24 July 1981, Volume 213, Number 4506

SCIENCE

Prehistoric Raised-Field Agriculture in the Maya Lowlands

B. L. Turner II and Peter D. Harrison

Research during the 1970's indicated that the prehistoric Maya of the Yucatan peninsular region employed a variety of technologies indicative of intensive agriculture, such as terraces (*1, 2*), raised fields (*1, 3–5*), and, possibly, dryland monolevel platform with associated canals to control water levels around the rooting layer and planting surface. Such hydraulic manipulation for drainage or irrigation is generally used in conjunction with numerous cultivation proce-

Summary. The ground patterns found in Pulltrouser Swamp, northern Belize, are vestiges of raised and channelized fields, types of wetland cultivation used by the ancient Maya. This form of hydraulic cultivation was apparently employed sometime between 200 B.C. and A.D. 850. The environment of the swamp, the fields and canals, and one nearby settlement, Kokeal, are described. The evidence indicates that the large number of well-defined ground patterns reported in other areas in the central Maya lowlands are probably vestiges of Maya wetland cultivation.

irrigation (*6*). The initial evidence of the use of raised fields by the Maya generated controversy and challenges because interpretations were based largely on aerial identification of the features and because the aerial extent of the projected fields suggested that the Maya were engaged in large-scale hydraulic cultivation. In turn, the scale introduced the possibility of centralized sociopolitical control (*7*).

A raised field is an agricultural feature created by transferring earth to raise an area above the natural terrain (*8*). Field morphologies, which vary, are largely related to the special function or functions of the field (*9*). For example, in inundated zones the raised field may be a

B. L. Turner II is an associate professor in the Graduate School of Geography, Clark University, Worcester, Massachusetts 01610; Peter D. Harrison is an adjunct professor in the Department of Anthropology, University of New Mexico, Albuquerque 87106. The authors were affiliated with the Department of Geography, University of Oklahoma, and the Middle American Research Institute, Tulane University, respectively, during the study.

dures to sustain intensive agriculture (*8, 9*). In Mesoamerica, the *chinampas* of the Basin of Mexico are examples of the monolevel platform type of raised fields; some have been in intensive production since the Spanish Conquest (*10*).

Vestiges of raised fields in the Maya lowlands were first discovered in the Rio Candelaria Basin of southeastern Campeche (*3*). Examination of these features confirmed that there were about 150 to 200 hectares of fields in that riverine habitat (*3, 11*). Larger areas of relic fields were later identified in both riverine and depression (*bajo*) habitats in northern Belize and southern Quintana Roo, Mexico, including Pulltrouser Swamp. From aerial observations and photography, Siemens (*11*) projected the existence of nearly 3200 hectares of fields in northern Belize alone; ground examinations, however, were limited to riverine habitats along the Hondo River, particularly near San Antonio, Albion Island, Belize (Fig. 1) (*12*). Other researchers reported ground and vegetation patterns indicative of raised fields in the large depressions of southern Quintana Roo (*1, 5*). These features, conservatively estimated to cover 400 square kilometers in Quintana Roo, were identified solely by aerial reconnaissance and photography (*13*).

The existence of relic complexes of raised fields identified from the air alone has been questioned (*14*). It was suggested that many of the finds, particularly the extensive patterns in southern Quintana Roo, could be *gilgai*, a natural formation resulting from seasonal extremes in the moisture content of expansible clays. Large surface cracks develop when the clays desiccate; when wet, the infilling material swells, and this promotes lateral and upward pressures that may result in a variety of regular ground patterns (*15*). In addition, pedological work near San Antonio (Fig. 1) has raised questions about interpretations from ground studies which indicated that raised fields occurred there (*16*). It was suggested that the surface features were naturally alluviated deposits that appear to be raised because a network of canals or channels had been cut through the area, apparently creating channelized fields. The existence of channelized fields has been supported by work on similar surface patterns along Barber Creek, near Lamanai (*17*) (Fig. 1).

Several issues related to the use of raised-field agriculture by the prehistoric Maya were investigated during the 1979 Pulltrouser Swamp Project (*18*). Because it was assumed that true raised fields were most likely to occur in interiorly drained depressions, the project focused on the identification of such features at one locale. The habitat in which the features occur and Maya settlements near the depression were also studied. The project's findings are summarized in this article.

The Study Area

The eastern peripheries of the central Maya lowlands in northern Belize and southeastern Quintana Roo are part of the flat, low-lying coastal margin of the limestone shelf known as the Yucatan Peninsula (Fig. 1). The terrain is karst.

0036-8075/81/0724-0399$01.75/0

The mean annual precipitation in this zone ranges from about 1400 millimeters in the north to 2000 millimeters in the south, but annual totals vary considerably [W.C.J.; see (*18*)]. Rainfall is seasonal, with a distinct dry season from February through April or mid-May.

At least two topographic zones, riverine lands and depressions, in the eastern peripheries of the lowlands are prone to seasonal or permanent inundation (*19*). Riverine lands, confined to narrow bands along the rivers, such as the Hondo and New, rarely desiccate. Depressions are either interiorly drained or maintain slow outward or subterranean drainage. They are locally referred to as *bajos*, *akalches*, savannas, swamps, or marshes, depending on their size, the severity of inundation, or the type of vegetation (*20*). Depressions are more common features in the area than are riverine lands.

The eastern riverine-depression zone of the central Maya lowlands was densely inhabited in prehistoric times. Remnants of Maya settlements stretch from north of Tzibanche, Kohunlich, and Nicolas Bravo to Lamanai in the south (Fig. 1). Ruins are especially abundant along the corridor between the Hondo and New rivers, beginning at Cerros, at the Bahia de Chetumal, and including Aventura, Louisville, Nohmul, Cuello, and El Posito. The area was apparently occupied very early in Maya prehistory. A series of radiocarbon dates from Cuello range from 3200 to 200 B.C. (*21*). The ceramic styles associated with the early dates at Cuello are found elsewhere in the corridor, suggesting that the early occupation was not limited to one site.

