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Radar Mapping, Archeology, and Ancient Maya Land Use

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The large area of ancient civilizations now known as Mesoamerica contains the remains of many cultural traditions. Aside from the Maya there are those leading to the historically known Aztecs, Zapotecs, Tarascans, Mixtecs, and other groups of the 16th century. The zones occupied by these groups, however, are dwarfed by the Maya lowlands. As traditionally defined, the Maya lowlands cover some 250,000 square kilometers (Fig. 1). Because this zone is nearly all below an altitude of 1000 meters and receives heavy rainfall, exuberant vegetation has hampered the use of rapid survey techniques such as aerial photography and wide-ranging ground reconnaissance. These constraints, in turn, have limited the perspectives of archeologists on regionalism and diversity within Maya civilization of the Classic period (A.D. 250 to 900). Indeed, even the size and the distribution of ancient cities are suspect.

Summary. A severe incongruity has long existed between the well-known complexity of ancient Maya civilization and the relatively feeble economic base that could be reconstructed for it. Recent fieldwork has indicated that much more intensive cultivation patterns were used than was previously thought. Data from the use of synthetic aperture radar in aerial surveys of the southern Maya lowlands suggest that large areas were drained by ancient canals that may have been used for intensive cultivation. Ground checks in several limited areas have confirmed the existence of canals, and excavations and ground surveys have provided valuable comparative information. Taken together, the new data suggest that Late Classic period Maya civilization was firmly grounded in large-scale and intensive cultivation of swampy zones.

At present, over 300 Maya centers with formal architecture are known; these range in size from centers with one paved courtyard and attendant buildings to the largest known site, Tikal, which has the equivalent of 85 courtyards and hundreds of associated buildings (*1*). The most complex of these centers contain temples, palaces, administrative headquarters, fortifications, sculptured monuments with written texts, and large reservoirs. These urban characteristics were fully developed by A.D. 250. Many centers are internally and externally linked by raised roads. Surveys of the countryside around these functional cities have found evidence of habitation by large numbers of people, ranging up to 600 people per square kilometer in the most densely populated zones (*2*). These densities were certainly reached by A.D. 600 and perhaps as early as A.D. 100 in some regions.

A generation ago, most archeologists thought that the Maya population was supported by a slash-and-burn system of agriculture similar to that practiced today by the sparse modern communities (*3*). In this form of cultivation, fields are cleared by burning off the vegetation, cultivated for 3 or 4 years, and then abandoned for 8 to 20 years. During the past two decades, data have been accumulating that indicate that the ancient populations were far larger than the capacity of such a system. Many archeologists have suggested modifications to slash-and-burn agriculture that would help close the gap between the size of the population and the manner of subsistence. For example, Puleston (*4*) suggested that breadnut or *ramón* (*Brosimum alicastrum*) may have supplemented maize or been a substitute for it as a staple food. Other mixes of subsistence systems have also been proposed, and evidence of intensive forms of agriculture has been found. Evidence of hillside terracing and field walls in the Rio Bec region led Turner (*5*) to conclude that the Maya in that region were entirely supported by intensive systems of agriculture by A.D. 600 and possibly earlier. Siemens and Puleston (*6*) found canals in the Rio Candelaria Basin and later in the Rio Hondo Valley of northern Belize. Work by Harrison and Turner (*3*) and Siemens (*7*) indicates that the extensive swamps of the Maya lowlands may also have been cultivated by means of canal drainage and raised fields. These data have been gathered mainly by aerial survey, although fields and canals have also been surveyed on the ground and excavated.

The idea that the Maya were cultivating vast swamps, which constitute up to 40 percent of the land surface in some zones, has met resistance. Puleston (*8*) argued that the aerially detected grid patterns are the result of soil expansion and contraction cycles that create patterns known as *gilgai*. Both Sanders (*9*) and Puleston also argued that aerial survey is not convincing evidence of the extent of ancient swamp drainage in the Maya lowlands, because the patterns can be the result of other, natural processes. Thus, while not denying that intensive cultivation, based on drainage and raising of fields, was practiced in certain zones, Sanders, Puleston, and others were unconvinced that such a system was in widespread use.

The theoretical implications of wide-

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spread intensive cultivation are significant and complex. Briefly, they revolve around arguments about the nature of Maya urbanism, the complexity and sophistication of Late Classic (A.D. 600 to 900) political systems, and the processes that led the civilization to its final collapse about A.D. 900. For example, the systemic model of the Maya collapse developed at the 1970 Santa Fe conference (*10*) assumed a larger population than could be sustained by slash-and-burn agriculture, but there was little data indicating the intensive means by which such a population could have been supported. There was also an assumption of a high degree of political sophistication, because of the numbers of people involved and the skills needed to manage an intensive subsistence system. Supporting data have been forthcoming, but were the interpretations of those data to be refuted, then grave doubt would be cast on the cultural processes reconstructed by the collapse model.

