REPORTS

AN EXPERIMENTAL APPROACH TO THE FUNCTION OF CLASSIC MAYA CHULTUNS

DENNIS E. PULESTON

ABSTRACT

Experimental techniques have provided an exciting breakthrough for the functional analysis of Maya *chultuns*. While deep cistern-like *chultuns*, common at certain sites in the northern lowlands, have been shown to be functional for water storage, smaller lateral-chambered *chultuns* characteristic of certain parts of the southern lowlands probably had a very different function. Excavation and examination of the latter features, in light of awhole range of possibilities, suggest that they were constructed to be used for food storage. Experimental studies, however, reveal them to be unsuitable for the storage of most traditional foods, including maize. At least one local food crop, the seed of the ramon (*Brosimum alicastrum*, Moraceae), appears to be ideally suited for long-term storage under these conditions. Chambers constructed beneath platforms in the northern lowlands may have been used for the storage of maize. A need for more experimental work is indicated.

Department of Anthropology
University of Minnesota
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Experimentation in archaeological research is a rarely used source of inspiration and data of much greater potential than is generally realized. A useful and recent review of past experimental work is found in Hole and Heizer (1969:184-186). In a stimulating earlier paper on the same subject, Ascher (1961:794) points out that imitative experiments, in vogue half a century ago, "are now seldom performed by professional archaeologists." It is to be hoped that, with the advent of what is sometimes called the "Age of Models," experimentation will come back into fashion as archaeologists become more inventive in their search for ways to overcome the limitations of excavated archaeological data.

In the study of alternative functions of ancient Maya *chultuns* at Tikal, Guatemala, the use of an experimental approach has proved particularly useful as a means of hypothesis testing after it became obvious that excavation was not going to produce the information needed to evaluate a whole range of possibilities suggested by the archaeological data.

HISTORICAL BACKGROUND

Speculation as to the function of curious subterranean chambers found in the Maya lowlands begins with John L. Stephens' (1843, Vol. 1:231) examination of *chultuns* at Uxmal and Labná. While he was inclined to believe that they were water cisterns, he found himself at odds with Don Simon, a local landowner, who held that they were for food storage. Clearly, at this stage excavation data was needed. Ethnographic analogy could offer little in the way of clarification, at least on a local level, for no nineteenth century Maya group made regular use of such underground chambers. Stephens (1843, Vol. 1:228) himself reports that at the time of his visit, "neither Don Simon nor any of the Indians knew anything about them." In fact, it was not until he reached Ticul that he found people who even referred to them as "*chultunes*," or thought that they had been wells (Stephens 1843, Vol. 1:284).

The etymology of the word "*chultun*" is of little help either. According to Tozzer (1913:190) it means simply, "excavation in stone," deriving from *ťšul*, to clean, and *tun*, stone.

The first archaeological investigation of Yucatecan *chultuns* was carried out during the years 1888 to 1891 by E. H. Thompson. Thompson, in his definitive study, *The Chultunes of Labná* (1897), investigated some 60 *chultuns* at Labná, an impressive sample even by today's standards. He concluded that *chultuns* as he knew them were for water storage. This conclusion was based on well-reasoned evidence including: (1) the frequency of the occurrence of *chultuns* at sites at which natural wells or *cenotes* were absent; (2) their location on terraces and beside buildings where they could catch the most water; (3) their bottle-shaped form with depths of more than 6 m beneath the orifice; and (4) the discovery of a thick lining of polished stucco or plaster on the insides of the *chultuns* which he assumed would make them waterproof. Several of these points

