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# Maya Lowland Hydraulic Systems

## Reservoirs, canals, drains, and other water controls were important in development of Maya civilization.

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Before they could establish permanent residence the early peoples who settled in most areas of the Maya lowlands had to develop an adequate water supply. Water is of prime importance in these lands in spite of the tropical climate. The Yucatan Peninsula, Tabasco, the Veracruz gulf lowlands, Belize, the Petén of Guatemala, and Honduras suffer long periods without precipitation, so unless settlers could locate at a karst-cenote, rare spring, or perennial stream or river, they had to develop a water system.

Researchers some years ago emphasized development of water systems for irrigation as a requisite for intensive farming, which in turn was supposedly required for urbanization (*1*). It is now clear that lowland settlers also used intensive farming methods that did not involve irrigation. The use of drained fields, raised rows of soil called ridged fields, terraces, check dams, platform or mounded fields, dikes, and aquatic cultivation is summarized by Turner (*2*). With this expanded perspective on water control, we can begin to understand why so many large ruins, suggesting such large populations, exist in the lowlands.

It now seems apparent that control of water by ancient peoples for many purposes other than irrigation was crucial in the development of civilization in the New World. Such devices as ridged fields and terraces were essentially means for controlling water for the primary aim of ensuring food production. Of course, maintaining supplies for drinking, food processing, cooking, and bathing was also vital, and various manufacturing processes not related to food but essential for peoples in a particular lowland environment also required water. Mud wall construction, lime cement production, and erection of platform and pyramid-plaza complexes, for example, sometimes required prodigious quantities of water. And water was sometimes used for community services, as it was in the Aztec capital Tenochtitlan where waterways were important in transportation and defense.

### Early Settlers of the Mexican Gulf States

The choice of location for Olmec sites of the Early Preclassic period (about 1500 B.C.) in the Veracruz and Tabasco lowlands seems to have been based on the resources of a riverine environment (*3*). La Venta, a major Olmec site found on the Tonalá River, Tabasco (Fig. 1), probably required considerable water during construction of its massive facilities. A nearby supporting population cultivated the rich alluvial soils of the river levees. The San Lorenzo group (*4*) near the Rio Chiquito is another example. At both sites, large basalt stones, some weighing 30 tons, were imported from the volcanic Las Tuxtlas Mountains 100 kilometers away. The sea and rivers must have been used in transport of the stones. Approximately 50 metric tons of serpentine were imported to La Venta as small pieces to be used in ceremonial displays. It is likely that much of this material also was transported by watercraft to workshops in nearby villages rather than being packed by human carriers the entire distance from the source on the west coast of Mexico.

Considerable manpower was required to build, maintain, and use the ceremonial-esthetic structures of stone and clay that are found in the area. The resulting degree of organization required food beyond the subsistence level to support artisans and priests. We do not know whether swidden or intensive agriculture was practiced, but there was concern about water. At San Lorenzo, water was carried out by conduits from reservoirs lined with bentonite (*5*). That the Olmecs laboriously carved these conduits from basalt imported at least 100 km through raw forest suggests that water must have been very important to them.

Ball (*6*) calls the Middle Preclassic (1000 to 600 B.C.) settlers on the Yucatan Peninsula, to the northeast of Olmec settlements, Pioneers. The term is an apt description of the first farmers known to conquer a rather hostile environment, perhaps as early as 1000 B.C. The major problem facing settlers of the limestone peninsula was water. There are only a few lakes, a few small coastal rivers or streams, a very few springs, an unknown number of shallow basins (aguadas) where rainwater collects, only to disappear during the dry season, and perhaps several hundred karst-cenotes and underground caverns where limited water may be obtained. In 1841, Stevens described what may be the ultimate hardship in obtaining drinking and cooking water after he had accompanied the Maya through an underground cavern to water level some 137 meters below ground (*7*).

The Pioneers settled in some areas that lacked cenotes or caverns (*8*). Toward the end of the Late Preclassic period (300 B.C. to A.D. 100), bottle-shaped underground cisterns called chultuns were dug into limestone bedrock and plastered with lime cement. These cisterns collected rainwater from the paved plazas and buildings constructed above them (*9*). Although chultuns are surely as old as the Late Preclassic period, it is

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likely that the Middle Preclassic Pioneers invented them. Their importance in northern Campeche, which lacks surface water of any consequence, has been shown by DeBloois, who calculated that during the Late Classic period more than 1500 $m^3$ of water storage was available at Santa Rosa Xtampak from 67 chultuns that were apparently the only means of collecting and storing water at the site. Impressive as these chultuns are, the importance of water in this semitropical zone is perhaps best seen in the elaborate hydraulic system discovered recently at Edzna.

