning by at least 9,000 years ago and possibly a few thousand years earlier, if some of the stone tools recovered from the surface of the Temaxcalapa Shelter turn out to indeed be Clovis in age. The archaeobotanical (28) and stone tool evidence from Xihuatoxtla indicates that plant exploitation and cultivation were important activities from the earliest stages of the site's occupation.

Xihuatoxtla is a small shelter that appears to have been repeatedly visited by small groups of people who stayed for significant periods of time (several weeks or more) based on the nature and density of materials left at the site. During the preceramic period, these groups likely shifted locations seasonally. Our data on early settlements from the Central Balsas region are insufficient to document this pattern in any detail. Nonetheless, the evidence we do have suggests that preceramic groups were occupying different settings and were engaged in different subsistence pursuits. The much larger El Abra Shelter, only 7 km distant from Xihuatoxtla and occupied over much of the same time span, included both small and large mammal bone in the limited sample of undisturbed deposits that were excavated in that site. The near absence of grinding stones at this site suggests that activities were directed more toward hunting than plant exploitation and cultivation. The surface collections from the Temaxcalapa Shelter, located at a higher elevation (1,350 m asl) than Xihuatoxtla (964 m asl) and in more broken terrain (Fig. 1), contained Archaic point types (Fig. 5) and other chipped stone tools (n = 38) and flakes (n = 128) but no grinding tools, hinting again at a different set of activities carried out there than at Xihuatoxtla.

Our paleoecological data from nearby lakes (Fig. 1) indicate that utilization of resource-rich lacustrine environments was an early and important component of subsistence and probably seasonal settlement cycles (27). At Laguna Tuxpan, phytolith data indicate that humans were exploiting lake edge settings and modifying the local vegetation, including with fire, during the early Holocene. Phytoliths of maize and domesticated *Cucurbita* plus *Zea* pollen were also recovered and minimally dated to 6000 cal years B.P., with a likely actual early Holocene age (27). At the Ixtacyola lake bed, chipped stone artifacts occurred in lake edge sediments to a depth of 4.3–4.4 m, 10 cm below a date of 6290 ± 40 ^{14}C years B.P. (7280–7170 cal B.P.) (27). These tools are accompanied by a major increase in pollen disturbance indicators and charcoal in the paleoecological records. The paleoecological data suggest that maize and squash were being planted in the productive soils near lake edges that were exposed during the dry season as lake levels fell. These practices would have provided attractive yields for minimal effort.

Our data from the Central Balsas provide a firm cultural and chronological context for early domesticated maize and a species of squash in their postulated Mexican homelands. They also add to the increasing archaeological and molecular evidence attesting to a primary role of seasonal tropical forests from Mexico to Brazil in the origins and dispersals of New World domesticated crops (e.g., 9, 15, 23, 26, 32).

Materials and Methods

Four contiguous 1-m^2 units were opened at one edge of the Xihuatoxtla Shelter. The excavations were largely carried out with hand tools in 5-cm levels and the deposits screened through 1/4- and 1/16-inch screens. Major artifacts were measured in situ, and those that were potentially used for plant processing were immediately sealed in plastic bags to avoid any possibility of contamination of plant residues. Sediment samples from the immediate vicinity of potential plant processing tools were taken and cataloged along with the associated tool. A 20×20-cm-column sample was removed from the north wall of unit 1 to a depth of 1 m for the purpose of extracting plant microfossils—phytoliths, pollen, and starch grains—if present.

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