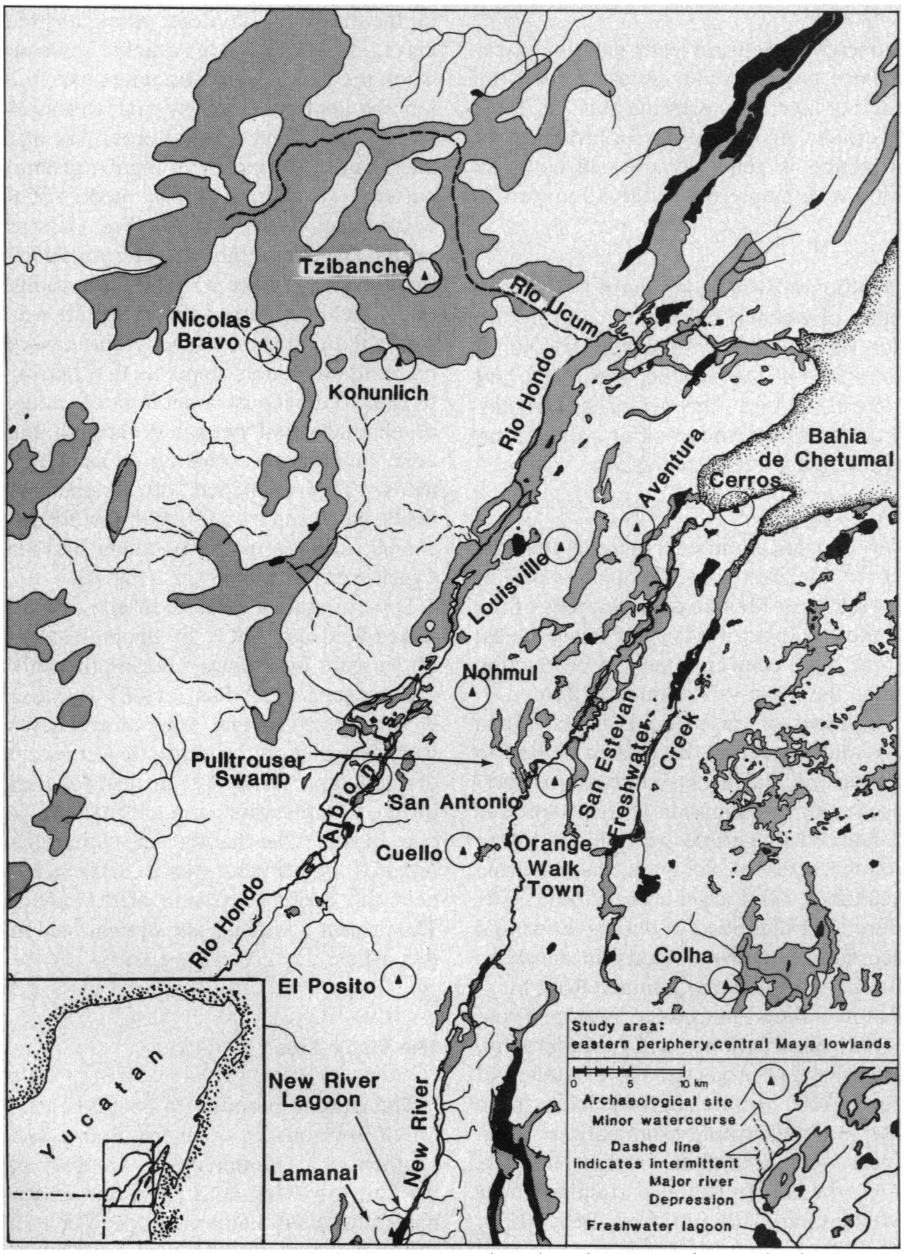

Fig. 1. Map of the wetlands of the eastern peripheries of the central Maya lowlands.

Ground patterns thought to represent vestiges of raised fields and canals have been identified in a large number of depressions in this zone (*1, 4, 5, 11, 12*). At least two distinctive ground patterns are prevalent: quadrilateral shapes in paired rows (Fig. 2) and quadrilateral to amorphous shapes in sectional or group patterns (Fig. 3). Pulltrouser Swamp was selected for study because it (i) contains both ground patterns, (ii) has a variety of bio-hydrological zones that are comparable to those found in virtually every depression in the area that has been reported to have raised fields, (iii) is near several major Maya centers, and (iv) is accessible.

Habitat

Pulltrouser Swamp is a large, Y-shaped depression located about 4.5 km north of Orange Walk Town, Belize. Its three major arms cover an area of about 8.5 km^2: there are about 3.6 km^2 in Pulltrouser South, 2.9 km^2 in Pulltrouser East, and 2.0 km^2 in Pulltrouser West (Fig. 4). Surface water is captured as runoff from the higher ground or ridgeland corridor to the west and drains very slowly from the two northern arms into the southern arm. Most of the area of the eastern and southern arms retains some water throughout the year, although only interior ponds may retain surface water during severe droughts. The occurrence in the southern arm of several species of freshwater gastropods, including the prosobranch *Pyrgophorous coronatus*, suggests that a large volume of well-oxygenated surface water is regularly present in the depression (A.C.). Because water levels fluctuate along the borders of the eastern and southern arms, the sediment-filled channels nearest the swamp-mainland border tend to dry annually, and an amphibious species of gastropod, *Pomacea flagellata*, is dominant. The higher lying western arm has a greater annual range of water levels. About 1 meter of surface water may stand in the western arm during the wet season. However, dry season surface water is limited to several interior ponds, and the water table throughout most of the western arm is found at depths exceeding 1 m.

These varying hydrologies produce distinct types of vegetation. The deeper and more stable water levels in the interiors of the eastern and southern arms support a sawgrass marsh. Toward the margins of the depression, but within the marsh zone, the mounds that produce the ground patterning are marked by

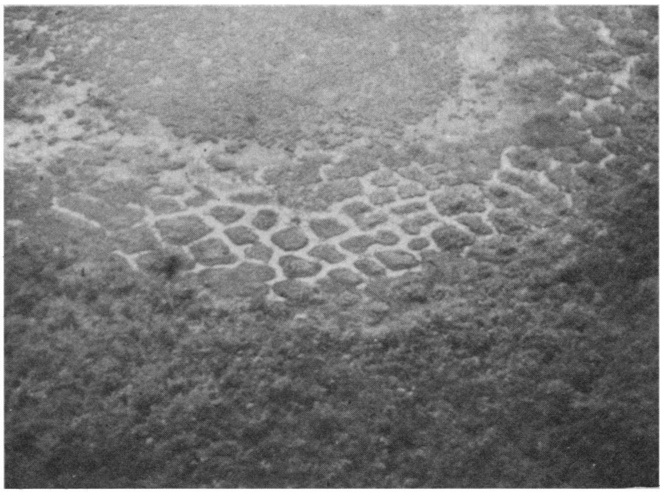

Fig. 2 (left). Paired-row ground pattern created by relic wetland (raised?) fields at Long Swamp, northern Belize. Fig. 3 (right). Sectional ground pattern created by relic raised fields at the north end of the eastern arm of Pulltrouser Swamp. The fields extend into the escoba-botan forest. The larger fields are 30 to 35 m in length. Palmettos grow in the nonforested fields.