To improve survey data on the Maya lowlands, we began a search for a remote-sensing technique that would be both rapid and reliable. Airborne, side-looking radar was among the techniques suggested, and W.E.B. at the Jet Propulsion Laboratory provided access to such a system.

The Imaging Radar

The National Aeronautics and Space Administration operates an imaging radar that is mounted on a CV-990, a four-engine jet aircraft which is generally used to evolve spaceborne radars, such as the Apollo 17 lunar sounder and the SEASAT synthetic aperture radar. The radar was originally designed and developed at the Jet Propulsion Laboratory in 1967 primarily for use in imaging the surface of Venus sometime in the 1980's.

In the initial discussion of the use of radar for archeology, the emphasis was on a sensor system that would penetrate foliage, silt, and root cover to map ancient roads, causeways, and other man-made structures. Previous work with this radar was not encouraging because it indicated that losses in microwave energy in the presence of moisture with a high ion content, which is found in the foliage and limestone in the Petén of Guatemala, would be very high. We embarked on an experimental program with radar characteristics chosen to avoid this problem. The wavelength was larger than usual, 25 centimeters, the effective peak power was 12×10^6 kilowatts, and the geometry was such that we could look almost straight down as well as off-nadir; therefore, there was a chance of success.

The synthetic aperture radar operates in a range-offset mode, with a center frequency of 1225 megahertz. The major parameters of the radar are given in Table 1. The antenna is mounted on the rear baggage door of the aircraft. Its effective pattern is a fan-shaped beam 90° cross-track, centered at 45° off-nadir, and 0.0057° along-track, centered at 90° off the aircraft heading. To reduce the speckle effect inherent in coherent monochromatic systems, about 20 observations are averaged for an effective along-track angle of 0.11°, or resolution of objects 20 m on a side in the direction parallel to the aircraft flight path at 45° off-nadir. The term synthetic aperture means that a small antenna with a large angular coverage is used to generate a very long synthetic antenna and to narrow the angular coverage by a factor of several thousand. The narrower the angular coverage, the better the angular discrimination, or the higher the along-track resolution.