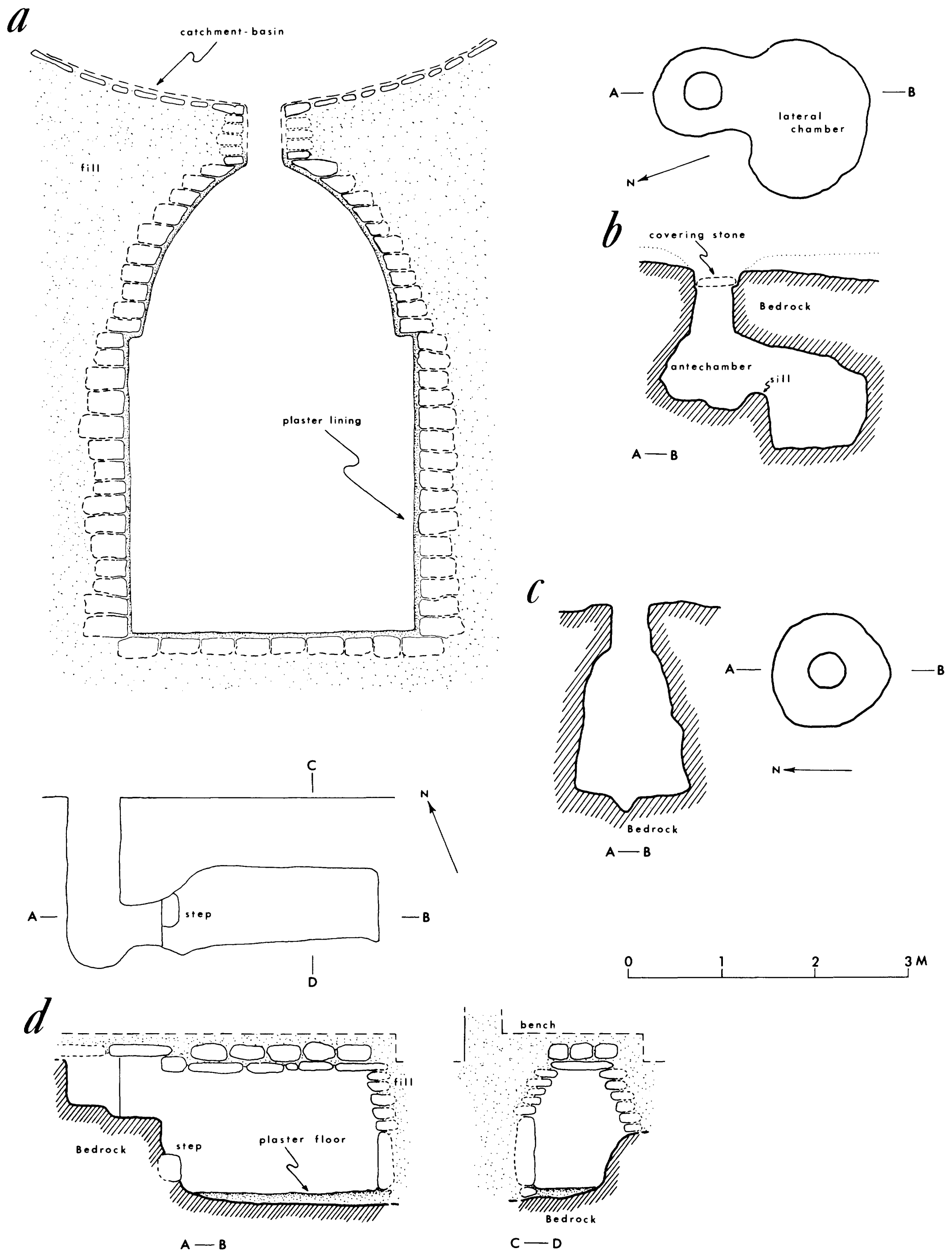

Fig. 1. *Chultuns* and a "burial vault" from the Maya lowlands: *a*, section of cistern *chultun* at Labná, built in an artificial terrace (after Thompson 1897, Fig. 2); *b*, section and plan of a lateral-chambered *chultun* at Tikal (Ch. 5C-1); *c*, section and plan of pit *chultun* at Tikal (Ch. 6F-5), a covering stone may or may not have been present; *d*, two sections and plan of Burial Vault 17, beneath Str. AA 60a, at Mayapan (after Smith 1962, Fig. 16, e). All drawings are to the same scale.

are illustrated in Fig. 1*a*. It should be noted that while the illustration shows a rather elaborate, vaulted, masonry *chultun* built in artificial fill, many, and probably the majority, of these cistern *chultuns* were excavated directly out of the limestone bedrock. These bedrock cisterns, without masonry or vaulting, were also lined with a heavy layer of plaster (Thompson 1897:77).

The assumption that the plaster lining made the *chultuns* waterproof remained untested until several *chultuns*, including at least one at Uxmal, were re-plastered and allowed to fill with rainwater by the enterprising chief inspector of archaeological monuments for Yucatán, Eduardo Martinez (Blom 1936:184). The water obtained from one of these restored *chultuns* at Uxmal was used to sustain Blom's field crew at the site in 1930. This was the first application of the experimental technique, to the problem of *chultun* function. Since that time other *chultuns* of this type have been restored with their circular catchment-basins, and are currently in use at Kabah, Sayil, and possibly other sites, as well as Uxmal. In former times, it is clear that whole terraces, sometimes some distance from the *chultun*, were used for catchment. At Chichen Itza a *chultun* was found with a masonry drain leading to it from a whole group of buildings (Morley 1928:306).

Ethnohistorical sources appear to confirm this picture provided by the archaeological and experimental data. In 1579, Juan Gutierrez Picon (Relaciónes de Yucatan 1898-1900, Vol. II:159) reported that on one of the larger buildings at Tiquibalon [Ekbalam (Tozzer 1941:60)] there were artificial cisterns which were used to collect rainwater, as well as *silos* which were used for storage of maize. The nature of the latter is yet to be determined and while it is unlikely that they are identical in form to the cisterns it is curious that they have not been recognized archaeologically. The reference suggests that there may have been substance to Don Simon's argument and that at least some *chultuns* or perhaps vaguely similar subsurface chambers were used for food storage. Charney (1887:302) in his visit to Ekbalam almost 300 yr later describes what seemed to be water-storage cisterns on what is probably the same platform. Apart from complicating factors of this nature, however, Thompson's hypothesis regarding the water-storage function of the northern cistern *chultuns* has not been seriously contested by anyone other than O. F. Cook, who will be mentioned subsequently.

The problem which concerns us now is the unintentional amplification of the designation "*chultun*" in the nineteenth century to include superficially similar holes-in-the-ground found only in certain parts of the southern Maya lowlands.

These southern *chultuns* differ in many ways from the cistern *chultuns* found in Yucatán and Campeche. Instead of deep bottle-shaped chambers, most of them have fairly small lateral chambers which often can only be reached from the surface by passing through a smaller and shallower antechamber (Fig. 1*b*). It is this form which will be the principal subject of discussion in what follows, though it must be mentioned that a small percentage at Tikal have turned out to be bottle-shaped (Fig. 1*c*); and an even smaller percentage are cylindrical pits. Unlike the comparatively huge cistern *chultuns* of northern Yucatán, however, the latter 2 forms are rarely much over 2 m deep and show no evidence of stucco or plaster lining. The bottle-shaped pits are quite similar to the bell- and bottle-shaped pits found in the Guatemalan and Mexican highlands, for which a food-storage function has been suggested by Shook (1951:96) and Borhegyi (1965:9).