### Hydraulic Construction at Edzna

Edzna (*10*) lies in a central Campeche valley where surface water is found only in an occasional aguada. Groundwater is 20 m below the surface in limestone formations. Apparently the Maya could dig wells through 20 m of soil and rock, but they chose not to do it at Edzna. Only 12 chultuns of the Late Classic period have been found at the site, suggesting that this method of obtaining water was too difficult to exploit (*11*). Soil in the Edzna Valley consists of stratified clay and has a high impermeability to water once it becomes soaked during the rainy season.

The first settlers at Edzna were Pioneers of the Middle Preclassic period. Although evidence for the Middle Preclassic period is moderate, it seems to parallel similar manifestations found at nearby Dzibilnocac, Santa Rosa Xtampak, and Becan. We assume that Pioneers settled at Edzna because naturally occurring aguadas could be developed into dependable water sources and, secondarily, because the valley soil was unusually deep for central Campeche.

During the Late Preclassic period a huge hydraulic system, consisting of more than 20 km of canals and an extensive array of reservoirs, was constructed at Edzna. Excavations and analysis of artifacts suggest that this system was operational by the time of Christ. The main canal ends (begins?) at a savanna 12 km south of Edzna. This canal is large—50 m wide for at least 6 km of its length. It may be equally as wide at the 12-km point, which has not been measured. Test trenches show that the canal was originally excavated to about 1.5 m below ground surface. The north end of the canal joins a huge moat system that surrounds an earthen fortress (*12*). The moat in turn joins to a canal that runs north to within 250 m of the ceremonial center of the site (Fig. 2). Other smaller canals join the main canal and moat system.

From the southwest corner of the moat the main canal is oriented nearly north-south for its first 4 km, aligning exactly on the main temple structure known as Cinco Pisos. The alignment is deliberate for this entire distance but then becomes less exacting as a crooked section of the canal leads to the savanna. The canal alignment was part of an overall plan for the ancient city.

There are seven large canals (averaging 40 m wide and from 0.6 to 1.5 km long) and two smaller ones in the northwest and northeast sectors of the site (Fig. 3). These canals, identified first as radiating lines on aerial photographs, are only nine of a larger number of lines that converge on the city center like the spokes of a wheel. Some of the lines may prove to be ancient roads or trails, but these nine are definitely canals.