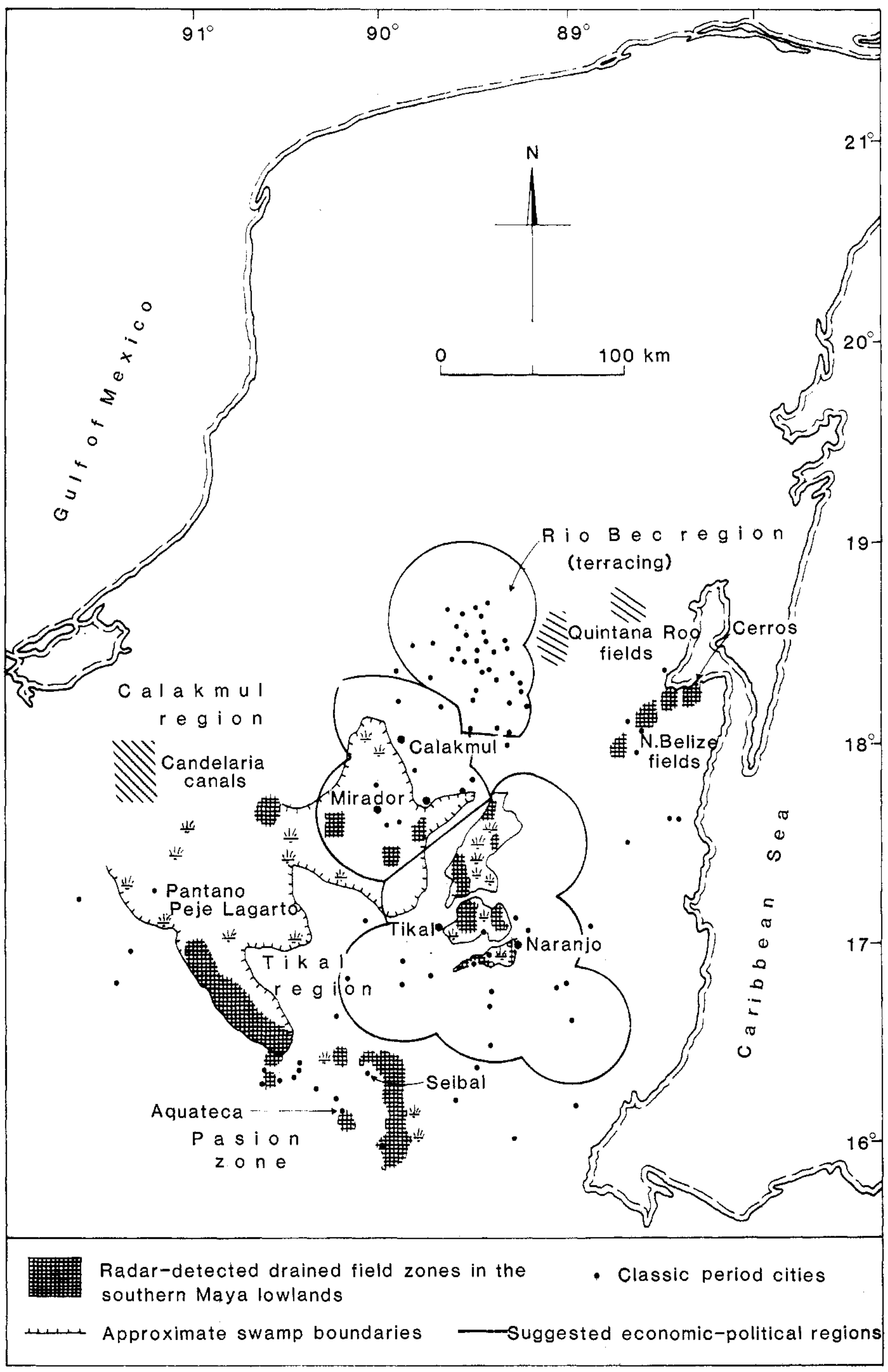

Fig. 1. Map of the Maya lowlands showing drained field zones detected by radar in relation to known Maya cities of the southern and intermediate areas.

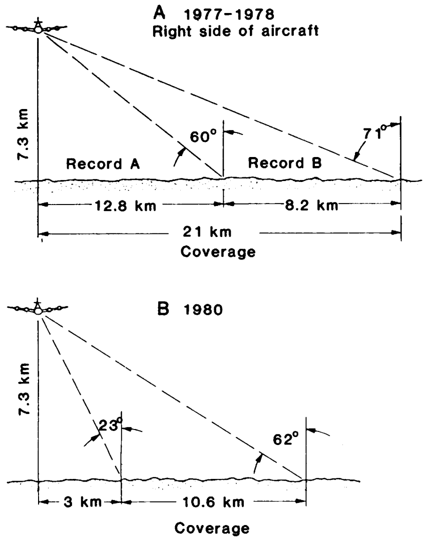

Fig. 2. Radar acquisition geometry.

The range resolution is determined by the bandwidth of the radar system and is nearly 15 m. At 45° off-nadir, the cross-track resolution on the surface would be about 21 m. A good description of the synthetic aperture radar system is given by Jensen *et al.* (*11*).

Data Acquisition and Processing

The Jet Propulsion Laboratory's L-band radar views the surface from nadir out to 71° from the vertical on the right side of the aircraft, or a usable swath 17 km wide. The data are collected on two recorders covering 0° to 60° on one and 60° to 71° on the other (Fig. 2).

The data were obtained in October 1977, April 1978, and August 1980. The 1977 and 1980 flights were of short duration and covered northern Belize, Tikal, and the Rio de la Pasión. The 1978 flights were made on five consecutive days and covered northern Belize and virtually all of the Petén. During these flights, black-and-white and false color infrared photographs were also taken. About 20 percent show the surface well; the rest are degraded by haze and clouds. During operations, coordinates are preset into the navigation system, and flights are conducted at an altitude of 7.3 km along the preset tracks, even when the ground is completely obscured by cloud cover.

The radar data were initially recorded optically. The data base, therefore, consists of radar echoes in a range-Doppler format and must be correlated to produce imagery. This was done on the optical correlator at the Jet Propulsion Laboratory with a system configured for SEASAT. The Doppler aperture is about 10 to 15 cm long on the film, and the SEASAT correlation can handle about 3 to 5 cm. Therefore, the full azimuth resolution was not realized on the data thus far correlated, but full processing is planned. A test on the August 1980 data with about 8 cm of the Doppler history processed (Fig. 3) shows a region around Tikal; the road, airstrip, Temple of Inscriptions, and other major structures can be identified.

The initial intent of the survey was to seek effects caused by structures hidden beneath the canopy and agricultural signatures. So far, only a very faint indication of the causeways in the Mirador area has been identified; the effects of agricultural activity are described below.