Unfortunately, the important subsurface differences between these southern *chultuns* and those described by J. L. Stephens (1843) and E. H. Thompson (1897) were not recognized by the first archaeologists to come into this region. These early explorers rather naturally assumed that the virtually identical appearances of the orifices from above ground indicated a corresponding similarity with respect to subsurface features.

Maudslay, who visited Tikal in 1881 and 1882, seems to have been the first to at least partially excavate and describe a southern lowlands *chultun*. In a paper he read before a meeting of the Royal Geographical Society in 1882 (Maudslay 1883:195), he described his investigation of what was certainly *Chultun* 5D-1 (Carr and Hazard 1961), located near the center of the Great Plaza of Tikal.

> In the plaza I found a small hole in the ground about eighteen inches across, cemented round the rim, and I set some men to work to clear it out, but as only one man could work at a time, he could only pass up the earth in small baskets-full, I

> was not able to clear it properly, but enough earth was removed to show me that it lead to two circular subterranean chambers, six to eight feet in diameter. The sides of these chambers were not cemented, and it seems probable that they were used for the storage of food. . . .

He went on to consider the possibility that the chambers were used for water storage but clearly favored the food-storage hypothesis. It is ironic that he subsequently abandoned this perceptive and original assessment. Approximately 13 yr later in 1895 when volume 3 of his major work commenced publication, he again refers to the *chultun* but makes no mention of food storage. He states merely that he found two "cisterns" and equates them morphologically and functionally with the "*chaltunes*" found to the north in Yucatán (Maudslay 1889-1902, Vol. 3:49). The influence of Thompson's work on the Labná *chultuns* along with the fact that he had not removed all the earth from the two small chambers, apparently convinced him that he had seen only the uppermost portions of a much deeper double cistern of some kind. Though his conclusion regarding the identity of the southern *chultuns* was soon shown to be erroneous, the name unfortunately stuck. The term "*chultun*" has continued to be used in unmodified form, camouflaging and confusing the essential differences between at least 2 very different and obviously functionally distinct constructions. It was next picked up by Maler (1911:5) who mentions finding a "*chultun* or rain-well" on his way into Tikal in 1895.

With the first complete excavations of lateral-chambered *chultuns* by Tozzer at Yaloch, Chorro, Nakum, and Holmul in 1909-10, their distinguishing characteristics were fully recognized for the first time. In a brief note published in *Science* (1912:669) Tozzer notes: (1) the predominance of lateral chambers in these *chultuns*; (2) their abundance in this region in contrast to the limited occurrence of water storage *chultuns* in the north; (3) their association with small mounds; (4) their abundance in areas far from the ceremonial centers; and (5) their occurrence in areas with abundant supplies of permanent water. The important observations relating to abundance and distribution were also recorded on a map which appeared with the Peabody Museum report on Nakum (Tozzer 1913, Pl. 31). In the text of the same report, Tozzer (1913:191) expanded on the distinctiveness of the southern *chultuns* noting further that they (6) are not located so that water can drain into them, usually being "found on ground slightly higher than that of the surrounding country" and (7) frequently lack any signs of plaster on the porous limestone walls. Most of these observations apply to the small bottle-shaped pits also found in this region (Fig. 1*c*), and though Tozzer (1913:192) distinguished these from the more elaborate of the northern water cisterns, noting that they lacked masonry walls and were not vaulted, he did not remark on their lack of plaster and comparatively small size. This oversight led him to confuse them with the bedrock variant of the cistern *chultuns* mentioned above.

The only plaster found in a *chultun*-like feature at that time in the southern lowlands was in a series of comparatively huge chambers discovered by Thomas Gann at the site of Santa Rita in northern British Honduras. One of these unusual features, described by Gann (1900:691), was entered by a half spiral staircase. The main chamber was found to be 18 ft long by 10 ft broad and lined with a layer of hard plaster. In this respect, these enigmatic chambers seem to be something like the northern cistern *chultuns*, and Gann referred to them as "underground rock-hewn reservoirs." We will leave these apparently unique features now to return to the discussion of the more typical chambered *chultuns* excavated by Tozzer.

On the basis of the points mentioned above, Tozzer felt that it was unlikely that the chambered *chultuns* he had investigated were water cisterns, and reviving Maudslay's original assessment now suggested that they may have been for "the storage of maize and other foods. . .as they are generally dry and would be suited for such a purpose." As time went on, more lateral-chambered *chultuns* were excavated, this time by Thomas Gann in British Honduras. Gann (1918:83) echoed Tozzer's opinions on function stating that they were probably used for the storage of maize and other provisions, with occasional secondary use for burials.

