

# NEW DIRECTIONS FOR ARCHAEOLOGICAL RESEARCH ON THE ANGKOR PLAIN: THE USE OF REMOTE SENSING TECHNOLOGY FOR RESEARCH INTO ANCIENT KHMER ENVIRONMENTAL ENGINEERING

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NB This paper has four figures. Figure 1 is printed in colour on the front cover and Figures 2 and 4 on the rear cover of this volume. Figure 3 is in the text.

After the Cambodian Peace Settlement was signed in 1991, one of the first acts of the new government of Cambodia was to ratify the 1972 UNESCO World Heritage Convention and to apply to have Angkor placed on the World Heritage List (UNESCO 1992). World Heritage listing has the advantage of making a site eligible for technical and financial assistance from the World Heritage Fund, something which was very much needed at Angkor where very little maintenance work--to say nothing of field research--had been undertaken in the 20-year period following the Khmer Rouge capture of the region in the early 1970s.

Although the state of conservation of the site did not, at that time, meet normal World Heritage standards, in recognition of the global significance of the Angkor monuments and associated archaeological features the World Heritage Committee placed Angkor on the World Heritage List in December 1992 and immediately made assistance funds and technical expertise available through UNESCO (see Appendix 1).

## THE "ZEMP" APPROACH

One of the specific forms this assistance has taken is that of a multi-disciplinary research and documentation project to produce a "Zoning and Environmental Management Plan" for the site, a process which has become known simply as "ZEMP". The main purposes of the Angkor ZEMP are twofold:

1. First, to identify, on and under the ground, the actual area of the site of ancient Angkor to be protected and

conserved as a national monument and archaeological reserve.

2. The second objective of the Angkor ZEMP is to collate all available documentation on Angkor, much of which had been lost or scattered during the Khmer Rouge period; to undertake basic research where there are lacunae in the information available; and thus to re-create a data base to serve future research.

For ZEMP to succeed and have meaning for the future, it was important: (a) to put together a multi-disciplinary, international team with wide-ranging research interests and expertise; (b) to use the most appropriate available technology for the recording and storage of the information the team would produce, in order that it could become the foundation of a data base available to all; and (c) to make the project a training ground for Cambodian site administrators and students of archaeology in order to begin to rebuild a corpus of Cambodian national professionals who will be able to study and preserve Angkor into the future. Working under the World Heritage Committee's deadline to produce a preliminary report within six months, a team of 25 international experts was assembled, consisting of archaeologists, hydrologists, anthropologists, botanists, specialists in the conservation of monuments and administrators from the National Park Services of several countries (see Appendix 2).

A 5000-square kilometer "study area" was defined for the project and special satellite and aerial photographs of the area were taken for use by the ZEMP team. The experts worked at Angkor from December 1992 through June 1993, compiling data, doing field research and entering their findings into a common computerized GIS, or "Geographical Information System."

It was evident to the multi-disciplinary ZEMP team that Angkor could not be considered apart from the environment in which it is located--both the natural environment and the environment so meticulously engineered by the ancient Khmer themselves. This has led to a management strategy which considers Angkor not as a group of monuments, but as a cultural landscape of monuments, archaeological features and niches all of which are in need of conservation and protection both as an historic public site and as a research reserve for the future. Although the data to come out of the collective ZEMP studies are still sketchy, as Head of the UNESCO team in Cambodia, I feel we have a responsibility to report our preliminary findings promptly so that our work may serve as a catalyst to interest other scholars to develop joint research projects with Cambodian scholars to revitalize the field of Khmer archaeology.

For the data presented in this paper, I am indebted to the work of all of the ZEMP Expert Team, including especially, Elizabeth Moore of the School of Oriental and African Studies (London); Claude Jacques of the Ecole Pratique des Hautes Etudes (Paris); Ferenc Garami and his team of hydrologists from Hydro-Ecosphere Ltd. (Budapest) and Heng Thung, geographer/cartographer of the Mekong Secretariat and specialist in remote sensing. These scholars and others who worked as part of the UNESCO ZEMP team will, no doubt, be presenting details of their research at later dates in various appropriate professional conferences and publications (see especially Moore, in press).