Analysis of the Radar Imagery

Positive transparencies of the radar imagery were examined on a light table for indications of archeological sites and ancient landscape modification with a ten-power handglass. Light passing through the imagery was subdued by covering it with medium thickness tracing paper, which also helped reduce the effects of speckle. Data were transcribed by hand onto tracing film with a mapping pen, and the overlays produced were compared with topographic maps of the same scale by placing the overlays directly on them. Comparisons were also made with aerial photographs of specific zones.

Archeological sites show up in two ways: as one or more large, irregular

Table 1. Parameters of the radar imaging system.

Parameter	Characteristic
Frequency	1225 MHz
Wavelength	25 cm
Peak power	400 kW
Pulse width	10 μsec
Bandwidth	20 MHz
Antenna azimuth beam	15°
Antenna range beam	90°
Recorder type	Optical
Receiver gain	80 dB
System bandwidth	10 MHz
Range compression gain	2000
Azimuth compression gain	1500
Synthetic aperture length	750 m
Slant range resolution	15 m
Azimuth resolution (single look)	8 m
Aircraft (Maya mission)	
Altitude	7.3 km
Ground speed (nominal)	200 m/sec
Time marker	WWV (1 msec)
Inertial guidance accuracy	100 m
Camera support	Black and white, infrared
Auxiliary data	Flight logs, ground track

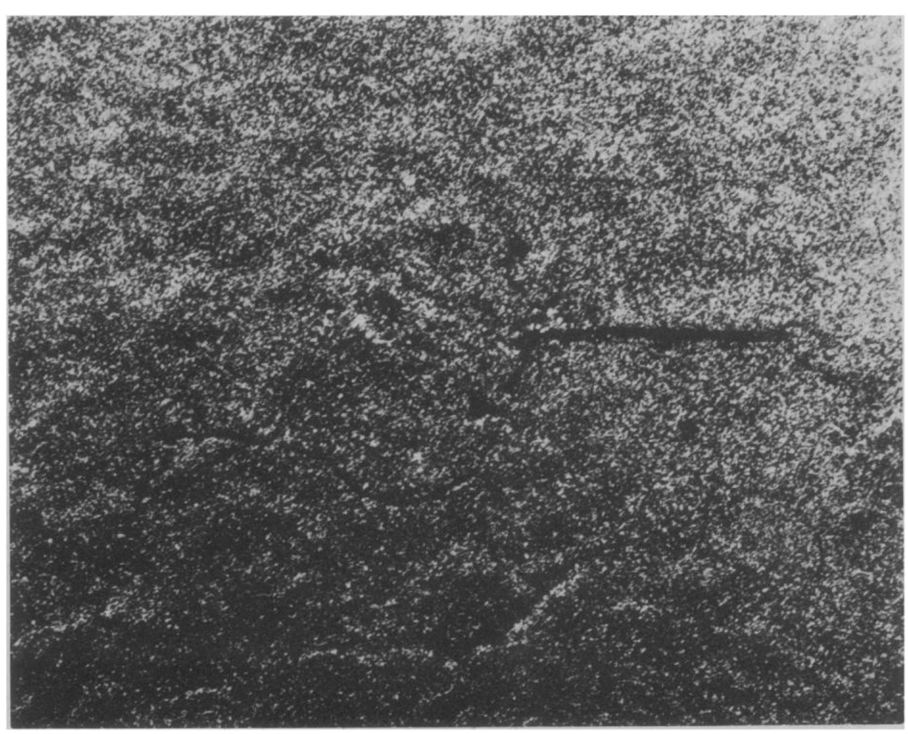

Fig. 3. Synthetic-aperture radar imagery of the Tikal zone, Guatemala. The heavy, dark horizontal line (right, center) is the Tikal airstrip. True north is 23° east of vertical. The main ruins show as a set of bright dots about 1 inch to the left of the west end of the airstrip. The Temple of the Inscriptions shows below and slightly to the left of the airstrip and in the loop of a road that leads up to the airstrip. Depression angle of the radar was 23° to 62°. Scale about 1:75,000.

Table 2. Summary of canal zones confirmed by ground checks (GC) in northern Belize. In addition, the zones were covered by the following as indicated: radar (Ra), aerial photography (AP), excavation confirmation (EC).

Zone	Major site	Coverage	Source
Cerros Peninsula	Cerros	Ra, AP, GC, EC	Friedel and Scarborough (*21*)
Pulltrouser Swamp		Ra, AP, GC, EC	Turner and Harrison (*12*)
Nohmul	Nohmul	Ra, AP, GC	Hammond (*14*)
San Antonio		Ra, AP, GC, EC	Siemens (*7*)
San Roman		Ra, AP, GC	Adams and Greaves

spots of light or as distinct shadows cast by large mounds. The spots of light show only on sites with large buildings on which the casings have either survived or been restored. Most sites do not have these features. At the present scale of 1:250,000 it is difficult, in all but the largest sites, to distinguish shadows of large mounds from shadows cast by natural hills. Where distinguishable, large mounds seem to cast conical shadows, and natural hills cast irregular shadows. These difficulties in site detection seem to be mainly a problem of scale of resolution, and the improved imagery from the 1980 flight gives hope of more detailed data from future surveys.