Excavations in some of the converging canals show they were dug to a depth of

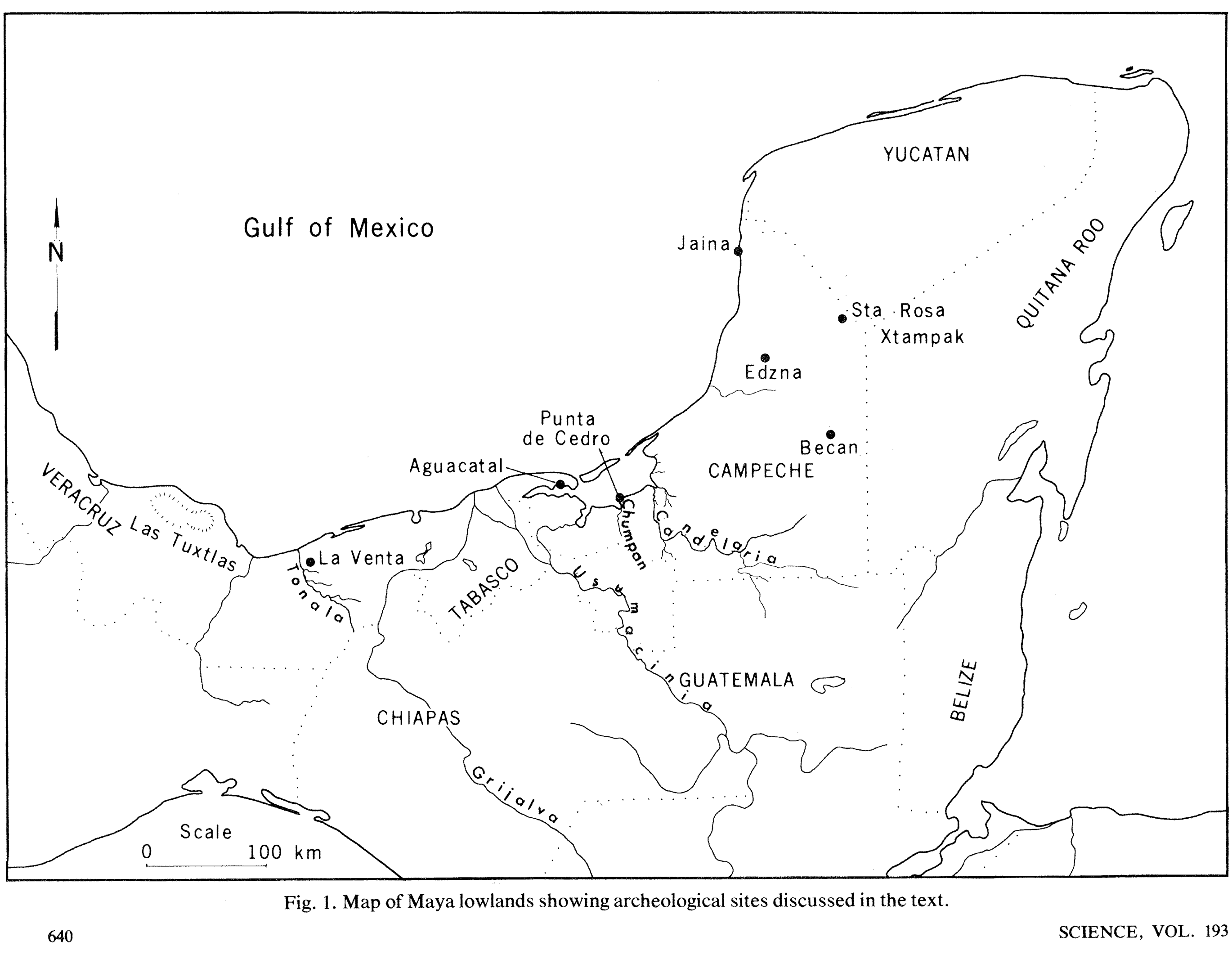


Fig. 1. Map of Maya lowlands showing archeological sites discussed in the text.

3 m. Earth from the original digging was used in constructing house platforms on or near the canal banks. Excavations in these platforms suggest that a Late Preclassic farming population lived along the canals adjacent to the city center.

All of the canals in the area may not have been detected; only three canals are easily detectable from the ground. The ancient channels are mostly filled with soil but, since they were dug down into an impervious layer of clay, they still retain water during the height of the rainy season, and differential vegetal growth may be seen on some of the filled canals. Others appear as faint lines on aerial photographs; however, we could not locate them on the ground in the limited time we have had for investigation.

The nine canals in the northeast and northwest sectors were suspected on a 1948 aerial photograph (Fig. 2) to be only faint tracings of unusual vegetation. With this clue, however, we reexamined the area in 1973 by aerial photography, using color infrared and black-and-white infrared films. These photographic combinations provided clear outlines of the nine canals that were oriented toward the site center. The infrared films are particularly sensitive to open water and are useful in detecting water-soaked areas where water accumulates on the surface (Fig. 4) (*13*).

We took the aerial photographs in October, at the height of the rainy season, to take advantage of water-soaked channels (*14*). These photographs of the canals provided maps which we then checked for ground truth. In the succeeding dry season we excavated the canals to determine the nature and date of construction. Mapping teams using standard procedures for plane table and alidade found that these procedures were inadequate to detect seven of the nine canals outlined in the infrared aerial photography.

We can only speculate that the orientation of the converging canals has some long-forgotten symbolic meaning that may be linked with celestial observation or some cosmographic concept.

The moated complex is 1.5 km south of the ceremonial center of the site (Fig. 5). We call the construction a fortress because of the moat, a restricted entry causeway, and strategically located mounds that appear to be in defensible positions. The moat is of primary interest for this discussion, and I will describe it in some detail.

With a minimum circumference of 1873 m and an outside circumference of 2700 m, the moat completely surrounds the fortress except for the narrow, loaf-shaped causeway on the north end. This causeway is 1.5 km long and leads to the center of the site, where public buildings are found. The width of the moat varies—it is as wide as 110 m on the north side of the fortress, 80 m on the south side, and an average of 25 m on the east and west sides. Excavation shows that the moat was about 1.5 m deep on the south, while the west side was 3 m deep.

In the northeast and northwest sectors of the site are a series of reservoirs. These are mostly independent although some connect to the canals. Large reservoirs—there are about 25 of them—are usually accompanied by a group of mounds, while the numerous small reservoirs are each accompanied by one or more house mounds.

Several reservoirs fed by canals lie upslope to the north, close to large ceremonial or public buildings. Water was conducted from about 1 km away to a densely populated sector of the city. It is likely that reservoirs and canals once provided water to nearly every area of the site except the center, which is built on a high outcrop of rock.

The canals and reservoirs collect rainwater. Approximately 1000 millimeters of precipitation occur each year, although this may vary depending on storm tracks. Single tropical storms at any time of the year can put down 100 mm or more of precipitation as far as 100 km inland. The main canal may also have served as a drain channel for surrounding soils to enhance farming; in any case, it collected and held a large quantity of water. The fortress moat and main canal held approximately $1.5 \times 10^6$ m$^3$ of water at the height of the rainy season. Other canals and reservoirs held approximately $0.5 \times 10^6$ m$^3$ more. In a land where surface water is scarce, $2 \times 10^6$ m$^3$ of water storage is an appreciable amount.