#### THE ZEMP STUDY AREA

The ZEMP study area extends from the Kulen mountain plateau in the north down to and including the inundated forests of the Tonle Sap in the south and from west of the Puok River east to the Damdek canal, including the Siem Reap and Roluos river basins. The site of Beng Melea at the foot of the easternmost extension of the Kulen plateau marks the easternmost extension of the study area (Figures 1, 2 and 4, located in colour on covers of this volume; Figure 3 in text).

This was an ambitiously large study area. We knew when we began the project that much of the area might be inaccessible because of continued Khmer Rouge guerilla activity and our research therefore limited to what we could read from the aerial photographs or glean from literature and informants. However, we were also aware that with this project we would be defining the Angkor area for the future and we wanted to be certain to include all of the important geographical features which were part of the ancient catchment area of Angkor. As

our field work progressed we were in fact able to access much of the study area for ground-truthing of our interpretations from the aerial photographs. Drs Moore and Garami were able to get far up into the river valleys of the Stung Puok, Stung Siem Reap and Stung Roluos. I was able to visit the Phnom Kulen and travel down the Damdek canal to the Tonle Sap.

The base topographical data used by the experts was taken from 1:50,000 topographic maps dating from 1968. Land use and infrastructure information was derived from 1:25,000 stereo-aerial photographs taken in 1990 and from LANDSAT imagery at 1:100,000 compiled in late 1992. Drs Moore and Heng Thung were also able to make comparative use of the 1945 aerial photographs of Willilams-Hunt in the SOAS and Siam Society collections. EFEO photo-documentation was also available for comparative purposes. UNTAC provided detailed and up-to-date demographic data compiled in a census taken just before the May 1993 elections.

#### ENVIRONMENT AND GEOLOGY

##### The Angkor Plain

Early human settlements were often located on ecotones. This is especially true of cultures, like that of Angkor, where both agriculture and gathering/hunting/fishing were important in the subsistence base. Ecological characteristics are, of course, influenced by the environment and underlying geology of the area. Therefore, we will turn first to some of the findings of the ZEMP team geologists and geographers, the implications of which led other members of the ZEMP team to re-evaluate some of the long-standing preconceptions about the distribution, chronology and even the engineering of Angkor structures and sites.

Since the early part of this century, following the extensive site surveys of Lunete de Lajonquière (1902-1912), it has been recognized that the major Angkorian archaeological sites in Cambodia are scattered throughout the northern slopes of the Tonle Sap drainage basin from the Dangrek mountain range down to the shore of the Tonle Sap lake (Figure 2). This geographical supposition is corroborated by the distribution of presumably prehistoric settlement mounds and by later Khmer-period field patterns, both of which are visible from satellite and aerial photographs. Because of this the Cambodian authorities have recently requested the UNESCO ZEMP team to extend the project's study area further to the west and north.

### The Kulen Plateau

From the Dangrek escarpment the landscape consists of a gently sloping undulating old peneplain covered by alluvium. This is, however, interrupted by the massive sandstone-capped plateau Kulen plateau which has been elsewhere eroded away. The escarpment face of the Kulen continues to erode leaving the alluvial sediments but exposing some ancient limestone deposits, which are characterized by sinkholes visible on the satellite imagery northeast of the Angkor complex. This limestone sinkhole area is covered with ancient forest indicating that it probably has never been farmed by the Khmer. Given the very early Khmer archaeological remains found on the Kulen and considering the ancient Khmer assumption--as read from Inscription No.1 (Jacques 1990)--that this site is very old, the exposed limestone escarpment has been identified by the ZEMP team as a target area for future survey for very early sites, perhaps comparable to Laang Spean cave in Battambang province which is situated in another part of the same exposed limestone formation (Mourer 1977).

Moving down from the Kulen, a series of coalescing alluvial fans have formed an extensive alluvial apron of more recent deposits drained by a series of roughly radiating parallel streams. This area of more permeable sandy soils, weathered from the sandstone of the Kulen were, and still are, the major areas cultivated by the Khmer (Heng Thung 1993) (Figure 3).

### The Tonle Sap

The lacustrine deposits which extend along the Tonle Sap form the southern boundary of the Angkor catchment area. These more clayey soils with a high moisture content are covered annually by the flooded lake. These fertile soils are exploited for receding rice, which is planted as soon as the soils are dry enough for cultivation after the retreat of the water. The area closer to the lake is covered by deepwater (or "floating") rice, which grows under flood conditions.