stands of palmettos or small palms, *Acoelorraphe* sp. (Fig. 3). The mounds continue toward the mainland-depression border for a distance of 80 to 150 m. These mounds are not visible from the air because they are obscured by a tall swamp or escoba-botan forest, characterized by the bully (or bullet) tree (*Bucida bursera*), chechem (*Metopium brownei*), and various palms such as escoba (*Cryosophila argentea*) that flourish on the mounds. Pulltrouser West is dominated by a shortgrass savanna, with the exception of an interior pond zone that is surrounded by mounds covered with an escoba-botan forest. The savanna is associated with severe seasonal fluctuations in water levels.

The soils of the mound and savanna zones are mollisols, belonging to the subgroups cumulic and vertic haplaquolls, respectively (J.P.D.). They are predominantly silt and contain small amounts of montmorillonite clay (*22*). In undisturbed conditions, a solum rests directly on weathered limestone or sascab (*23*). The light-colored sascab is found at depths ranging to 50 centimeters on the mainland border of the depression and to 100 centimeters in undisturbed sections of the depression proper (*24*).

The data provide several clues to the conditions of the depression from Maya occupance to modern times. The fossil pollen indicates that Pulltrouser South may have been dominated more by the marsh habitat in the past (F.M.W.), and the molluscan remains suggest that the depression rarely, if ever, desiccates (A.C.). The degree of water level fluctuations within the ground pattern zone in the past is uncertain, although seasonal fluctuations apparently occurred (*25*). The extension of the escoba-botan forest into the depression is apparently a response to the presence of the mounds. Pulltrouser South appears to have been similar in terms of surface water characteristics to the swamp-lakes of Chalco and Xochimilco in the Basin of Mexico at the time when the chinampa system was constructed by the pre-Hispanic occupants of the basin (*10*). Climatic changes that may have taken place during Maya times have not yet been documented at Pulltrouser Swamp, nor at this time has evidence been found in the swamp of major sedimentation that has been recorded in the more rugged Petén of Guatemala (*26*).

Ground Pattern Study

About 311 ha of well-defined ground patterns are visible along the edges of Pulltrouser South and East and in the southern interior of Pulltrouser West (Fig. 3). Less distinctive patterns cover an additional 357 ha of some of the interior portions of Pulltrouser South and East (*27*). The well-defined patterns are located principally along the mainland edge, which rises about 1 m above the depression, and along the exterior portions of the depression proper.

Three sites were selected for study. Sites 1 and 2 were located along the south central portion of the western side of Pulltrouser South, and site 3 was situated at the base or southern end of Pulltrouser East, where it connects with Pulltrouser South. Twenty-nine units were excavated in various mounds at the three locations. In addition, numerous soil pits were dug and samples taken with a bucket auger in the pits and at other locations, including the shortgrass savanna and the mounds in the interior of Pulltrouser West. Mounds situated along the mainland edge in the escoba-botan forest and on the edge of the marsh (mounds with palmettos) were excavated. The studies demonstrate that the mounds of the ground pattern zones at Pulltrouser Swamp are vestiges of channelized and raised fields and associated canals built by the ancient Maya. Channelized or border fields, which are situated along the mainland edge of the depression (Fig. 5), were created by the construction of short canals, generally not exceeding 10 to 20 m in length and 2 to 3 m in width, that connect the depression with the mainland. Major field raising was apparently not involved with these features (Fig. 6). Soil profiles reveal a solum of about 30 to 50 cm, resting on sascab. Artifacts were found in the solum and on the solum-sascab contact, but were not in the sascab zone. The inland canals had been cut as deep as 1 m into the sascab.

True raised or island fields are located in the depression proper, often in a line or other symmetrical arrangement with the adjacent channelized fields (Fig. 5). Raised fields are elaborate constructions (Fig. 6) and are more numerous than the channelized fields. They comprise about 90 percent of the total area known to contain relic fields and canals. A solum, 30 to 50 cm thick, rests on gray fill material that is about 100 cm thick and is speckled with small, angular fragments of limestone. In most excavations this material rests directly on sascab, but several soil sample cores taken at raised field site 1 (Fig. 5) revealed a 20-cm-thick deposit of black soil with abundant aquatic remains; this soil was interpreted as part of the original depression topsoil.

The intervening canals have been cut as deep as 100 cm into the underlying sascab. Artifacts were found in the solum and fill material and in the canal sediments. No cultural remains were located in the black layer or in the sascab.

These fields were apparently constructed in the following manner. The original depression soil was removed (although not completely in all circumstances) and, presumably, set aside. Canals were cut into the exposed sascab. A fill mixture, composed of sascab from the depression and adjacent mainland and subsoil from the depression, was laid down between the canals (W.C.J. and J.P.D.). This fill created a platform elevated about 100 cm above the sascab floor and about 200 cm above the bottoms of the canals. A planting medium was added to the platform surface, presumably including the stored depression top soil. The result was a monolevel platform type of raised field (*8*).

In some instances channelized fields were extended toward the depression by the addition of a raised surface (Fig. 6). An excavation in the extension of a channelized field yielded a biface pick at the junction of the gray fill material and the underlying sascab, 75 cm below the surface. Analysis indicates that the pick was probably hafted and used as a hoe or mattock (H.J.S.). The provenience and patterns of wear of the biface pick suggest that it was deposited during the construction of the extended segment of the field or of the adjacent canal. Another fragment of a biface pick was found in the fill material of another field.