Thus, up until sometime during the Carnegie Institution sponsored excavations at Uaxactún, the food-storage hypothesis seemed to be gaining acceptance. Wauchope (1934:151), in confirmation of Tozzer's and Gann's observations, noted that the interior of *Chultun* 53 at Uaxactún was not plastered and suggested that it had "probably been used for storage." In an article that appeared in 1935 in *Science* (1935:615), O. F. Cook went so far as to suggest that all *chultuns*, including the bottle-shaped ones of northern Yucatán, were used for food storage and went even further by stating that he believed the food stored in them was the nut-like seed of the ramon tree. The Uaxactún studies, however, shifted the emphasis away from food storage by producing a more comprehensive list of possible functions as well as some rather startling experimental data. Ricketson (1925:390) includes in a list of possible functions their use as water cisterns, storage places, burial chambers, ceremonial chambers, and places suitable for fine weaving where moist conditions were required to make the strips pliable. Sweat bathing, originally suggested by Maudslay (1889-1902, Vol. 2:25), was added to this list in the Uaxactún report on Group E (Ricketson and Ricketson 1937:123). O. G. Ricketson (1925) seems to favor the latter possibility suggesting that hot rocks could have been dropped into the *chultun* to produce steam by pouring water on them. Blom (1936:128) favors water storage. A. L. Smith (1950:85) while stating that function remained problematical, favors the hypothesis that the orifice served as an efficient means of getting through the hard, 0.5 m thick layer of caprock so that the Maya could mine the soft limestone marl below. Schufeldt (1950:227), who also felt that *chultuns* were the result of mining for marl, offers the thoughtful suggestion that the small orifice allowed mining to go on with minimal disturbance of valuable topsoil. Bullard (1960:362) states his preference for a storage function. Pollock (1956:540), in discussion of a small bottle-shaped *chultun* found at Mayapan, suggests that they might have served as drains or refuse pits. He also mentions, as does Haviland (1963:505) apropos of the lateral-chambered *chultuns* of Tikal, the possibility that *chultuns* functioned as latrines. Finally, Ursula Cowgill (Cowgill and Hutchinson 1963:41) poses the novel idea that most *chultuns* were not man-made at all but rather the creations of uprooted palm trees, which "in some cases the ancient Maya may have modified. . . ."

Most of these possibilities, along with the Uaxactún experimental data alluded to above, tended to draw attention away from food storage. The experiment, which seems to have occurred accidentally, rather dramatically disproved Tozzer's contention that *chultuns* were "generally dry" and therefore suitable for the storage of maize. The incident that produced these data seems to have occurred as follows. Blom, at the end of the 1924 field season at Uaxactún, decided to cache in a convenient *chultun* a number of spades and machetes for use in some future season. These were prepared for storage by greasing them with vaseline and tying them up in burlap before sealing them into the *chultun* with the usual covering stone. Twenty-one months later, in 1926, Ricketson returned to Uaxactún and has provided us with the following graphic description of what he found when the *chultun* was reopened.

> The horn handles of the machetes were cracked and broken and in some cases the horn had completely fallen from the tang. The blades of the shovels were represented by thin areas of rust; their wooden handles could be broken between the fingers. The steel blades of the machetes still existed, but were rusted and quite unfit for use [Ricketson and Ricketson 1937:172].

This striking demonstration of the high humidity prevailing in *chultuns* had an obviously negative effect on the likelihood and popularity of the food-storage hypothesis.

INVESTIGATIONS AT TIKAL

It was in the face of this bewildering array of possible functions and data that systematic excavation and investigation of *chultuns* was begun at Tikal. The problem was to assemble clues from wherever possible in an attempt to elicit the primary function of the lateral-chambered *chultuns*. Over 220 *chultuns* have been found in the central 9 km^2 of Tikal. Of these, a sample of about 60 has been excavated. Between 80% and 90% of these have lateral chambers.

Some of the clues which eventually led back to the food-storage hypothesis have already been presented (Puleston 1965). While there is not room to discuss them in light of supportive data here, they will be so presented in a forthcoming Tikal report on the *chultuns* of that site. Summarizing briefly, they include the following: (1) the large number of *chultuns* found at the site and their apparent broad distribution in time, suggesting some basic and widespread function; (2) the distribution of *chultuns* all through the residential areas of the site in contrast to their virtual absence in the ceremonial nucleus, suggesting a secular rather than ceremonial function; (3) their frequent occurrence on higher ground where they would less likely be flooded by rainstorms; (4) the use of lid-like covering stones, as if a specific effort had been made to "protect" the contents of the *chultun;* (5) the frequent use of a raised sill between the antechamber and the main inner chamber, suggesting that in the event of rain it was desirable to keep water from trickling into the inner chamber (Fig. 1*b*); (6) the fact that most *chultuns* were left empty and did not contain burials or ceremonial deposits; and (7) the lack of any evidence of plastering apart from two obviously aberrant situations in which well-preserved plaster floors were found. These examples clearly demonstrated that if *chultuns* had been plastered the plaster could be expected to survive in fairly good condition. Finally, there is the evidence provided by (8) the discovery in *Chultun* 3F-6 at Tikal of 5 large, wide-mouthed vessels, apparently left in situ. Although these vessels are somewhat atypical, fragments of what may have been storage vessels have turned up in 2 or 3 other Tikal *chultuns*.

On the basis of points (3), (4), (5), and (7) above, it seemed safe to eliminate the possibility of water storage, as Tozzer had. Goaded on, however, by a colleague's suggestion that the limestone might be self-sealing once it became wet, in 1965 we performed the simple experiment of pouring 400 gal of water into a *chultun* and observed the results. Within 3 hr there were only 100 gal left and before 8 hr were up the last of the water had completely drained away into the obviously very porous limestone.