Many little-known varieties of rice are to be found growing in ecological micro-niches along the lakeshore and may prove to be useful to study, both for understanding the evolution of rice production at Angkor and for the interpretation of pollen cores from archaeological sites. During the ZEMP field research, a series of cores was taken from the lakeshore and from the reservoirs near and the moats surrounding monuments and sites. These are being studied by the ZEMP geologist, botanist and hydrologist and we hope they can form a base line of data which other researchers can use to compare against cores from their future sites.

The lake is unique in the sense that the water level fluctuates due to the influence of the much larger Mekong River system which captured the smaller Tonle Sap river approximately 5000 years ago (Heng Thung 1993). Annually, the Mekong River rises far above the level of the Tonle Sap and overflows into the lake, more than quadrupling its size and moving the lake shore 10-20 kilometers inland, creating the special environments along the shore of the lake. According to ZEMP team geographer, Heng Thung of the Mekong Secretariat, there is evidence suggesting that the Tonle Sap was part of an inland sea during the Tertiary and thick alluvial deposits were laid in the basin which is connected with the Mekong Delta. ZEMP zoologist Richard Salter of the World Conservation Union has re-confirmed the presence in the Tonle Sap of several species of normally marine fauna which have evolved an adaptation to fresh water, confirming the thesis that the Tonle Sap was once part of a sea or at least suggesting for it a special evolutionary history (Salter 1993).

### RECENT CHANGES AND MODIFICATIONS

According to ZEMP hydrologists, the drainage pattern of the Angkor area is unusual in that it shows entrenched meanders which indicate the down cutting of the streams, instead of the lateral erosion characteristic of an old age of meandering streams (Garami and Kertal 1993). This indicates a gradual lowering of the base level of the drainage system, which can be caused either by an even slower lowering of the lake level, or an uplift of the land, or a combination of both. There is an indication that the uplift rotated along an NW-SE axis, following the orientation of the Kulen plateau, as the entrenched meanders appear to be much deeper in the eastern part of the area (Heng Thung, pers. comm.). Measurements taken by the ZEMP team of hydrologists have shown a downcutting of as much as six meters below the original base of the 10th and 11th century canals of Angkor. Although this phenomenon requires more detailed study, it could form an explanatory model for the seemingly permanent abandonment--during early Angkorian times--of the numerous prehistoric settlements and early field systems found along the upper Stung Puok river valley. If the uplift was sufficient to drive the small streams underground these settlements would have been left without access to water. Later, the Khmer sought increasingly sophisticated technological solutions to this problem, including dams, dyking and the canalization of rivers to divert water into large above-ground level reservoirs to increase the water level, and the use of water current-driven waterwheels of a type still in use today.