The raised fields vary in shape and size. Quadrilateral shapes are prevalent, particularly on the palmetto-dominated fields that extend into the deeper, interior sections of the depression. Amorphous shapes are common along the mainland edge, where the configuration of the mainland-depression border apparently influenced the shape of the channelized and adjacent raised fields. Sizes of fields range from about 80 to 750 m^2, although 500 m^2 is an average size. The thickness of the fill material varies with the depth of the depression, surface water levels, or both, but a conservative average thickness is 100 to 150 cm.

A hierarchical system of canals extends through the fields. Generally, the larger canals, from 7 to 10 m in width, link the interior of the depression with various segments of the fields. Larger canals commonly bifurcate and join medium-sized canals, about 4 m in width, which surround most of the raised fields. The depression-mainland edge is usually paralleled by medium-sized canals from which smaller canals, 2 to 3 m wide, cut into the mainland.

Whether a canal network existed in the interior portions of the depression is not certain. However, the discovery of two long canals (about 200 m long and 6 to 8 m wide) that connect the southern part of Pulltrouser South with the New River indicates that a canal network did once exist throughout the depression. Whether these long canals were used for drainage or water-level control in the depression or as transportation links from the depression to the river is not known. Furthermore, local accounts of past logging activities indicate that logs were "floated" out of the depression to the New River. This practice probably involved the use of old Maya canals, but this interpretation is not certain.

Pollen, phytoliths, and other plant remains are indicators of some of the cultivars that may have been associated with the fields and of past environmental conditions. Maize (*Zea mays*) pollen is found throughout the solum and fill of the island fields (F.J.W.). A fragment of a carbonized maize stalk was recovered at a depth of 35 cm in the solum at raised field site 2 (C.H.M.). In addition, a *Gossypium*-type pollen, perhaps cotton, and pollen of *Amaranthus* were found in the soils of the raised fields. Maize, cotton, and amaranth have been suggested as cultivars grown on wetland fields by the Maya (*4*). Although the pollen and other plant remains found at Pulltrouser are directly associated with the fields, it is not yet certain whether they represent the remains of raised-field cultivars. The maize pollen and fragment may have been deposited directly by cultivation or by the use of a mulch that contained maize. Maize pollen in the fill material may also have been introduced during the construction of the fields. The *Gossypium*-type pollen may represent wild cotton or some malvaceous species other than cotton. Finally, the *Amaranthus* pollen may represent wild species, not the domesticate (F.J.W.).

Paleoecological work indicates that at the time of field use the adjacent upland forest and the escoba-botan forest were virtually absent and that the marsh grasses were more dominant (F.J.W.). Phytoliths of water lilies (*Nymphaea*) found in the fields indicate the presence of permanent water, either at the time of construction of the fields or within the canals during field use (F.J.W.). Experiments on raised-field agriculture (*28*) indicate that water lilies from the canals are a good mulch for various crops grown on the fields. This evidence, coupled with the data on molluscan species diversity, may indicate that the canal system was permanently inundated.

Ceramics and radiocarbon materials provide preliminary dates of field construction and use. Ceramics were present in the solum and fill zones of the fields but were usually vertically mixed. Ceramic types ranged from Lopez Mamon (1000 to 400 B.C.) to Santana Tepeu (A.D. 600 to 850) (R.E.F.) (*21*). Although mixed materials are generally dated by the latest ceramics, there is evidence that the fields may have been in use before Santana Tepeu. A radiocarbon date of charcoal from raised field site 2, at a depth of 75 cm, was A.D. 150 ± 150 (*29*). This date corresponds with an estimate based on ceramics that may date the fields from Cocos Chicanel (400 B.C. to A.D. 250) through Nuevo Tzakol (A.D. 250 to 600) (R.E.F.). The frequency of striated wares, rare until the very Late Preclassic (Cocos Chicanel), Nuevo Tzakol sherds found at lower levels in the fields, and the Cocos Chicanel and Nuevo Tzakol components of surface sherds on the mainland adjacent to the raised-field sites at Pulltrouser South were the bases for this estimate (*30*). It should be emphasized, however, that the ceramics in the fill material may have been redeposited during construction of the fields.

Settlement Study

Examination of the Maya settlements adjacent to Pulltrouser revealed the existence of at least three sites of habitation (Fig. 4) (*31*). Time constraints prohibited a thorough survey of the perimeter of the depression. Kokeal was selected for systematic survey and limited excavation because it was the first and closest settlement located to the ground pattern study at raised field site 1.

Kokeal is an elongated settlement situated on a low escarpment that parallels the New River but changes direction to parallel the western side of Pulltrouser South (*32*). Survey results revealed 117 structures of different sizes that demarcate a 1.08 km^2 territory. The majority of structures appear to have been the platforms of medium-sized houses that lacked masonry walls and vaults (*33*). One such structure yielded a wide range of artifacts—a freshwater clam cache, a lithic cache, and a limestone figurine, items suggestive of ceremonial behavior and indicative of some degree of wealth. To the south of the zone of houses are two small acropolises that are built of stone and fill masonry and support at least four pyramidal bases. There is no evidence that masonry walls or vaults were used (N.E.). Furthermore, one structure was built of earth only, piled in strata in the manner of earth mounds in North America.

The majority of the lithics taken from excavations at Kokeal were broken, retouched, and recycled formal tools and debitage from retouching and recycling (H.J.S.). Kokeal and Pulltrouser are not located in a chert-bearing zone; there is no evidence of the manufacture of formal tools at Kokeal; and the chert lithics found at Kokeal are indistinguishable from those produced at the major lithic workshop site of Colha, about 26 km to the south (Fig. 1). The majority of chert tools at Kokeal appear to have been used in association with agricultural activities. Analysis indicates that large oval biface picks, including those taken from the fields, were hafted and used in a chopping motion against a soft but abrasive material, which they consistently penetrated for about one-third of their length and, occasionally, for their entire length (H.J.S.). Hoeing or digging into the mollisols of the mainland and field surfaces or the underlying sascab could have produced the wear patterns found on the oval bifaces (*34*). It is probable that the oval bifaces were hoes or mattocks used to construct and cultivate the fields at Pulltrouser.