Moving on to the other possibilities, the excavation data argued strongly against burial chambers as a primary function. Only 1 out of 6 or 7 *chultuns* seems to have been so used. Even in those cases where they were used for burials it was often clear that they had served some other function first. A ceremonial function also seemed very unlikely in light of the apparent irregularity of the orientation and location of *chultuns* the scarcity of ceremonial deposits in them, and their overall frequency and distribution. In view of the cramped conditions often found in *chultuns*, time-consuming human activities such as weaving and sweat bathing seemed unlikely. The backaches produced by even relatively short spells of crouching in the smaller *chultuns* while excavating or drawing provided convincing experimental data. Furthermore, no good evidence of rocks used for steam production, as suggested by Ricketson (1925), could be found, nor could we come up with an explanation as to how hot air and steam could be kept in the *chultun* when the lid was removed to drop in more rocks and let in the air necessary for breathing. With the discovery by Christopher Jones in 1964 of what was clearly a sweathouse, much like those identified by Satterthwaite (1948) at Piedras Negras, the likelihood of this explanation declined. The "necessity" of finding some kind of evidence for sweat bathing at Tikal, with *chultuns* as the most likely candidates, was no longer present. Smith's marl extraction hypothesis seemed unlikely when considering the fairly regular size and shape of *chultun* chambers and the need of an explanation for the floor sills and covering stones. Nearby quarries, as pointed out by Bullard (1960:362), would have been a more convenient source for marl. Finally, the latrine hypothesis was rejected since it also provided no explanation for the lateral chambers and sills. Ethnographic data on modern Maya Indians (Steggerda 1941:18) suggests that the disposal of human feces was left to vultures and dogs. Even supposing that such customs have changed since Classic times it seemed unlikely that latrines would be secondarily used as burial chambers. No evidence of the expected deposits was found in excavation.

This series of eliminations left us with the food storage hypothesis again which actually seemed to fit the clues we had assembled fairly well. Food storage was certainly a basic, secular activity which would not require long periods of sitting in the *chultun* and yet would require them to be capable of being entered and sealed. Having spent the night in a maize storage house at Uaxactún in 1963, we could well appreciate the utility of rodent-proof underground storage. Our quarters literally swarmed with rats during the night and their annual toll on the stored crop must have been significant. While we could not be sure these were not introduced species, native rodents such as *Heteromys* are known to be granary pests (Walker 1968:746). Other native rodents including *Oryzomys* (?) and another unknown species, possibly *Heteromys*, have been trapped with baited traps in storehouses and habitations at Tikal by Peter Puleston. The only problem that nagged us was the question of why *chultuns* did not seem to be used in the Petén in historic times. Apart from this, however, it all seemed to make good sense and all that apparently remained was to demonstrate that though *chultuns* may have been unfavorable for the storage of metal tools at Uaxactún, they were fine for the storage of certain Maya foods, in certain ways. Which foods though and in what way? Experimental studies seemed an obvious course.

EXPERIMENTAL CONSTRUCTION OF A *CHULTUN*

Initially, we had intended to use a Maya *chultun* for our experiments but later decided against it in favor of constructing and using our own *chultun*. This not only eliminated the possibility of uncontrolled variables accruing from the age of the Maya *chultuns*, but it also afforded an opportunity to study the techniques of *chultun* construction and the use of stone tools. Accordingly, in 1965 a number of stone tools of the types called biface ovate and biface elongate were hafted Polynesian fashion to wooden handles and used to excavate our own lateral-chambered *chultun* out of the limestone bedrock (Fig. 2).

Fig. 2. Starting the experimental *chultun* antechamber. Stone tools were found to be entirely adequate for cutting through the limestone caprock. At about this stage we had to start using the bit-ended tool. (Photograph by Francis P. Bowles.)

Summarizing very briefly, information resulting from this exercise included the discovery that, (1) flint tools were entirely adequate for cutting through the hard surface layer of limestone and that it would have been quite easy for us to expand our orifice if our only concern were the extraction of the softer marl below. (2) Tools of different kinds were needed to construct the *chultun*. While the adze-hafted tools were adequate for most of the work, we had to devise a long handled bit-ended tool to dig out the deeper portions of the narrow antechamber. (3) Tool marks on the walls of our *chultun* corresponded well with similar marks observed on the walls of ancient *chultuns* in respect to width, length of stroke, angle of stroke, etc. (4) The amount of time and labor required to excavate a *chultun* with stone tools was relatively little. In all, it required approximately 30 hr of work with the assistance of someone to haul out basketfuls of marl when work got going in the inner chamber. More time was required to cut out a circular covering stone which was accomplished with the help of wooden wedges.

EXPERIMENTAL FOOD STORAGE

In the following season of 1966, we assembled an assortment of vegetables including maize, beans, squash, *yuca* or cassava (*Manihot esculenta* Crantz), *camote* or sweet potato [*Ipomoea batatas* (L.) Poir], *macal* (*Xanthosoma* sp.), and potatoes. The potato, of course, was not a Maya food and was included only for comparative purposes. Two varieties each of beans and sweet potatoes were used while maize was tested fresh on the cob, dried on the cob, and as dried kernels. Samples of all these vegetables were placed in the *chultun*, a control series was also stored above ground. This aboveground series was divided in two, half being stored on a screened-in porch which provided protection from rodents and some insects, while the other half was stored at the mercy of these vermin in an unprotected outbuilding. All the samples were examined, weighed, and photographed every 2 weeks for a period of 8 weeks and finally at the end of 11 weeks.

Measurements of the humidity in the *chultun*, taken on June 5, 1966, indicated a figure of 100%. No difference was observed between the wet and dry bulb readings even after vigorous fanning. While the humidity of the *chultun* micro-environment must go up and down to some degree it is unlikely that it is ever low for very long. The temperature in the *chultun* during the day in June fell in the range of 75°-80°F.