It was noted that areas of wet season swamp (*bajo*) near known sites often had irregular grids of gray lines within them. Upon careful examination, these lines were seen to form a multitude of ladder and lattice patterns as well as curvilinear patterns. Overlays of these zones, such as one constructed for northern Belize (Fig. 4), were compared with overlays of aerial views of confirmed ancient canal systems from the Valley of Mexico and the western Maya lowlands around the Rio Candelaria (Fig. 5). After differences in scale are taken into account, the radar patterns match the aerial views. This suggests that at least some of the grid patterns produced by the radar represent ancient canals. Only the largest and most widely spaced canals are picked up by the radar, however. The gray line patterns are almost certainly created by slight differences in elevation of vegetation. Trees growing on the raised fields between canals are taller and therefore overshadow those growing in the former canals. This effect can be seen in some aerial photographs of Maya lowland swamps taken in March and April, when the jungle is in bloom.

Further pattern analogy that tends to confirm our interpretation is that the grid lines in the swamps and along the watercourses have the same visual quality as do the abandoned stream channels. Moreover, grids are closely associated and correlated with the known areas of swamps, edges of lakes and ponds, and watercourses. There is a negative correlation between grids and upland areas, karst landscape, and mountains. Finally, aerial identifications of grid and linear patterns within the swamps have been made by Turner and Harrison (*12*) and Siemens (*7*) separately, and at widely different points within the areas covered by radar imagery.

There is not, however, an invariable correlation between the radar imagery, the aerial photographs, and the ground features. The radar does pick up individual large canals, such as those at Cerros and near Seibal (Fig. 1). Aerial photographs show many of the same canals but in much greater detail and with many more of the smaller, interstitial canals (Fig. 6). Pattern analogy is not proof, of course, and visual and aerial photographic data have not convinced all archeologists. Therefore, ground checks, which almost always deal with fragments of major canals and even more with the interstitial canals, were carried out by R.E.W.A. and T.P.C., together with H. W. Lende and T. C. Greaves. Confirmations from ground work were also provided by other colleagues.

Five separate zones in northern Belize (Figs. 4 and 6) have been ground confirmed as locations of ancient canals and raised field systems (Table 2). These five zones were covered not only by radar imagery, but also by visual and aerial photography, the five ground confirmations were made by five separate groups of archeologists. Among the most important findings are those of Scarborough (*13*) at Cerros, where the major canal surrounding the site shows clearly in the radar imagery. The site also contains closely packed raised fields that are about 3 m on a side and intervening canals that are about 1 m wide. These features do not show in the imagery because minimum object definition obtainable from the data is 15 m. Scarborough's data indicate that there are many other nonarcheological features recorded by the radar, including modern road networks, old logging trails, hurricane beach swales, abandoned jungle airstrips, river terrace edges, and fault