It is likely that naturally occurring

Fig. 2. High-altitude aerial photograph of Edzna taken in 1948. The 12-km-long canal is at the bottom and connects to the moated fortress. The faint lines at the top that converge toward the center of the site are ancient canals.

aguadas were first modified by cleaning them out or enlarging them. Evidence of this comes from pollen and spore samples taken from excavations at the fortress. *Isoetes* sp. (a water plant) spores have been found more than 2 m below the ground surface of the causeway next to the northwest moat. The spores are also found in several successive levels above the original find. Our interpretation of this is that, as an aguada was deepened and enlarged, the water plants were thrown up along with the excavated soil that formed the causeway. We regard the successive occurrences as evidence of cleanout activities.

The reason for the fortress construction is not known, although it probably coincided in time with the fortifications of Becan, Campeche, about 100 km south of Edzna. Webster (*15*) suggests that the huge dry defensive ditch surrounding Becan may have been constructed in the Late Preclassic period. If there was a cause for defense at both Becan and Edzna at about the same time, it likely was a short-lived cause. However, once the fortress moat at Edzna was built, the reasons for maintaining it were centered around the 186,000 $m^3$ of water stored there. The main canal may have been dug at the same time. Test excavations in the canal have revealed pottery from the Late Preclassic period.

The locations of the fortress, main canal, and radiating canals are not the result of haphazard additions; they show deliberate and precise planning. A hydraulic system designed to bring water into populated areas of the city was laid out symmetrically, with the city center as the focal point.

We also have evidence of deliberate water control. Reservoirs in the northwest sector are at a higher elevation than connecting canals. As the water ran from these reservoirs to the south end of the canals, small feeder channels directed it to other reservoirs closer to public buildings. One such linkup provided water for a large public building complex not far from the center of the city.

Initial construction of this elaborate system was a major undertaking that required a highly organized labor force over a considerable period of time. The builders removed approximately $1.75 \times 10^6$ $m^3$ of soil in constructing the canals. Most reservoirs probably were enlarged or otherwise modified aguadas that required much less labor to build. In view of the volume of soil moved in the entire operation, this monumental building project was at least as ambitious as the Pyramid of the Sun at Teotihuacán (*16*). The great pyramid contains approximately $1 \times 10^6$ $m^3$ of compacted earth and rock fill. In volume of earth moved, then, the Edzna canals are about equal to the pyramids of both the Sun and Moon at Teotihuacán. Maintenance of the system must have been an awesome task, with choking weed growth as probably the chief concern. Several canals are still functioning; some hold water as deep as 1 m.

A tall grass has entrenched itself in most of these canals, along with spiny, water-tolerant shrubs. Trees do not grow in the water channels, although they do flourish along their banks. The Edzna people may have solved the problem of the grass by keeping the channels cleaned of slumped-in soil, a task requiring considerable labor. Actually, some channels that now contain water nearly through the dry season do not have the grass and shrub problem. Interestingly, these channels do have the aquatic plant lechuga (*Pistia stratiotes*) growing on the water surface. By providing shade, lechuga lowers water temperature of shallow bodies and retards evaporation. Although this particular plant is a recent import that was not present in the times of the original channel builders, it seems likely that the people of Edzna maintained some such water plant (perhaps, lilies) to prolong water storage.

Since water now remains in nearly filled channels, it is reasonable to suppose that, if the canals and reservoirs were kept free of grass and slumped soil, maintenance of an adequate year-round supply of water in them was surely possible.

Exact special purposes for which the hydraulic system was used are not known. We can say safely that the rainwater was used for drinking. Modern Maya use the water in these ancient channels for drinking and bathing up un-