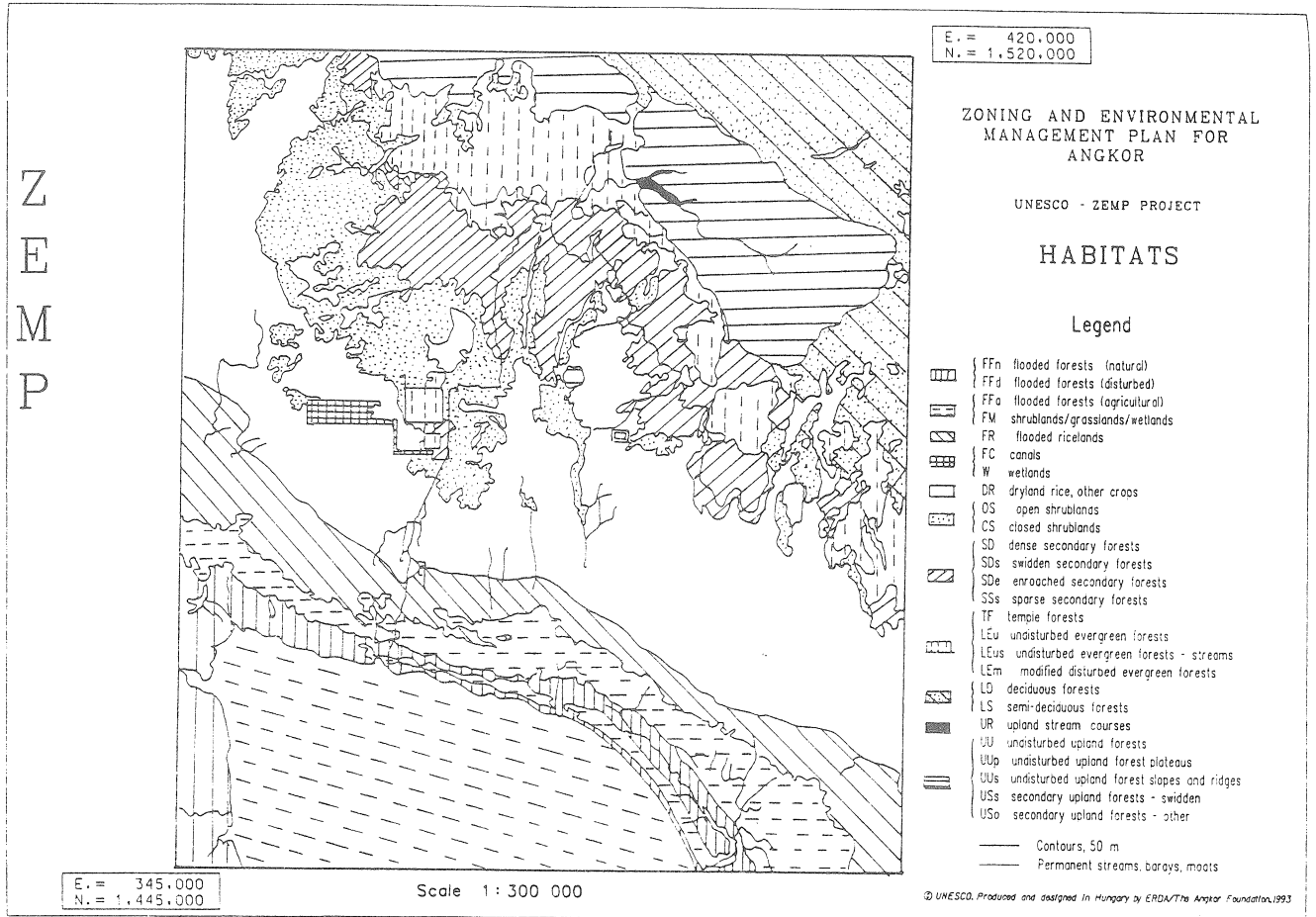


Figure 3: Habitats of the Angkor region.

ARCHAEOLOGY

To examine this proposition concerning the link between changing Angkorian settlement patterns and water engineering technology, the team of ZEMP archaeologists headed by Elizabeth Moore extensively surveyed the ZEMP study area for evidence of early habitation (Moore 1993). Previously there was very little evidence for habitation of the Angkor area prior to the establishment of the Khmer Empire in the 9th century. The Kulen inscription of the Empire's founder, Jayavarman II, has been interpreted to indicate that he established his capital

in a pristine area, but of course that cannot be true. ZEMP historian Claude Jacques has shown through careful re-reading of the corpus of inscriptions that Jayavarman II seemed to have a peripatetic base, moving between sites throughout the Angkor plain, presumably where there were villages loyal to him, or rich, or in need of the presence of his army and administration.

It is true that Bernard Philippe Groslier noted prehistoric remains for three sites at Angkor: Auk Yum, Chaw Say Tevoda and Baksei Chamkrong (Mourer 1977). But none of these are from stratified excavations or in association with anything except the earth removed for the

foundation of a much later monument. The most tantalizing site noted by Groslier was a lakeside habitation with "neolithic" remains, but this site was not fully reported.

Through examination of the satellite imagery I was convinced that we would find evidence of early settlement in the Angkor plain if we looked for it systematically, based on an understanding of how prehistoric peoples in Southeast Asia characteristically took advantage of the economic opportunities offered by biotically rich ecotones (Engelhardt 1987). Moore's work on moated sites in northeast Thailand established a methodology for this sort of investigation and a typology for early Khmer habitation sites (Moore 1988, 1989, 1992).