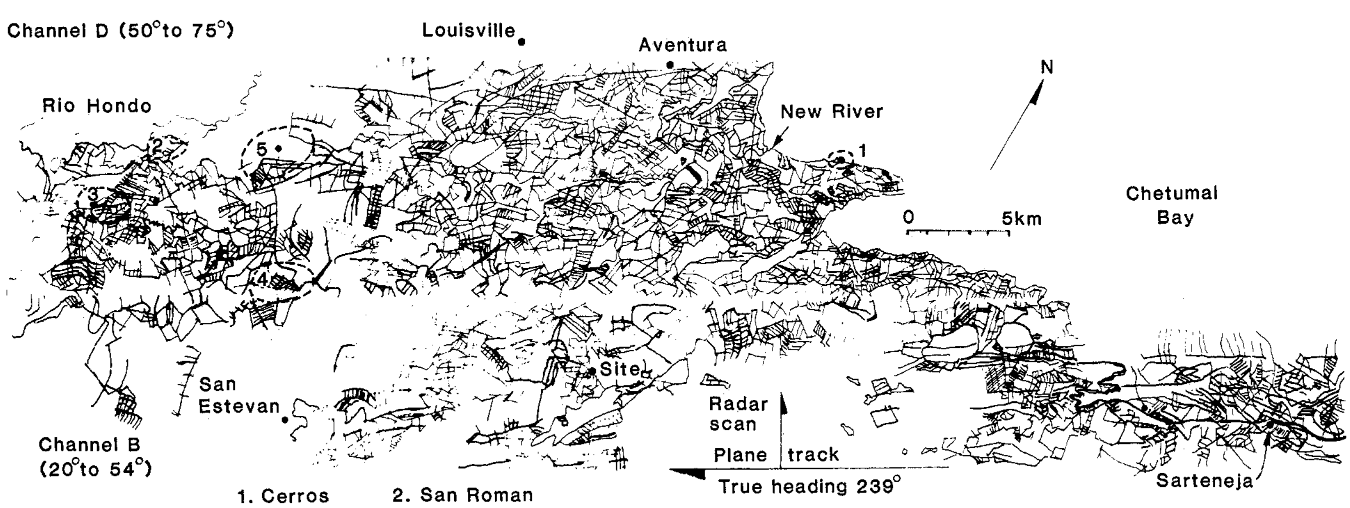

Fig. 4. Overlay of northern Belize, transcribed from radar imagery, showing the lattice structure of canal lines and the five zones where the existence of canals has been confirmed by checks.

lines. None of these or other nonarcheological features show the characteristic grid, ladder, or lattice patterns associated with known canal areas. Overlays produced from the imagery must be filtered by pattern analysis after all data are taken from the negative images. Analysis of 20 overlays thus far studied indicates that between 20 and 40 percent of the lines have pattern characteristics suggesting canals. In addition to canals and large mounds, archeological features that have been detected by radar include the edges of extensive paved surfaces.

The work of Turner and Harrison (*12*) at Pulltrouser Swamp is the first extensive excavation of raised fields carried out in a lowland swamp. They report that the canals are artificial, ancient, and associated with raised field agriculture. These canals and fields show up in the radar imagery as well as in aerial photographs. As in all cases, the radar gives a gross idea of the presence of canals and fields, but at present not a great deal of detail.

Swamp zones along the present stream beds, such as the San Roman Swamp on the Rio Hondo, are annually flushed by floods. No cultural remains are likely to be found in such areas, and only regular islands of swamp grass remain within the watery grids at San Roman (Fig. 6).

Hammond (*14*) found canals and raised fields near Nohmul. Siemens (*7*) also found such features at San Antonio on the Rio Hondo.

The data from northern Belize thus provide convincing confirmation of widespread intensive cultivation. The data from the Guatemalan Petén zone are less satisfactory. Three Petén zones (Table 3) were ground-checked in February and March 1980. One zone is on the south edge of Lake Petexbatun and associated with the major site of Aguateca. The swamp shows some regularity of water channel patterns both from water level and from low-level flight, but no cultural material was found.

The zone north of the Rio de la Pasión in the vicinity of the site of Seibal was also explored. The Arroyo Cantemó, evidently a major canal, was explored by dugout canoe. Tributaries, which are long and linear and enter the Arroyo Cantemó at right angles, were identified from the canoe, from low-level aerial observation and from photographs taken at low and high altitudes. No cultural material was found during the brief ground exploration. The third zone examined in the Petén was around the large center of Tikal (Fig. 3). Swamps gird this center, and brief examination of the edge of the Bajo de Santa Fe to the east located what is apparently a raised field and possibly some canals. The raised field is approximately 30 m wide, 2 m high, and more than 100 m long. The canals are heavily obscured by vegetation. A possible canal was seen about 12 km north of the center of Tikal on the trail to Uaxactún. This is probably part of the northern "fortification" ditch (*15*). Our panchromatic photographic coverage of the Bajo de Santa Fe near Tikal and in the Seibal zone shows the presence of grid patterns identical to those found in the northern Belize zones.

Table 3. Summary of canal zones confirmed by ground checks (GC) in the Petén, Guatemala. The zones were also covered by radar (Ra) and aerial photography (AP).

Zone	Major site	Coverage	Source
South Petexbatun Swamp	Aguateca	Ra, AP, GC	Adams, Culbert, and Lende
Great Bend, Rio de la Pasión	Seibal	Ra, AP, GC	Adams, Culbert, and Lende
Bajo de Santa Fe	Tikal	Ra, AP, GC	Adams and Lende

The poor results in the Petén zones, in comparison to those from Belize, are due to two related factors: the much denser and higher forest cover in the Petén and the relatively small scale of resolution in the radar imagery. However, definite grid patterns and lines were identified from low-level flights over rush and sedge swamps in a zone of the Petén between the Rio de la Pasión and Laguna Mendoza. Figure 1 shows the distribution of radar-detected canals thus far found in the southern Maya lowlands.