With the ensuing activity of storage fungi and rodents, developments over the 11 weeks were fairly rapid both above and below ground. Below ground, the maize in all forms did very poorly. The fresh maize decomposed first after sprouting vigorously. It was followed by the shelled maize which seemed to be particularly susceptible to the attacks of fungi at the base of the kernel where it attaches to the cob. By the end of 11 weeks the shelled maize, along with the dried maize still "on the cob," suffered from a heavy infestation of mites. Only 10% of the dried maize on the cob was judged edible after 11 weeks.

The beans fared little better. After a short time, they became soft as if they had been soaking in water and soon afterward succumbed to vigorous growths of fungi and mite infestations. The latter included specimens of the species *Tyrophagus putrescentiae* (Schrank). The one exception to this was a sample of black beans which had been placed in a deep but open glass jar. For some reason, although the beans became soft, they remained edible when beans on raised ceramic dishes decayed rapidly. One green squash, while it lasted longer than the aboveground controls, decomposed suddenly and completely sometime after the eighth week. The root crops produced ambiguous results. The potatoes and *macal* survived with minimal spoilage but underwent continuing if gradual weight loss. The *yuca* was 95% decayed by the end of 11 weeks. One variety of sweet potato became covered with fungi (*Rhizopus*, a

Fig. 3. Maize storehouse situated near the center of a milpa at Tikal, 1967. Maximum contact of dry, circulating air under these conditions helps keep down the moisture content of the maize, preventing the growth of fungi.

common cause of rot in sweet potatoes) early in the experiment while the other variety did not. Both varieties sprouted but were still apparently edible at the end of the experiment.

Meanwhile, above ground, the depredations carried out by rodents and insects were impressive. By the end of 11 weeks virtually nothing remained of the maize, *yuca*, or sweet potatoes. The beans which had been placed in glass jars where only certain flying insects could get at them were virtually untouched. The root crops, and particularly the decaying *yuca* were heavily attacked by the larvae of an as yet unidentified species of microlepidoptera and a beetle, *Colopterus posticus* (Er.), Nitidulidae. Apart from the mites and some weevils (evidently *Sithophilus zeamais* Motsch.) which seem to have come in with the maize, no such attacks took place in the *chultun*.

In conclusion then, while the *chultun* apparently offered valuable protection from vermin, it evidently could not be used for the storage of maize, beans, or squash. Even the root crops did not do particularly well.

In light of the high humidity and temperature of the *chultun* micro-environment, these results probably could have been predicted. Maize, in the lowlands today, is stored under the driest, best ventilated conditions possible. This is often in cribs in a storehouse located in the center of the milpa (Fig. 3). Modern Yucatecan storehouses and granaries have been described by Wauchope (1938:133, 136).

Christensen and Kaufmann (1969:25) indicate that primary factors in the growth of storage fungi on grains include temperature, length of time in storage, and moisture content of the stored grain. Since the latter remains in equilibrium with the relative humidity, the higher the humidity, the higher the moisture content of a particular grain will be. The actual ratio between humidity and moisture content and at what level of the latter fungi can begin to be a problem, varies from one crop to another. For maize, a moisture content of a little over 15%, which can be produced by a relative humidity of only 75% at 68°-77°F, is perfect for some of the most common storage fungi. A temperature of 85°-90°F is ideal for the most rapid growth of the most common storage fungi. Optimum conditions for both mites and fungi tend to be about the same, and they seemed to characterize the conditions found in Classic Maya *chultuns*.

In respect to root crops, *chultun* storage did not seem to be particularly beneficial. Some, like the *macal*, would obviously do better if simply left in the ground and used when needed. The roots of the *yuca* are best "left in the ground, as they decay quickly when harvested" (Bailey 1935:1991). The tubers of the sweet potato apparently rot in conditions of excessive humidity and temperature and are best stored for the wet season by harvesting and drying, otherwise they may be left in the ground and used as needed (Netting 1968:74). A certain amount of experimental work has been done with artificial storage of sweet potatoes, and it is worth noting that under conditions of high humidity (85%), best storage temperatures fall in the range of 55°-60°F (Cooley and others 1954). This is 20° cooler than that recorded for the *chultun*, and it is perhaps for this reason that drier storage conditions are preferable for sweet potato storage in the tropics. Finally, the possibility that *chultuns* were used for storage of root crops seemed unlikely in view of the fact that such an evidently popular innovation as the *chultun* did not continue to be used into historic times by groups who still consumed a fair amount of this type of food as indicated by Bronson (1966:258). These points in combination with the marginal performance of root crops in the experiment left us with the feeling that the raison d'être for lateral-chambered *chultuns* was still eluding us.

In the following year, 1967, we made one more try with maize, parching it in a fire as the Navajo do before storing it underground. The results were disastrous. The parched maize began to mildew vigorously (*Aspergillus glaucus*?) long before the unparched samples showed the first signs of fungi.