Materials from the excavations at Kokeal included one maize cob fragment and stem and several species often found in dooryard orchards, such as sapodilla (*Achras sapota*) and copal (*Protium copal*) (C.H.M.). Evidence for cacao (*Theobroma* sp.) was limited to a few wood fragments obtained by flotation of fill from an earth mound. In addition, remains of *Pinus caribea*, a species of pine that does not occur in the immediate Pulltrouser region, were found (C.H.M.). Remains of 32 *Pachychilus*, an aquatic gastropod eaten by the Maya, were found at Kokeal. The species does not now inhabit the depression, and it is not known whether it lives in the slow-flowing New River (A.C.).

The abundance of ceramics of the Cocos Chicanel phase and the Santana Tepeu phase at Kokeal suggests that peak periods of Maya activity there are associated with the Late Preclassic (300 B.C. to A.D. 150) and the Late Classic (A.D. 600 to 850) (R.E.F.). Cocos Chicanel material is particularly abundant in midden and fill contexts, and radiocarbon analysis of charcoal remains from a midden produced a series of Late Preclassic dates: 35 ± 55 B.C., 20 ± 50 B.C., A.D. 60 ± 45 (*35*). However, the Preclassic materials have not been found in a confirmed constructional context (N.E.), although experience suggests that this circumstance is related to the sample size. The earliest confirmed construction at Kokeal relates to the Nuevo Tzakol ceramic phase, or the Early Classic (A.D. 250 to 600) (N.E.). Nevertheless, the abundance of Cocos Chicanel materials in contexts ranging from surface to construction fill indicates that the Kokeal location was occupied during the Late Preclassic. The abundant Santana Tepeu material (Late Classic) is confirmed in constructional context.

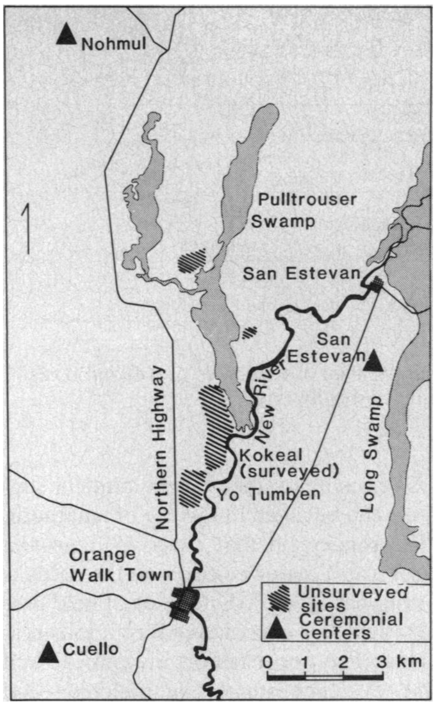

Fig. 4. Map of Pulltrouser Swamp and adjacent settlements.

Interpretations and Implications

Identification. Several lines of evidence indicate that hydraulic agriculture was practiced in depressions by the prehistoric Maya. The mounds of the zone of ground patterns at Pulltrouser are not gilgai or other natural features. Gilgai do not form now and probably never did form in the depression because of chemical and physical characteristics of the soils (J.P.D. and W.C.J.). This observation is corroborated by recent work at Albion Island (*16*). At Pulltrouser, the morphologies of fields and canals, the provenience of artifacts in them, and the nature of the fill material attest that the fields and canals were constructed by the Maya in the manner described above. The evidence demonstrates that at least two wetland field types, channelized and raised, occur in the Maya area. The morphology of channelized fields is similar to that described at Albion Island (*16*), Barber Creek (*17*), and Cerros (*36*), although the composition of the bedrock varies slightly between locations. In contrast, raised fields (monolevel platforms) have an intervening fill between the soil surface and the sascab.

Distribution. The evidence from Pulltrouser indicates that the fields are associated with escoba-botan forest and marsh grasses, but not with shortgrass savanna. Channelized fields were used where inundation could be offset without major field raising, such as along the edges of depressions and higher ground adjacent to rivers; raised fields were used where inundation was deep or prolonged, such as within the lower parts of depressions.

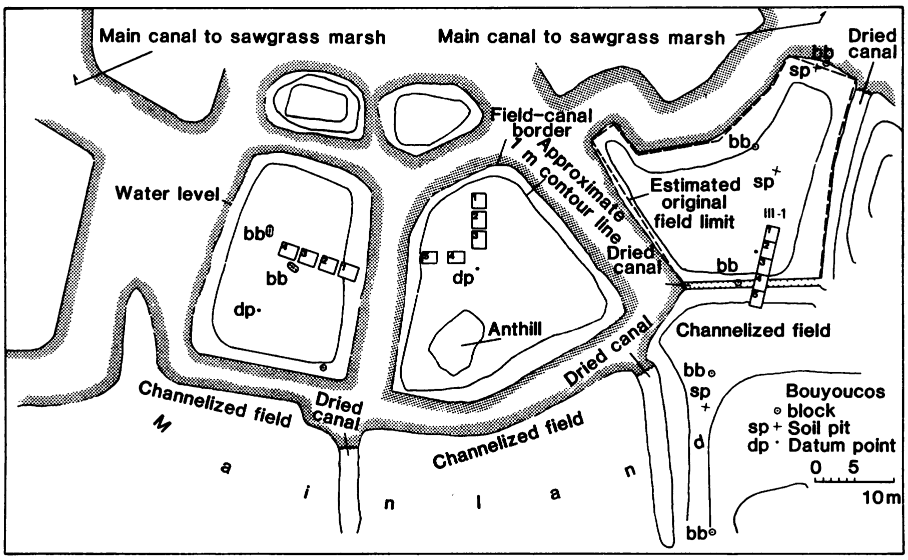

Fig. 5. Aerial plan of raised and channelized fields and canals at raised field site 1, located along the midsection of the western side of the southern arm of Pulltrouser Swamp. The numbered squares are excavation units.

The fields and canals have been confirmed in both riverine and depression contexts. These features display such a consistent range of patterns and sizes that their presence can be confirmed by aerial means where the patterns are distinctive. The identification of well-defined patterns in southern Quintana Roo and other areas of Belize as relic fields and canals is thus supported by this work (*37*). Indeed, the best-preserved fields at Pulltrouser are found in the bio-hydrological zone that is most comparable to the *bajos* of southern Quintana Roo. Furthermore, the evidence complements remote-sensing work in Belize and Petén that indicates the existence of 1250 to 2500 km^2 of terrain covered by relic fields and canals, mostly in depressions (*38*).