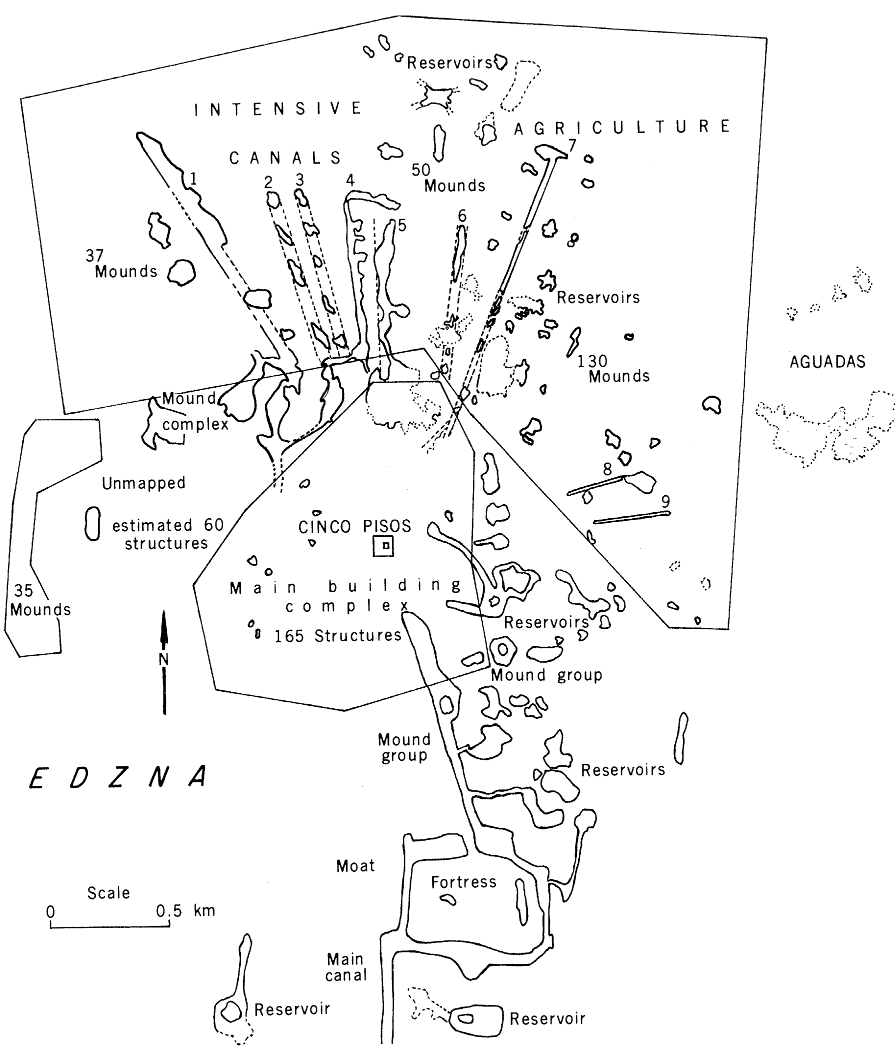


Fig. 3. Map of hydraulic features at Edzna. Outlined areas represent water-soaked canals and reservoirs determined from infrared aerial photographs and wet season mapping. Note alignment of canals toward the center of the site. The seven large canals are labeled 1 through 7; the two smaller ones are labeled 8 and 9.

til about February (the normal dry season runs January through May), when the water level is so low that it is full of aquatic life and is unfit for drinking. It is also probable that gardens were hand-watered from the canals, although there is no evidence that fields were irrigated. Insufficient storage volume and a very small gradient to fields rules out irrigation agriculture in the usual sense. Some "pot-irrigation," a practice not unknown in Mesoamerica (*17*), could have been undertaken, but it would have required much labor.

It is possible that soils accumulating in the water system at Edzna were cleaned out and used to renew farm plots, as was done in Tlaxcala in recent times (*18*). It is also possible that vegetal mulch, along with canal muck, could have revitalized some of the heavy clay soils of the region. If all parts of the water system were cleaned out periodically, about 400 hectares of muck to be worked into garden or farm plots would have been provided. Another possibility is that some of the channels were used as chinampa plots, which could account for their present obscurity. In any case, we think that the water system figured importantly in some form of intensive agriculture at Edzna.

The benefits of this extensive water system were not restricted to agriculture, cooking, drinking, and bathing. The canals now contain the edible water snail *Pomacea flagellata*. Fish, including alligator gar (*Lepisosteus tropicus*), catfish (*Ictalurus meridionalis*), and mojarra (*Xystaema cinereum*), abound in the canals during a normal wet season and remain dormant in the canal muck during the dry season. The Maya have also found crocodiles (*Crododylus moreletti* or *C. acutus*) here in the last few years.

The possibility that the canal builders of Edzna also harvested fish is strengthened by numerous references to pisciculture that occurred in the lowland area in protohistoric times (*19*). In fact, the Maya were probably unable to keep the fish out of the canals. Even though there is no water channel between the canals and a freshwater source, it is highly probable that fish were widely dispersed from perennial streams and lakes during the rainy season, when large tracts of land were flooded. Aquatic birds could also have been responsible for the distribution of some fish.

The present-day Maya harvest fish from the canals in late February and March, when the water has been reduced to small pools. In past times, assuming the canals were kept in repair, fish harvest could have been appreciable throughout much of the year.

In addition to aquatic life, the canals attract migratory fowl, including geese, at least three species of ducks, and several species of cranes. A host of smaller, but nevertheless, edible, species of birds


Fig. 4. Infrared aerial photograph shows reservoir with a smaller feeder canal channeling water to a large canal at Edzna. White diagonal lines are wind-rowed trash left from recent chaining and burning of forest.

continues to live near the water. Among them are the large forest dove, the small ruddy dove, the chachalaca, and the quail, as well as other, unidentified, forest dwellers. Moreover, deer and many smaller forest mammals now depend on the water in the moat, canals, and reservoirs.

The canals may have played still another important role at Edzna—a role in transportation. The canals in the north sectors extend out into what we believe were farm lands. Small house platforms dot the area, suggesting that a scattered segment of the population lived there. The canals are large enough to have readily accommodated canoe traffic, and it seems incongruous with what we know about the Maya to ignore the probability that the canals were used for transportation of produce from the cultivated plots to the populated areas. This is especially true of the 12-km-long canal that joins another, smaller, canal to provide water passage for a total of 13.5 km, from near the center of the city to a savanna.