THE RAMON

Then, in that same year, in the course of another study, we discovered the phenomenal correlation between the present distribution of the ramon tree (*Brosimum alicastrum* Sw.) and the remains of Maya house platforms, suggesting that these trees were the descendants of trees cultivated, in the vicinity of their homes, by the Classic Maya of Tikal. Subsequent recognition of the high nutritional value of this dense carbohydrate food, coupled with the discovery of the staggering productivity of the

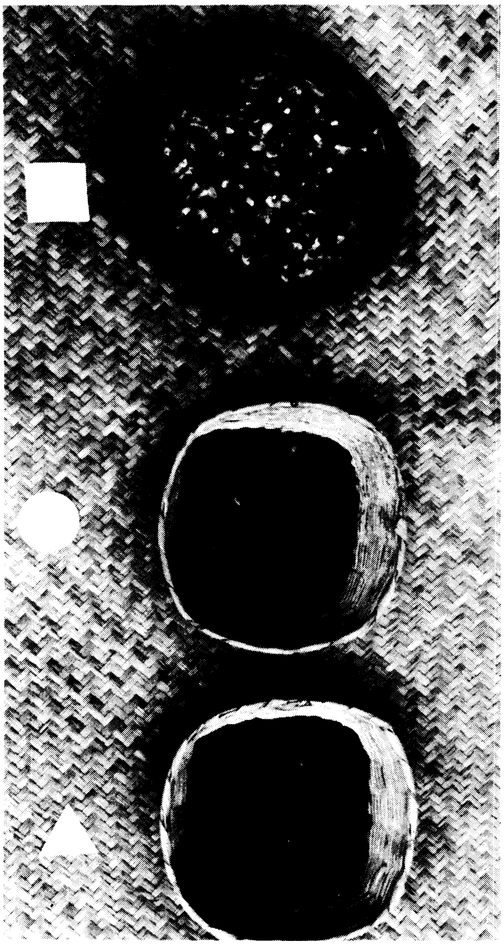

Fig. 4. Dried black beans after 3 weeks of storage; in the *chultun* (square): above ground, unprotected by screening (circle); and above ground, protected by screening (triangle). Note extensive growth of fungi on the *chultun* sample and discoloration of the decaying basket.

trees all served to confirm the potential significance of this crop for ancient Maya subsistence (Puleston 1968). The appropriateness of a test run for ramons in the *chultun* was self-evident by the end of the 1967 season. The fact that O. F. Cook (1935) had anticipated by more than 30 yr the possibility of this relationship between *chultuns* and the fruit of the ramon tree remains a credit to his insight.

Thus, in 1968, a new series of fruits and vegetables including the ramon were stored in the experimental *chultun* with a single protected control above ground. The results of this experiment confirmed our suspicions beyond our expectations. After 9 weeks, the previously tested vegetables produced much the same results as before (Figs. 4, 5). The corn and beans were quickly reduced by fungi and mite infestations. The manioc rotted quickly while the sweet potatoes and potatoes sprouted but did not rot seriously within the period of the study. A few new fruits including avocados (*Persea americana* Mill.) and *zapote mamey* [*Calocarpum mammosum* (L.) Pierre] became inedible within 3 weeks. The ramon seed, however, after 9 weeks gave every appearance of being as fresh as when it had been put in (Fig. 6). Though some of the seeds had pro-

Fig. 5. Dried, shelled, yellow maize after 9 weeks in the *chultun*. Dissected kernels reveal the extent of internal decay. Note the solidified mass of decayed maize at the top.

Fig. 6. Undried ramon seed after 9 weeks in the *chultun*. Dissected seeds reveal their excellent condition, one out of hundreds that decayed is at the top. Most of the seeds had begun to germinate.

duced short sprouts, they were unaffected by fungi or mites. The seeds remained hard and did not soften up as the beans in the jar had. These seeds were left in the *chultun* at the end of the summer, and as of July, 1969, after 13 mo of underground storage, they were still in excellent condition and completely edible (Fig. 7) though the wicker baskets they had been placed in were reduced to a brown debris.

Why does the ramon preserve so well under conditions which are so destructive to so many other foods? The answer may lie in the very low water content of the seeds. Ramon seeds have a measured water content of only 6.5% as compared to 10.6% for dried maize and 12% for dried beans (Leung 1961). In this regard, certain parallels can perhaps be drawn between ramons and acorns as used by the Indians of California. The great importance of acorns in these cultures is attributed to the fact that, of all the available wild foods, acorns were the most amenable to storage because of their low water content which is reported to be 9% (Baumhoff 1963:161). Thus, even with a relative humidity of 100% the equilibrium moisture content of ramon seed does not seem to come up to a level that would permit the growth of fungi. The possibility of the existence of a natural antibiotic in the seed might also be considered. The astonishing ability of these seeds to resist decay is not coincidental and probably represents a selective adaptation of the fruit to the highly humid microenvironment of the forest floor where the seeds eventually must germinate.

Fig. 7. Ramon seed after 13 mo in the *chultun*. The seeds are still firm and completely edible. Sprouting seems to have been retarded.

MAIZE STORAGE

At this point, a very real problem remains to be dealt with which leads from the statements of Landa, and possibly others, as well as the previously referred to 16th century report on Ekbalam. Landa states that "*el maiz y las demas semillas*" were stored by the Yucatecan Maya in "*muy lindos silos y trojes*" (Relaciones de Yucatán 1898-1900, Vol. 2:322) [Tozzer (1941:96) translates *silos* as "underground places" which in the light of the sixteenth century usage is apparently correct (Corominas 1954, Vol. 4:224-227)] and that they gathered great quantities of maize and made granaries (*trojes*) and kept it in underground places (*silos*) for the barren years (Tozzer 1941:195). The apparent inconsistency of these statements with the experimental data reported above suggests that underground storage in northern Yucatán may have been somehow more conducive to the storage of maize than in the *chultuns* of the southern lowlands. In fact, it is curious that Landa's "fine underground places" for maize storage have never been identified archaeologically. Though an obvious place to start would be Ekbalam, an intriguing case can be presented for the possibility that they have already been discovered. In the course of the excavation of residential and associated structures at Mayapan, chambers were frequently found beneath, or rather within, the structure platforms (Fig. 1*d*). Some of these could be entered from above, others from the side by means of lateral openings in the sides of the platforms or benches, and in several instances by means of stairways that passed down through the floor from inside the structure. Many of these contained burials, and on this basis, A. L. Smith has suggested that all were intended for this purpose. Those which did not contain interments (about 18) he classifies as burial vaults, "apparently prepared for future interment of the dead but never so used" (Smith 1962:232). In view of the fact that so many of these chambers were found to be empty, however, alternative hypotheses seem to exist in the possibilities that, use of the chambers for interment was secondary rather than primary, and at least 2 functionally distinct chamber types, that happen to occur at the same locus, have been lumped together in a single category. The strong possibility exists that the majority of these chambers, constructed in aboveground deposits of dry fill and beneath a plastered platform with a structure on it, may have provided a comparatively dry storage place. This in combination with the drier climate of northern Yucatán (Vivó 1964), may have made it possible to store maize "underground" in this region. The practice of locating granaries within structure platforms seems to be confirmed by the description of the *silos* at Ekbalam mentioned earlier, but experimental work on storage under these special conditions in northern Yucatán would seem to be in order.