During the Zemp survey nearly 1000 archaeological sites were identified. Of these, approximately half were previously unrecorded sites, most of which have been tentatively identified as habitation mounds. The majority of these, like Angkor itself, are spread across the terraced alluvium coming off the eroded southern face of the Kulen (Figures 2 and 4). Although no archaeological excavation of any of these mounds has yet taken place, surface finds indicate that evidence of pre-Angkorian habitation will be found at many of the sites. Rather than existing isolated on the Angkor plain, the Khmer Empire's capital city area was situated in a heavily populated area, surrounded by settlements dating back before the founding of the Empire itself.

Unlike most contemporary habitation sites identified in the western part of the Khmer cultural area across the Dangrek mountains on the Khorat plateau in what is today northeast Thailand, not all of the Angkor sites are moated (although some are). Most sites in the Angkor area appear to have depended for their essential water upon seasonal inundation of the area immediately surrounding the slightly raised settlement site. This difference is explained by the much lower elevation of the Angkor plain in comparison with the Khorat plateau.

This association of settlement with higher ground continues to the present day, according to the demographic survey conducted by UNTAC. It was noted by ZEMP archaeologists that present-day settlements are, in general, located in the same place, on the same mounds, as prehistoric archaeological sites. Although close to 500 hundred previously unrecorded habitation mounds were potentially identified by the ZEMP team from aerial and satellite photographs, a sample of 69 were surveyed in the field for "ground-truthing" during the initial phase of ZEMP research. The sample was limited because of an increase in Khmer Rouge activity in the area during the ZEMP study. UNESCO envisages a complete archaeo-

logical survey of the extended ZEMP study area in the near future.

#### The Stung Puok Basin

The first group surveyed were located along the old course of a western tributary of the Siem Reap river, which originally may have flowed into what is today the Stung Puok. Most of the water of this stream was diverted eastward in Angkorian times (Groslier 1979), perhaps partly as an engineering response to the uplift and tilting of the land discussed above, and formed what we know today as the Stung Siem Reap. Today, what remains of water from the original river drains into the Stung Puok river.

Thirty-four of the 69 newly-identified surveyed prehistoric sites are located in the area of the old Stung Siem Reap-Stung Puok drainage basin. This, historians have identified with some certainty from inscriptions, was the site of a 7th century pre-Angkorian town called Ananditapura, the remains of which are now mostly under the Western Baray which was first built in the 11th and extended in the 12th century. This town or village was one of the spots to which Jayavarman II brought his nomadic capital during the Empire's early days, and here we have identified at least eight pre-Angkorian settlement sites (Figure 2). The remaining 26 sites form a continuous distribution up the Puok valley. There is evidence of a canal, which in addition to playing a role in the diversion of river water toward Angkor may--judging from the concentration of ancient rice paddies nearby--have been part of an Angkorian period attempt to re-animate the rice fields of the upper Puok drainage basin.

The distribution and dating of these sites needs further investigation. We have, however, been able to do some more concentrated survey work at two sites, Lovea and Phum Reul. Lovea has been known as an early (or possibly pre-) Angkorian site for a long time (Martel 1975). The habitation mound is roughly circular with a diameter of approximately 350 meters. Its enclosing earthworks increase this area to 600 meters. According to Elizabeth Moore, a moat surrounds the mound's perimeter and a second moat can be detected between the earthworks. There is possibly a third moat further out. Malleret reports that in the late 19th century, skulls, bronze and iron implements were found at the site (Malleret 1959). Moore's survey for the UNESCO ZEMP study yielded weathered ceramics of two types: an oxidized coarse earthenware, and a finer-bodied thin blackware. A bifacial stone axe 10.6 cm long was also recovered from the site (Moore 1993).

Phum Reul is a similar site 6.5 kilometers up the river bed northeast of Lovea. In her ZEMP field report Moore (1993) describes the site as follows:

The mound is on the southwest tip of an eroded upland area which extends to the northeast. Vestiges of two earthworks and moats are found on the southwest, downslope side of the site. Traces of the old river can be seen north of the Phum Reul mound, but its course has since been interrupted by two later angular water retention devices.

From Phum Reul, a total of 11 stone tools was recovered during ZEMP site survey. The presence of stone tools in the Angkor plain links these sites to the few other "protohistoric" Cambodian sites which are known, such as Samrong Sen (Mansuy 1902, 1923) and Mlu Prei (Levy 1943).