**Potential Research**

The hydraulic system of Edzna is an example of how the peoples of the Maya lowlands in the Preclassic period and later controlled and utilized water. At present, Edzna is the only site in the lowlands where a hydraulic system has been investigated, but the probability that other complex hydraulic systems exist is great. Acalan, the Boca de Balchacah, the delta of Rio Champotón, and the north coast of Campeche, for instance, are only a few of the locations where evidence of what may be significant hydraulic construction is known.

A major problem in continuing such research is that archeologists usually work in the field only during the dry season and do not have the opportunity to observe ancient channels when they are filled with water. Furthermore, some of the best observations can be made from the air, but flying and photographing during the rainy season are difficult. Often there is not a single hour during the day for weeks at a time when aerial photography can be done.

Siemens and Puleston (*20*) report a "web of hundreds of narrow straight lines throughout the core of Acalan," south of the Laguna de Terminos. These lines are artificial cuts (canals) into the soil and most are perpendicular to the Candelaria River, Campeche, although some run parallel to the river and often seem to shortcut the distance between bends [figure 3 in (*20*)]. The Acalan canals perhaps were constructed to drain land adjacent to the river and also to facilitate movement of goods by canoe. Thompson (*19*) suggests that they were used for pisciculture. It is likely that they were used for all these purposes as well as others not yet considered.

The large numbers of ridged fields along the Candelaria River are interpreted by Siemens and Puleston as evidence of intensive agriculture in the area. They also report 1.5-km-long parallel swales (encaños) that "reach from what were probably earlier stream banks to higher ground inland." The function of these hydraulic features is unknown. These authors report similar lineal features "near the La Mar and Budsilha sites just opposite the western extremity of Guatemala's Petén, as well as around the northern end of Lake Santa Clara and in several other locations between there and Bonampak." Most recently, they have investigated similar hydraulic features in Belize (*21*).

The canals and sites along the Candelaria River fit well with the historic description of the province of Acalan left by Cortés and Bernal Díaz (*22*). Numerous canoes habitually moved trading cargoes over long distances. In fact, the Cortés party was able to obtain canoes from the Maya for 80 soldiers. Also, food was abundant in the area and was readily available to the Spaniards, who, according to Díaz, obtained "100 canoe loads of food supplies from 'certain [towns] lying between some rivers' " (*22*). This abundance of food would not likely have been available in the absence of intensive agriculture that made use of such methods as the drained and ridged fields reported by Siemens and Puleston.

Fig. 5. Infrared aerial photograph of the fortress at Edzna. The moat system once held 186,000 $m^3$ of water, which supported fish and alligators.

It is evident that, along the Gulf Coast states of Mexico, people were oriented toward water travel and the control of surface water (*23*). Other examples of water control facilities in the area reveals several site complexes in low, poorly drained lands. Stands of mangrove trees at the water's edge provide an effective screen for the traveler in a small boat and are best spotted from the air. Figure 6 shows two such sites at the Boca de Balchacah—one on the Rio Chumpan, the other on a peninsula known as Punta de Cedro.

The latter site (which I have named Punta de Cedro for the peninsula) is surrounded by a low-profile wall running in three legs of 750 m each and terminating in a mangrove swamp without connecting to form a continuous enclosure. The walls may have been defensive, with palisades, but more likely they were built to control water from the rising lagoon during northwest blows (northers). With its 16 mounds in a single row and three larger mounds on the east side of the row, the site plan is non-Maya. Potsherds from the site are Postclassic (after A.D. 1000) (*24, 25*).

I have not yet visited the site on the Rio Chumpan and so I do not know its cultural affiliation; however, its layout suggests Maya construction. Interestingly, two short legs of a canallike cut lead from the river to within a few meters of the 30 mounds at the site. Apparently, water travel was possible from a populated area directly to a waterway leading out to the river upstream, or out into the lagoon and thence to the Laguna de Terminos. Other alignments on aerial photographs of the site may represent storm drain channels.