SUMMARY

Usage of the term *chultun* has been confusing. At least 2 distinct functions may be attributed to morphologically distinct archaeological features that fall under this term. In the northern lowlands deep, plaster-lined, bottle-shaped pits constructed of masonry in artificial fill or excavated directly out of the bedrock, appear to have functioned as cisterns. These remain to be distinguished archaeologically from possibly similar *silos*, mentioned in historical sources, that were apparently used for the storage of maize in Postclassic northern Yucatán. The function of shallow, lateral-chambered excavations in the limestone bedrock of the southern lowlands has not been so obvious. Of the many hypotheses presented, the results of extensive excavation and experimental studies appear to be most consistent with the suggestion that they were used for food storage. Maize does not appear to be amenable to storage under these conditions, however. Of a series of experimentally stored foods, the hard seed of the ramon (*Brosimum alicastrum*) did best, remaining entirely edible for at least 13 mo. This fact, in combination with a high correlation between large numbers of ramon trees and the remains of Maya housemound settlement; and the prevalence of Classic and apparently Preclassic *chultuns* in certain parts of the southern lowlands, suggests that this fruit may have held a position of considerable significance in the subsistence systems of the Preclassic and Classic Maya over a good part of this region.

Subsurface food storage does not appear to have been restricted to the southern lowlands. Historical sources indicate fairly clearly that large quantities of maize were stored in artificial *silos* within structure platforms. Chambers within structure platforms, which could not have been used for water storage, have been discovered in archaeological contexts at Mayapan. Though many of these contain burials, many others do not. Experimental work is needed to show that maize can in fact be successfully stored in this region under these conditions.

CONCLUSIONS

In respect to the lateral-chambered *chultuns* of the southern lowlands, it appears that O. F. Cook's hypothesis (1935) that they were used for the storage of ramon seed is viable. The hypothesis lends itself to an explanation of why lateral-chambered, bedrock *chultuns* are not in use among the Maya today and apparently have not been made or used in that form since the time of the collapse of Classic civilization, ca. A.D. 900. This explanation is, that for some reason, the fruit of the ramon ceased to be an important staple for the Maya after this time. The continued use of somewhat similar sub-platform chambers in the northern lowlands may be associated with the storage of better known crops.

By way of conclusion, I wish to point out the key role experimentation can play in hypothesis construction and testing when dealing with problems of function. It offers a potent means of getting beyond what would otherwise be dead ends in archaeological research if only archaeological data were used as evidence.

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ARCHAEOLOGY, HISTORY, AND ANTHROPOLOGY IN THE MIXTECA-PUEBLA REGION OF MEXICO

SHIRLEY GORENSTEIN

ABSTRACT

Cultural change from the prehistoric to the protohistoric period is seen as a subject of anthropological study in which archaeological and ethnohistorical data are complementary sources. It is suggested that an interpretation of the effect of the postconquest economic and political innovations in Tepexi, a Mixteca-Puebla community in Mexico, can be made only after an examination of the condition of the preconquest economic and political systems. Tepexi was economically overburdened in preconquest times as a result of Aztec tribute demands, and the introduction of the silk industry by the Spaniards may have been responsible for sustaining the failing community.

Department of Anthropology
Columbia University
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The archaeologist who is an anthropologist is concerned with the ethnology of prehistoric times. In order to elicit the information he needs from the sources available to him, he has devised special techniques and methods which enable him to reconstruct and interpret past lifeways. Although these reconstructions are not full, they yield sufficient relevant data which can contribute to the understanding of problems of cultural change. The source material for understanding cultural change can be greatly expanded if prehistory, whose circumstances are not often duplicated in history, is included in the body of information and interpretation on which all anthropologists may draw. In pointing out that the data collected and analyzed by archaeologists may be of use to cultural anthropologists and suggesting that cultural anthropologists may profit from the examination of prehistory, I am drawing on the general principle that archaeological data are of value equal to those of ethnology for interpretation in anthropology.

There is, however, in the protohistoric period a very *specific* relationship between prehistory and history in which the two are inextricably intertwined. While the date 1519 marks a historical event in Mexico, and in that sense is a firm boundary line between history and prehistory, it does not demarcate change in culture in the same way. Mexican culture was not entirely different in 1518 from what it was in 1519. For the anthropologist and historian of the conquest period to understand the circumstances of that time, they must examine the background against which the circumstances were being played; and that background has its roots in prehistoric times.

It is the thesis of this article that an evaluation of cultural change after the