#### The Stung Siem Reap Basin

Turning to the Stung Siem Reap river system, 13 habitation mounds, both moated and unmoated, were surveyed in the valley north of the main Angkor complex by Dr Moore and the ZEMP team. This is the valley where an eastern tributary of the Stung Siem Reap river flows from the principal Kulen plateau springs. All the sites are located along or near a water course north of the Angkor-period dam and canalization of the Siem Reap river into the baray reservoirs of Angkor. As noted earlier, this diversion of the Siem Reap river dates from the 10th century reign of Rajendravarman I. As no habitation mounds have been found south of the diversion, it seems a likely hypothesis that the sites north of the diversion are earlier in date. However, during the ZEMP survey access to these sites was limited because both the route to and the sites themselves remain heavily land-mined. Further survey and excavation of these sites is required before any more conclusive statement can be made.

#### The Stung Roluos Basin

The valley of the Stung Roluos is perhaps the most interesting of the three river valleys surveyed. Here 21 sites were ground surveyed by the ZEMP team. Like the Puok and Siem Reap river valleys, some, but not all of these sites have vestiges of moats. The mounds range in diameter from 150-350 meters with elevations between 10-30 meters. The site which yielded the most abundant surface finds was Phum Stung, which is located just north of the northeast corner of the Lolei Baray where the river makes an east-west jog and is incorporated into the site's moat. Coarse earthenware and polished stone tools were picked up from the surface of this site, and most of the

other sites visited.

While the artifact remains from the sites described above are all from surface collections, the distribution of the sites is interesting. When plotted, the distribution appears relatively dense throughout the Angkor Plain. However, when the size of each site is taken into account and "nearest-neighbour" statistical tests applied, the computerized GIS system plots a weighted site distribution map which shows the heaviest concentrations in the three river valleys, with the intervening areas evenly but not so heavily settled (Figure 4). What is most interesting about this distribution is that the area of concentration of archaeological sites is continuous, thus seeming to confirm the hypothesis of a considerably large population in the Angkor Plain during the pre- and early Angkor periods.

#### Agricultural Field Systems

The interdisciplinary UNESCO ZEMP study also suggested some interesting possible interpretations of ancient Khmer field patterns and the implications these have for changing agriculture productivity before, during and after the imperial period, and the consequent effects on population and settlement. It has long been hypothesized that the mosaic of tiny regular square fields is an Angkorian field pattern. We can see for, example, that south of the Eastern Baray in the central Angkor area and overlaying an earlier water reservoir, this old field pattern has been overlaid with a more recent rectangular pattern. In the upper reaches of the old Siem Reap-Pouk river system, the early pattern is still visible in aerial photographs, although on the ground it is totally invisible and the area is both uncultivated and depopulated at present.

In recent years, satellite and aerial photography has proven a powerful tool in helping to identify and interpret many types of archaeological sites and, in particular, ancient field patterns. Present-day botanical patterns remain extremely sensitive to past land use, especially if that land use depleted soil resources. If the ZEMP map of present-day botanical habitats within the Angkor area is overlain with aerial photographs of ancient rice fields and a map of archaeological habitation sites, a clear pattern emerges:

1. The area presently under cultivation (unshaded on Figure 3) is that area which remains well-watered by the diverted Siem Reap or other rivers and/or the stored water from the Western Baray. Underlying the present day rectangular fields are the old square fields of the Angkor period. Present-day habitation is concentrated in this area, often in continuous association

with earlier (archaeological) habitation sites.

2. There is another area (OS and CS in Figure 3) which has recently reverted to shrubland, having been abandoned following the disastrous re-organization of agriculture during the Khmer Rouge period. This area is typically north and west of the main drainage systems and, due to the engineering mistakes of the Khmer Rouge and also due to the lack of manpower to maintain the system, it now lacks sufficient water for rice agriculture. Population has also moved away from these areas and migrated to Siem Reap town or towards the flooded forests near the lake where they have cleared the forest to establish new farm lands.
3. Further to the north of the recently abandoned paddy fields are areas of former rice fields, as seen from the aerial photographs, which have been re-colonized by forest species. According to the ZEMP team's botanist from the World Conservation Union, complete re-forestation takes 200-500 years, so we can conclude that these fields were farmed during the height of the Angkor Empire, but were abandoned sometime after the move of the capital away from the area.
4. Finally there is an area which coincides with ancient Angkor paddy which has never recuperated and where the soil has been so depleted or water resources are so scarce that other species have been unable to colonize the area. This coincides almost exactly with that of the moated habitation mounds, corresponding to the earliest type of site in Moore's typology.