In summary, we have confirmed by aerial photography, visual reconnaissance, and ground checks the existence of ancient canal systems in five zones in northern Belize. The existence of the canals is less certain in three zones in the Petén, where they were indicated by the radar survey. These sites amount to pinpoint checks of the total area covered by radar imagery. With the technique proved valid, the question is no longer one of the widespread existence of canals but becomes one of their total extent. Radar imagery provides preliminary estimates of that dimension. Although further analysis and new imagery with higher resolution are needed, the available data allow us to set the probable minimum and maximum extents of Late Classic canal systems.

Applications of the New Data

The total area of the Department of Petén in Guatemala is approximately 36,200 km^2, nearly all of which was covered by radar survey. Another 670 km^2 was covered in northern Belize. Approximately 8000 km^2 of the Petén is estimated to be periodic swamp. Another 6000 km^2 needs drainage for agricultural purposes (*16*). These 14,000 km^2

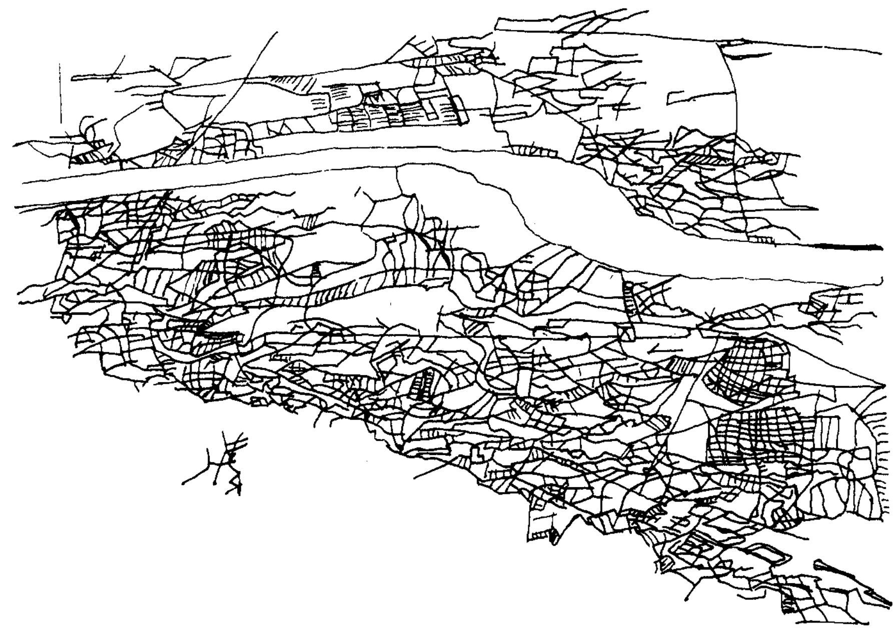

Fig. 5. Overlay of a low-level oblique angle aerial photograph showing confirmed ancient canal patterns in the Rio Candelaria zone of the Maya lowlands. Scale about 1:1000 [figure 2 in (*6*)].

represent the outside theoretical limit of canal-drained land in the surveyed area, but it is reasonable to suppose that the actual maximum was less than this. As judged by the radar imagery, nearly all swamps, edges of watercourses, and lands surrounding lakes and ponds in the Petén have been modified by drainage canals, with the possible exception of some areas in the northwest. If this northwest zone (~ 1575 km^2) is omitted from the calculation, we have a theoretical maximum of 12,425 km^2 of canal-drained land. The Bajo de Santa Fe, Azucar, and Maquina in the areas east, north, and south of Tikal show the greatest density of canals. Another major zone is just east of the Sierra de Lacandon, from the Rio de la Pasión north to the Pantano Peje Lagarto. If we assume that only 20 percent of the radar-detected lines are actual canals, on the basis of the Cerros assessment, then an adjusted maximum of 2475 km^2 of the total area that would require drainage for agriculture is reached. To estimate the minimum area, the swampy zones are used as a calculation base (8000 km^2) to yield a

Fig. 6. Aerial photo of the San Roman Swamp zone of northern Belize along the Rio Hondo. Ancient raised fields and canals are visible as cellular patterns to the right of the river around where it forms a hook. Scale about 1:2000. [Courtesy Belize Sugar Industries]

figure of 1285 km^2 [0.20 (8000 − 1575 km)]. Both of the adjusted figures are large for preindustrial irrigation or drainage enterprises. In contrast, the well-known Aztec *chinampa* system covered only 120 km^2. However, the estimates of the population in the Valley of Mexico (1.5 million in A.D. 1519) are much lower than those in the Maya lowlands (14 million in about A.D. 800), and the areal extent of the valley (7833 km^2) is only a little more than 10 percent of that of the southern Maya lowlands (75,000 km^2) (*1*, *17*). Therefore, there are proportional and correlated differences in sizes of total area available, total area intensively farmed, and total population sustained. We assume that most of the drained field areas in the Maya lowlands were in simultaneous use in the Late Classic, the period of maximum populations. More extensive excavation data are needed to verify this assumption, however.