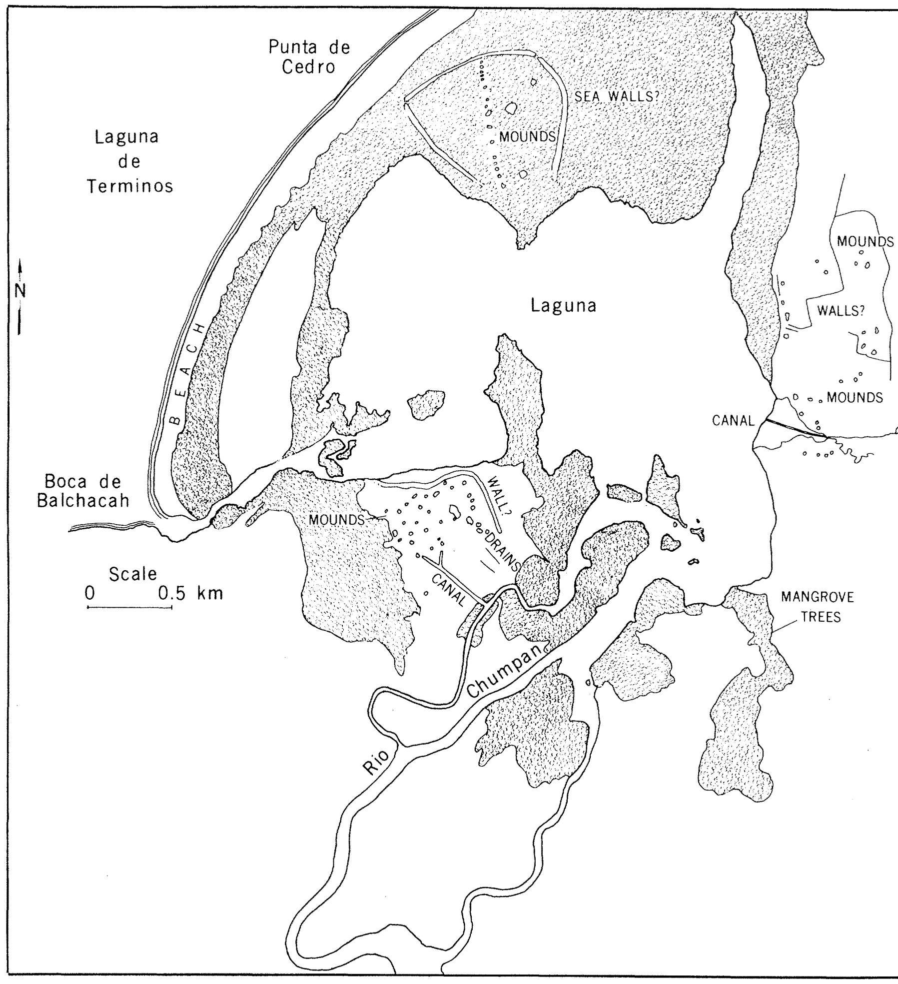

Fig. 6. Newly discovered sites on the shore of the Laguna de Terminos, Campeche. Site Punta de Cedro has three walls that might have been used to ward off high water during norther blows. The site at the bottom has an access canal leading to a natural waterway.

In the delta of the Rio Champotón, raised, circular- to oblong-shaped structures are now used for milpas. These structures—60 to 100 m in diameter—are located in silted areas of the river a few meters above the river sediments. They may have been used exclusively for intensive farming in the past. Their archeological association is unknown.

Along the north coast of Campeche are numerous (perhaps hundreds) of artificial cuts that lead inland from the sea (*26*) and appear as straight lines through mucky coastal land. Vegetation grows in small clumps that mark the higher ground irregularities on otherwise flat land. Sometimes these artificial cuts are connected to estuary deposits and provide a clear waterway to the sea. The banks of the larger cuts are lined with tall trees that grow well on the higher, slightly drained soil thrown up. Some natural levees may also be present on the estuary channels, since trees often grow on their banks, especially inland. Many of the cuts lead directly to clumps of small trees, sometimes passing through one clump and leading to another.

We do not know what the clumps of trees represent, since we have made no ground investigation. Some cuts, however, have been visited and they are definitely artificial, with soil that was thrown up on both sides to form banks. Villages or a house or two are located at the heads of several cuts near the city of Campeche. The present inhabitants do not know who made the cuts, but they do call them canals. All of the canals contain water during the dry season, and in those immediately adjacent to the sea, water flows in and out with the tides. Although we do not know the use of these artificial channels in the past, we can state some possibilities: (i) canoe transportation of cargo to inland stations in order to avoid mucky land where no natural "harbor" landing could be made and (ii) drainage of flooded coastal lands for agricultural purposes.

Another striking hydraulic feature in the same area is what appears to be canals connecting with Isla de Jaina, a Maya site of the Classic period, with elaborate burials that contain hundreds of figurines. The island is located about 25 km north of the city of Campeche. It is barely separated from the mainland and is part of an estuary system. The mainland near Jaina rises gradually to only a few meters above sea level several kilometers inland, and it is inundated by heavy rains. Transportation to Jaina must always have been by water. Several artificial cuts in the low, wet ground appear to link with natural estuary channels and lead to the island diagonally across the deposits that form the natural coastline. It is possible that the Classic Maya brought their dead to Jaina by canoe in ritual processions through artificially cut channels that join natural waterways. The ground truth of the aerial photographs of the Jaina waterways has not been established.

The wet lowlands have received little attention because of the highly undesirable conditions that exist there. They have been written off by most archeologists as not even potentially significant for major settlement. It is noteworthy that only two archeological explorations of any significance have been reported for the Campeche coast (*24, 27*).