One important implication of this pattern, as revealed by the botanic recolonization of abandoned rice paddy, is that the Khmer field pattern--and perhaps much else in Khmer culture--may have origins far earlier than the classic Angkor period.

Alternatively, if the square field system is characteristic of classical mature Angkor, then we may have found in these northernmost parts of the plain, the fringes of the Angkor catchment area, settlements of frontier farmers, presumably impoverished and perhaps cut off from the imperial system's network of public waterworks. Evidently, they pushed their poor fields beyond the point of productivity.

In either case, observations from the separate disciplines of geology, hydrology and botany all provide evidence to support the archaeological hypothesis that Angkor was abandoned because of a collapse in agricultural productivity sufficient to sustain a large urban population. This collapse in agricultural productivity was a result of an overwhelmed ecosystem which was, in any case, deteriorating because of incremental changes in the natural hydrology of the region. These changes required

a technological investment which became increasingly less cost-effective to maintain. With this hypothesis, and the multi-disciplinary approach of the ZEMP study, it may be possible to investigate the causes for the eventual collapse of the Khmer Empire. A first step will be the dating of the presumed early habitation mounds identified by Moore and the ZEMP archaeologists.

#### HYDROLOGY

Whatever the interaction of these various factors, it seems clear that Khmer engineers since well before the height of the imperial period were preoccupied with the problem of dealing with a surplus of water during the flood season and a shortage during the dry season--with the purpose to extend the agricultural growing season. The flood water problem seems at first to have been seasonal and was met, as Moore (1990) has shown in her study of moated settlements in northeast Thailand, by moating even small villages or homestead sites. But that this solution was not entirely successful is evidenced by the early and progressive abandonment of far-flung agricultural fields and the clustering of people into pre-urban centres which could provide the infrastructure to contain and control the water supply. The problem also seems to have been met first and was most acute in the northern and western parts of the Angkor plain, due to the gradual geologic uplift of the northwest discussed earlier. Throughout the Angkor period this problem progressively worsened due to continued uplift coupled with the growing population's need for more water.

Offsetting this was the draining of the swampy low-land areas by turning the natural rivers into more efficient man-made canals and the transformation of the vast and fertile seasonal flood plain just above the Tonle Sap into rice paddy. The Khmer gradually and progressively prolonged the growing season with a simple but effective system of dykes which first of all trapped the early rain water as it flowed down toward the lake and then, at the other end of the wet season, retained the retreating flood water from the lake.

#### Construction of Water Reservoirs

Technologically, reservoir construction appears to be part of the same simple technology as the building of a rice paddy bund and, when further elaborated, the same as the technology that went into building the great *baray* water storage reservoirs. The Khmer word *baray* comes from a Sanskrit word meaning "to traverse" or "to cross".

Study of the aerial photographs reveals that parts of earlier systems were incorporated into new town planning designs as the city of Angkor was renovated and

remodeled by successive rulers. One example is the re-use of the old moat of the first city of Angkor around the Phnom Bakheng as a spillway to channel excess water out of the Western Baray into the Siem Reap river/canal south of the new city of Angkor, thus preventing the possibility of a disastrous flood during periods of excess water. On the other hand, after the move of the capital to Yashodarapura (the site we know today as Angkor) the old capital of Hariharalaya (Roluos) was apparently still linked into the greater metropolitan area's water system through a long dyke which channelled water down to the old city from the new.

#### The Barays as Possible Laterite Quarries

A hypothesis regarding the development of Khmer engineering technology which has been suggested by the ZEMP team concerns the source of the laterite used to build the monuments. This has always been a puzzle to archaeologists and has proven to be even more so by the conclusive demonstration by ZEMP geologists that the weathered laterite outcrops at the foot of the Kulen and in the lower part of the Angkor plain, for example Phnom Krom, could not have been the source of the laterite used to build the monuments.