Development. The evidence supports the position that Maya agriculture in the Pulltrouser area developed first on drylands and subsequently included wetlands as land pressures increased (*39*). Cuello, situated on the high ground between the Hondo and New rivers, was occupied by agriculturalists as early as 1950 to 1000 B.C. (*21*), while habitation at Kokeal and development of the Pulltrouser fields probably did not emerge before 200 B.C. to A.D. 250. The early radiocarbon date (1110 ± 230 B.C.) for a canal adjacent to a wetland field at Albion Island suggests that riverine zones may have been used for wetland cultivation before depression zones (*11*). However, a caveat may be warranted in regard to the interpretation of that date. The ceramics taken from the fields adjacent to the canal date no earlier than the Early Classic (A.D. 250) (*4, 40*). The incongruent dates from the two, presumably associated, features have not been explained.

Construction. It is not clear whether the Pulltrouser field-canal network evolved incrementally or was implemented as a large project. The near-level bed of the depression and the slow drainage within it suggest that major drainage or other regulation of water levels could not have been accomplished in the raised-field sections without a depressionwide network of canals. The hierarchy of canals and the canals linking Pulltrouser South to the New River suggest an overall plan for implementing the system. A conservative estimate of the labor required to construct the field-canal network for the 300 ha of well-defined fields and canals is 6000 worker-years (*41*).

Production. The only positively identified cultivar that may have been grown on the fields is maize. Cultivation of cotton is a possibility, and minimal support can be given to the use of amaranth. The suggestion that cacao (*Theobroma* sp.) was a major cultigen on the fields is unsupported (*42*). Estimates of field productivity are speculative for various reasons. The construction investment and the evidence suggesting mulching and mucking procedures can be interpreted as indicative of high-output agriculture. Mexican chinampas are estimated to support about 19 people per hectare (*43*); a conservative figure of 4000 people can be derived from that estimate for the 300-ha Pulltrouser network (*44*). It must be emphasized that many more wetlands in the immediate area also contain raised fields and that many of the dryland soils are of good agricultural quality.

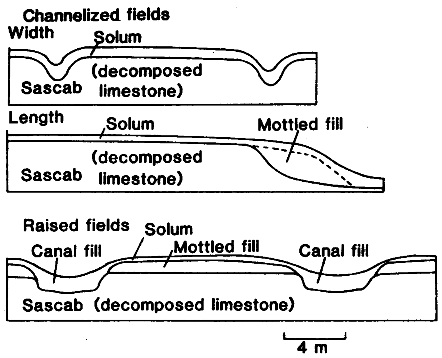

Fig. 6. Plan of two types of wetland fields at Pulltrouser Swamp.

Settlement. Settlements immediately surrounding Pulltrouser were apparently clustered, with few structures located between clusters. If Kokeal is typical, the settlements were apparently occupied by farmers who cultivated the depression. Remains of chert tools, presumably used to build and cultivate the fields, are abundant at Kokeal. Farmers must have cultivated the mainland also; botanical evidence suggests the use of species that are often found in orchards or house gardens. A conservative estimate of the population of Kokeal during the Late Classic is 400 to 500 people (*45*).

Kokeal may be a unique site of special status, or it may represent a previously unrecognized class of such sites common to the locality or even to the Maya lowlands in general. For example, one structure at Kokeal is a large mound constructed entirely of earth, whereas other building support platforms at the site are constructed with masonry and earth fill. No platform at Kokeal supported buildings with masonry walls or vaulted roofs, although these are found at nearby San Estevan. The only parallels that can be found for such construction shortcuts are either Olmec-dated earth structures in the Gulf Coast region or Postclassic construction devices in the Maya lowlands (*46*). In the Postclassic such building style has been interpreted as a cost-control mechanism (*46*). Evidence of cost-control in architecture at Kokeal may also be reflected in the consistency of recycling of chert tools. The periods of cost-control in architectural construction temporally flank the major dates of occupance at Kokeal and Pulltrouser at Late Preclassic and Late Classic. For this reason a unique character is postulated.

Conclusions

The Pulltrouser Swamp study has provided evidence that the prehistoric Maya used channelized and raised fields and canals to cultivate depressions as well as riverine lands. This hydraulic technology apparently allowed them to manipulate water so that field soils were neither severely inundated nor desiccated, promoting conditions suitable to cultivation throughout the year. The Pulltrouser fields were constructed no earlier than the Late Preclassic, apparently by farmers from adjacent sites such as Kokeal, and were abandoned before the Postclassic. This usage correlates with a recognized pattern of population growth throughout much of the Central Maya lowlands, including the eastern peripheries.

The aerial patterns of the Pulltrouser fields and wetland fields examined in riverine zones are similar to those of numerous wetlands throughout the eastern and western peripheries and, perhaps, the interior of the central Maya lowlands. The similarities indicate that wetland cultivation was widespread in prehistoric times. This interpretation suggests that several arguments linking the agricultural base of the civilization to sociopolitical issues may require reevaluation. Some of these arguments involve the size of prehistoric populations in the region, the relation between hydraulic types of cultivation and levels of social organization, and the agricultural-environmental components that may have been associated with the collapse of the Classic Maya civilization.

References and Notes

1. B. L. Turner II, *Science* **185**, 118 (1974).
2. ——, in *Pre-Hispanic Maya Agriculture*, P. D. Harrison and B. L. Turner II, Eds. (Univ. of New Mexico Press, Albuquerque, 1978), pp. 163–183; in *Maya Archaeology and Ethnology*, N. Hammond and G. R. Willey, Eds. (Univ. of Texas Press, Austin, 1979), pp. 103–115; P. F. Healy, C. vanWaarden, T. J. Anderson, *Am. Indig.* **40**, 773 (1980).
3. A. H. Siemens and D. E. Puleston, *Am. Antiq.* **37**, 228 (1972).
4. D. E. Puleston, in *Social Process in Maya*