However, it appears evident to me that water controls in the lowland Maya area played an important role in the development of Preclassic and Classic civilizations and that we are only beginning to understand the adaptability of a remarkable people of the past.

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7. J. L. Stephens, *Incidents of Travel in Yucatan* (Harper, New York, 1848), vol. 2, p. 146. The cavern is located outside the town of Bolonchenticul, northern Campeche.
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10. My own research at Edzna was funded by the New World Archaeological Foundation, Brigham Young University, and the National Geographic Society for the years 1971–74.
11. Chultuns are more successful when constructed in limestone than in soil. There is little exposed limestone at Edzna, thereby limiting the choice of where chultuns could be placed. Stephens (*7*) shows chultuns constructed of cut limestone blocks placed in soil which were plastered with stucco. See R. T. Matheny [*Am. Antiq.* **36**, 47 (1971)] for examples of modern chultuns constructed in soil.
12. The fortress is a defensive construction surrounded by a moat that is identical in size to the defensive dry ditch surrounding Becan. The Edzna fortress was built at about the same time as Becan. See R. T. Matheny [*Mem. Soc. Mex. Anthropol.* (1973)] for a description of Edzna defensive works.
13. The multiple films aid in interpreting differential vegetal growth. Plants in full chlorophyll process show up as white to gray on black-and-white infrared film and show a range of red to magenta (false colors) on color infrared film. Plants responding to the extra moisture in filled channels are usually ahead in growth of plants outside such areas and show as brighter hues of red. Open water is rendered black.
14. Commercial photography is done only during the dry season when skies are free of clouds. Therefore, I had to make arrangements to take my own aerial photographs.
15. D. L. Webster, *Preliminary Report on Archaeological Investigations in the Rio Bec Area, Campeche, Mexico* (Middle American Research Institute, Tulane University, New Orleans, 1974).
16. Using Erasmus's formula for moving soil in Mesoamerica, we can calculate that approximately 4 million man-days of labor were required for construction of the canals at Edzna. This does not include building either the reservoirs and small feeder systems or undetected parts of the hydraulic system that may have existed. A 2000-man labor force would have had to work 6 hours a day for nearly 2 years to accomplish the feat.
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23. Scholes and Roys (*22*, p. 50) say that the word Acalan comes from the Nahuatl *acalli* ("canoe") meaning "the place of the canoes."
24. A. Ruz L., *Inst. Nac. Antropol. Hist. Ser. Invest.* **18** (1969).
25. The site was spotted during an aerial reconnaissance of the Candelaria River. A ground exploration was made confirming the presence of low-profile walls. There is a possibility that this site is the same as "Cuyos de Avila" marked on a map by Arturo Shiels, in (*24*).
26. F. R. Hauck, "Preconquest Mayan overland routes on the Yucatan Peninsula and their economic significance," thesis, University of Utah (1975).
27. R. T. Matheny, *N. World Archaeol. Found. Pap.* *27* (1970).


# Baccalaureate Origins of American Scientists and Scholars

## The undergraduate institutions from which women have gone on to doctorates differ from those of men.


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Until the passage of federal antibias regulations pertaining to women in institutions of higher education, few of these institutions found it necessary or useful to examine themselves for evidence of policies or attitudes that affect women and men differentially. As a result there have been very few studies that would enable the characterization of colleges and universities with respect to their advancement of the status of women (*1*).

The present article is concerned with but one aspect of such a characterization: institutional productivity in terms of baccalaureate recipients who have subsequently earned research doctorates (*2*). The productivity of an institution is here measured in two ways: by the absolute number of its graduates of each sex who went on to attain the doctorate, and by the percentage of its graduates of each sex who did so. Both these productivities have been assessed also with respect to the decades when the baccalaureates were granted and to the various fields of doctoral study. Apart from their intrinsic historical interest, it is hoped that these data will suggest ways of characterizing educational institutions that will describe more fully their involvement in the higher education of women.

### Historical Perspective

Early in the 17th century the first American colleges were founded—for men. Two hundred years later the notion that women were also educable found expression in the establishment by Emma Willard of Troy Female Seminary (1821) and by Mary Lyon of Mount Holyoke Female Seminary (1837). While neither institution was chartered to grant the baccalaureate degree, both offered two or more years of courses in all academic disciplines patterned after those available in the best men's colleges and universities (*3*). In 1837 Oberlin College became the first institution to admit women to a baccalaureate degree program, although full access to all courses and departments was not permitted until some time later. By the 1870's there were 97 major coeducational institutions (*4*) and some 28 women's colleges (*5*) in the United States.

Women were not admitted to graduate schools before the 1880's, and even after they had gained admission they were not necessarily permitted to receive advanced degrees (*6*). Nonetheless by 1920, the first year in which doctorate


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