The radar data provide new perspectives on Maya civilization in several ways. First, there is the possibility that the southern lowland Classic Maya were the largest-scale users of intensive cultivation systems in Mesoamerica. Second, problems of locational analysis become simpler when applied to Maya centers. Swamps are recognized as assets instead of wasteland; indeed, the swamps may have been the most productive land available. Modern experimental plots in lowland Veracruz, Mexico, have produced data on the productivity of such systems in tropical forest environments. It is estimated that a hectare of land cultivated by the raised field and canal system will support a minimum of ten persons (*18*). This means that the locations of such large sites as Tikal on the edges of large swamps can be explained as the result of successful exploitation of a nearby rich resource. Although all Maya sites are located near a water source, and although intensive cultivation of wetlands dates to the Late Preclassic (~ A.D. 100), the largest Maya cities of the Late Classic are located only on the edges of swamps (*19*). Third, the economic base of Maya civilization, one that could support the great numbers of people implied by settlement pattern surveys, becomes more convincing and coherent in structure. Fourth, canals through shallow lakes and swamps could have provided the means to transport bulk commodities. This use of canals for both water control and transportation is well known for the traditional canal systems of Southeast Asia, as well as for the historical Aztecs. Such a transport system would aid in explaining how the masses of people in the preindustrial cities of the Maya, 50,000 at Tikal alone (*20*), were supported. Finally, the use of an intensive and sophisticated system of agriculture, one requiring considerable management, may also explain at least part of the vulnerability to the systemic collapse that the Maya suffered about A.D. 900.

We recognize that this work is preliminary. The radar imagery represents a large-scale perspective on ancient land use that has not been available before, but it also presents us with problems of full validation. The immense area covered means that it will be sometime before adequate ground checks can be made of all the potential canal areas. To date there has been some excavation of raised fields in Belize and in the Candelaria zone (*3, 6*). Only excavation can produce more precise estimates of the total areas of raised field growing surfaces used in any given period. Excavated data are also needed on the populations in the raised field zones, as well as detailed information on water and land management techniques. Excavation at hamlets associated with raised field zones will throw light on matters such as stone technology, food crops, and developmental trajectories of the canal systems.

Finally, the new information may allow more effective land use planning by the modern governments of Guatemala, Belize, and Mexico. These nations are using the Maya lowlands, and their people are moving into the zones in great numbers in both planned and unplanned agricultural colonies. Radar technology and archeology may combine to provide at least some of the data needed about intensive agriculture in these tropical forest areas.

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Fermentation in the Rumen and Human Large Intestine

Meyer J. Wolin

A portion of the intestinal tract of mammals is a chamber where a large microbial community ferments components of the host's diet. In many mammals the fermentation occurs in a complex stomach. Ruminants (for example, cows, sheep, and deer) are the most familiar of these animals. Nonruminants, including those that chew their cud, that is, ruminate (for example, camels and llamas) and those that do not ruminate (for example, colobine monkeys and kangaroos) also have complex stomachs that are microbial fermentation chambers. Mammals with simple stomachs that do not support pregastric fermentation include herbivores (for example, horses and rabbits), carnivores (cats and dogs), and omnivores (humans and rats). Whether mammals have a complex or a simple stomach, they usually have a fermentation chamber in the large intestine.

The microbial ecosystem of the complex stomach (rumen) of domesticated ruminants is the most clearly understood intestinal fermentation system (*1–3*). Ruminants rely on digestion of food by microorganisms for essential macro- and micronutrients. Because these animals are excellent sources of milk, meat, wool, and leather, there is a significant amount of contemporary research on ways to manipulate the rumen community, for example, by adding antibiotics or other chemicals to feeds in order to increase the animals' economic value. The intestinal microbial ecosystems of other animals with complex stomachs have not been studied in as great detail, but there has been a recent surge of interest in the large intestine ecosystem of humans. There is increasing recognition that interrelations between diet and the characteristics of the microbial community are significant for human health.

I review here the general features of the rumen ecosystem and indicate how (and why) manipulations of the microbial community are being carried out. I also compare the features of the rumen and large intestine ecosystems and indicate how fermentation may influence human health.

Fermentation in the Rumen

The forestomach of ruminants is a self-contained factory where fermentation of the animal's food forms products essential to the animal (Fig. 1). Ingested polymers in grasses, hay, corn, and silage, for example, are comminuted by masti-

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