Prehistory, N. Hammond, Ed. (Academic Press, New York, 1977), pp. 449–467.
5. P. D. Harrison, in *ibid.*, pp. 469–508; C. M. St. G. Kirke, *World Archaeol.* **2**, 181 (1980).
6. R. T. Matheny, *Science* **193**, 639 (1976).
7. P. D. Harrison and B. L. Turner II, Eds., *Pre-Hispanic Maya Agriculture* (Univ. of New Mexico Press, Albuquerque, 1978).
8. W. M. Denevan and B. L. Turner II, *J. Trop. Geogr.* **39**, 24 (1974).
9. G. C. Wilken, *Geogr. Rev.* **62**, 544 (1972); E. Waddell, *The Mound Builders* (Univ. of Washington Press, Seattle, 1972); L. M. Serpenti, *Cultivators in Swamps* (Royal Van Gorlum, Assen, Netherlands, 1965).
10. P. Armillas, *Science* **174**, 653 (1971); A. Palerm, *Obras hidráulicas prehispánicas en el sistema lacustre del valle de Mexico* (Instituto Nacional de Antropologia e Historia, Mexico D.F., 1973); T. Rojas R., R. A. Strauss K., and J. Lameiras, *Nuevas noticias sobre las obras hidráulicas prehispánicas y coloniales en al valle de Mexico* (Instituto Nacional de Antropologia e Historia, Mexico D.F., 1974).
11. A. H. Siemens, paper presented at the Memorial Conference for Dennis E. Puleston, Minneapolis, 1979.
12. J. Belisle, S. Musa, A. Shoman, Eds., *Journal of Belizean Affairs Special Issue 5* (1977).
13. An original estimate of the area covered by raised-field networks in a segment of southern Quintana Roo between Nicolas Bravo and Ucum, 2460 km^2, was in error [*5*; P. D. Harrison, in (*7*), pp. 247–253]. The correct figure for that area only is 246 km^2.
14. D. E. Puleston, in (*7*), pp. 225–245.
15. W. R. Wood and D. L. Johnson, in *Advances in Archaeological Method and Theory*, M. B. Schiffer, Ed. (Academic Press, London, 1978), vol. 1, pp. 315–381; L. F. Duffield, *Am. Anthropol.* **72**, 1055 (1970). W. C. Johnson (*18*) notes that ground patterns could be created by bedrock joints. Faulting could create a regular pattern of fractures in the underlying sascab, and these fractures or joints could be enlarged by solution or weathering. The result would be a surface pattern of ditches or canals. The data from Pulltrouser do not support this explanation of the ground patterns.
16. P. P. Antonie, R. L. Skarie, P. R. Bloom, paper presented at the Memorial Conference for Dennis E. Puleston, Minneapolis, 1979.
17. J. D. H. Lambert and J. T. Arnason, unpublished data.
18. The 1979 Pulltrouser Swamp Project, sponsored by the University of Oklahoma and the National Science Foundation, included as field members and analysts the following personnel in addition to the authors: R. E. Fry, W. C. Johnson, F. M. Wiseman, A. Covich, J. P. Darch, N. Ettlinger, A. Madeira, H. J. Shafer (from the Colha Project), C. H. Miksicek (from the Cuello Project), T. Lhurman, and C. Lincoln. In addition, floral and faunal identifications were provided by A. Gomes-Pompa, P. Cowan, and M. Pohl. This article is abstracted from the works of the personnel involved. Various finds, analyses, or interpretations of the project members are designated in the text by their initials. Details of the project are forthcoming in B. L. Turner II and P. D. Harrison, Eds., *Maya Raised-Field Agriculture and Settlement at Pulltrouser Swamp, Northern Belize* (Univ. of Texas Press, Austin, in press).
19. A. H. Siemens, in (*7*), pp. 100–143.
20. For descriptions of depressions throughout the area, see C. L. Lundell, *Carnegie Inst. Wash. Publ. 478* (1937); A. C. S. Wright, D. Romney, R. Arbuckle, V. Vial, *Colonial Res. Publ. 24* (1959), pp. 28–33; F. Miranda, in *Los Recursos Naturales del Sureste y su Aprovechamiento*, E. Beltran, Ed. (Instituto Mexicano de Recursos Naturales Renovables, Mexico, 1959), vol. 1, pp. 215–271.
21. N. Hammond *et al.*, *Am. Antiq.* **44**, 93 (1979); *Nature (London)* **267**, 608 (1977). The chronology of the major ceramic phases follows that of Hammond and his colleagues; their radiocarbon dates have been corrected to tree-ring dates. The dates reported in this article have not been corrected in order that they may be readily compared to the larger sets of radiocarbon dates from other Mesoamerican locales. Tree-ring corrections for the periods in question are not large. For example, the radiocarbon date of 120 B.C. is corrected to 155 B.C., a 35-year difference. In most cases our chronological controls are not sufficient to warrant consideration of such short temporal distinctions.
22. Soils on the mounds have a black A horizon (for example, Munsell color 5Y2.5/1) and a gray to dark gray B horizon (for example, 5Y4/1), resulting primarily from decreasing organic carbon with depth. High calcium carbonate content is due to the calcareous parent material. Base saturation is approximately 50 percent. Soils are predominantly silt, but 2:1 silicate clays are present, imparting a high cation exchange capacity. The soils correspond to the humic gley category of the old U.S. Department of Agriculture (USDA) soil classification systems (J.P.D.).
23. The solum refers to the A and B horizons only, following USDA guidelines [*Agricultural Handbook 18* (1962), p. 183].
24. Sascab (C horizon) around the perimeter of the swamp is apparently the product of deep weathering. Large gypsum crystals were found at depths of about 1 m or more into the sascab. Initial interpretations are that the gypsum is a substitution product associated with drier climatic conditions in the past (J. P. Darch, *Z. Geomorphol.*, in press). The depth of the large gypsum crystals suggests that they formed long before the cultural periods discussed in this article.
25. The presence of prosobranch (gill-bearing species) gastropods, such as *Pyrgophorus coronatus* (Pfr.), in the excavation materials from the raised fields may indicate that the habitat once had permanent water 1 to 5 m deep. The habitats of these snails are incompletely known, but the predominance of *Pomacea flagellata* (Say) in the excavations suggests that the margins of the habitat were shallow, and the water level probably fluctuated seasonally. If *Pomacea* shells were used by the inhabitants for lime, the reduction in the number of the species was not sufficient to prevent our recovery of the shell material. *Pachychilus glaphyrus* (Mor.) was recovered from excavations at Kokeal only; the source of the species is uncertain as it is thought to inhabit windswept, large, deep lakes or fast-flowing rivers. If Pulltrouser was once a habitat suitable for the species, the paucity of shell remains might be explained by harvesting of the snail for consumption by the Maya or by the relatively low density of the species in the habitat which precluded detection by our recovery procedures (A.C.).
26. E. S. Deevey, D. S. Rice, P. M. Rice, H. H. Vaughan, M. Brenner, M. S. Flannery, *Science* **206**, 298 (1979).
27. The less distinctive patterns may be vegetation lines. It is likely, however, that they represent field surfaces and canals that have been highly eroded by the more permanent and deeper waters of the interior depression. Other depressions in the area have distinct quadrilateral patterns in their centers which are topped by palmettos and are sufficiently similar to their counterparts at Pulltrouser to be identified as raised fields. This evidence supports the interior field-erosion argument at Pulltrouser.
28. Various agricultural experiments on wetland fields have been conducted at the Colegio Superior de Agricultura Tropical, Cardenas, Mexico, under the supervision of S. Gliessman, by the Instituto Nacional de Investigaciones sobre Recursos Bioticos, Xalapa, Mexico, under the direction of A. Gomez-Pompa, and at Lamanai, Belize, by J. D. H. Lambert.
29. The date for this sample (Q-3117) was produced by V. R. Switsur and A. P. Ward, Godwin Laboratory, Cambridge University.
30. A temporal and spatial relation among the fields and canals in various segments of the depression has not been established. Several fields could be assigned dates by ceramic content. The fields at site 3 (southern terminus of Pulltrouser East) appear to predate those at sites 1 and 2 (along western edge of Pulltrouser South). However, the radiocarbon date of A.D. 150 ± 150, coherent with the earliest ceramic materials found mixed in several fields, comes from carbon material found at site 2.
31. Mile 70, a presumed site on the northwest side of Pulltrouser South, has not been confirmed. N. Hammond (personal communication) observed another site located east of the southern arm during an aerial reconnaissance. P. D. Harrison has identified from aerial photographs a large structure associated with this site.
32. Situated about 200 m south of the acropolises of Kokeal is a small rise on which a large platform has been constructed to support several small structures. This configuration is the first of several that extend south toward Orange Walk Town along the New River. These structures lay outside the mandate of the Pulltrouser study and were not examined in detail. Sherds collected from one test pit in the platform and from the platform surface were Late Preclassic. This group of structures has been designated as Yo Tumben in that it may be chronologically distinct from Kokeal.
33. Because excavations were limited to test pits and trenches, the structures have not been directly confirmed as habitation structures, although their forms and sizes suggest that most of them were; the excavations produced no major evidence to suggest otherwise. Further, the absence of permanent superstructures in house mounds has been reported for the Belize River Valley [G. R. Willey *et al.*, *Pap. Peabody Mus. Archaeol. Ethnol. Harv. Univ.* **54**, 562 (1965)]. It is possible that the absence of masonry walls in houses might be a regional feature. The evidence from the San Estevan study [W. R. Bullard, *R. Ont. Mus. Life Sci. Occas. Pap. 9* (1965)] and the Corozal Project is uncertain on this point. However, ceremonial structures did have masonry walls and sometimes vaults.
34. Other uses and materials could have produced the striations on the biface picks, such as cutting various palms (H.J.S.). This explanation is not as consistent with the provenience and characteristics of the artifact as that presented.
35. The first three dates were produced at the Godwin Laboratory, Cambridge University, and the latter two by H. Haas, Radiocarbon Laboratory, Southern Methodist University. The 600-year error parameter for one date resulted from the small size of the sample that was analyzed.
36. D. Friedel and V. Scarborough, paper presented at the Memorial Conference for Dennis E. Puleston, Minneapolis, 1979.
37. Recent agricultural and environmental work by S. Gliessman and B. L. Turner (in preparation) with the Colegio Superior de Agricultural Tropical at Bajo Morocoy, Quintana Roo, provided confirmation of fields and canals there. Reports are forthcoming.
38. Various types of imagery were taken by the Jet Propulsion Laboratory, Pasadena, Calif. [R. E. W. Adams, *Antiquity* **54**, 206 (1980)].
39. W. T. Sanders, in *The Classic Maya Collapse*, T. P. Culbert, Ed. (Univ. of New Mexico Press, Albuquerque, 1973), pp. 325–365; B. L. Turner II and P. D. Harrison, in (*7*), pp. 337–373.
40. M. Pohl, personal communication.
41. This estimate is obtained from a construction rate figure of 0.172 m^3 per hour per worker derived from experimental work in Vera Cruz (A. Gomez-Pompa *et al.*, paper presented at the Memorial Conference for Dennis Puleston, Minneapolis, 1979) and an 8-hour workday for 365 days. The estimate may be conservative in that the Pulltrouser fields are more elaborately constructed features than those from which the work rates were obtained and because it is doubtful that a 365-day work-year was used by the Maya.
42. More than 100 soil and fill samples from the fields and structures at Kokeal were floated for plant remains and analyzed (C.H.M.). Only a few cacao fragments were found, and they were taken from the fill of an earth mound at Kokeal.
43. W. T. Sanders, in *The Valley of Mexico*, E. Wolf, Ed. (Univ. of New Mexico Press, Albuquerque, 1976), pp. 101–159.
44. This estimate is based on the calculation that about 70 percent of the 300-ha zone was field surface.
45. This estimate is based on 94 occupation structures, a traditional occupancy of 5.6 persons per structure, and use of an estimate for the noncontemporaneity of occupation for the lower figure.
46. M. D. Coe, in *The Origins of Maya Civilization*, R. E. W. Adams, Ed. (Univ. of New Mexico Press, Albuquerque, 1977), p. 190; W. J. Rathje in *Ancient Civilizations and Trade*, J. A. Sabloff and C. C. Lambert-Karlovsky, Eds. (Univ. of New Mexico Press, Albuquerque, 1975), pp. 415–416.
47. We thank the Belizean Department of Archaeology, particularly E. G. Pendergast, H. Topsey, and M. Gutchin, the Royal British Air Force, the Belizean Sugar Industries, the Cuello Brothers, J. Bohland, the Colha Project, and various members of the 1979 Cuello Project for their assistance. Special appreciation is given to the assistance provided by N. Hammond and the critique of the referees of this work. Most figures and the typing were done by Clark University personnel. Funding was provided by NSF grant BSN 78-12537 and the University of Oklahoma.