Laterite must be mined, or cut out, while it is below the water table and still wet and soft. Upon exposure to air it gradually hardens as the moisture between the flat clay platelets evaporates and the larger molecules of iron lock into a rigid lattice structure. ZEMP geologists (and EFEO scholars before them) have attempted various calculations to determine if the moats surrounding the monuments could have been the sources of the constructional laterite. Laterite cores taken by the team from Sophia University of Japan have convincingly shown this to be part of the answer for the monument of Banteay Kedei (Moriai 1992). However, ZEMP coring has also shown that the layer of laterite in the Angkor plain is relatively thin and that the volume of the moats cannot account entirely for the amount of laterite used in building the monuments, roads, bridges and other massive public works for which Angkor is best known.

A hint about the solution to this problem came when Bernard Groslier excavated the Sras Srang and found that it had been dug considerably below surface level. Could this have been--in addition to whatever other ceremonial, symbolic or practical function(s) it served--the quarry for the laterite of the nearby monuments? This question led ZEMP hydrologists to look more closely at the *barays*. While both the Lolei Baray (the Indratataka) and the Eastern Baray (the Yashodarataka) are above-ground reservoirs which apparently worked on the gravity prin-

ciple, the situation is not so simple when one looks at the Western Baray which has always posed a problem for archaeologists, with its much-too-high and thick southern wall which rises 8 -14 meters above the highest possible water level. Another problem is that the Western Baray has a series of north-south internal dams crossing it which seem to indicate that it was indeed built in phases.

Although 20th century rehabilitation of the *baray* has obscured much of the original structure, upon investigation the ZEMP hydrologists found that the Western Baray indeed appeared to have been originally excavated below the surface level, down to the water table and through a large and relatively thick lens of laterite. The walls of the *baray*, which are composed of the spoil from the process of quarrying for laterite, are high because of the need to remove a large quantity of earth to get at the laterite below. The series of north-south dams would have been needed to isolate and dry newly-opened areas of the quarry and could (although there is no evidence for this as yet) have been part of a system enabling the blocks of laterite to be transported by water out of the quarry westward toward the city, following the natural slope of the land and flow of the water. The Northern Baray, or Jayatataka, also is excavated below ground level.

The conversion of laterite quarries into large water reservoirs; re-use of older parts of the system (such as use of the Bakheng moat as a spillway) and evidence for continual modification of the system (such as the gradual diversion and canalization of streams, discussed earlier in relation to the Stung Siem Reap), indicate that what appears to have been an extremely elaborate system linking reservoirs, canals and rivers actually arose gradually in response to the immediate needs of the time and in conformity with local landforms and ecology. There is no evidence for a predesigned master plan.

These, and many more, are some of the intriguing new pieces of archaeological evidence emerging for a re-examination of the Angkor plain and the attempt to understand the cultural landscape engineered there by the ancient Khmer from prehistoric times.

#### ACKNOWLEDGEMENTS

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was also tested and is being used in a second phase of the ZEMP project. UNESCO and the author would like to thank the Angkor Foundation of Hungary for providing and developing the INTERGRAPH software.

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#### APPENDIX 1: DECISION BY THE WORLD HERITAGE COMMITTEE ON THE INSCRIPTION OF ANGKOR ON THE WORLD HERITAGE LIST

Given the unique situation in Cambodia, which in accordance with the Paris Accords, has been placed under the temporary administration of the United Nations since July 1991, the Committee decides to waive some conditions required under the operational guidelines and based on criteria (i), (ii), (iii), and (iv), inscribes the Angkor site, together with its monuments and its archaeological zones as described in the "Périmètre de Protection" accompanying the ICOMOS report on the World Heritage List.

This action is not to be taken as setting a precedent for inscription but as a response to a unique situation.

And therefore, to guarantee protection of the site during the three-year period (1993-1995), the Committee decides that a special in-depth study will be made of the Angkor site, and that reports will be made periodically to the Bureau and Committee on the status of the monuments and the protective perimeter; the first report to be made at the July 1993 session of the Bureau to be followed by a report to the Committee during its seventeenth session in December 1993.

#### II

With an on-going concern to deal with urgent problems quickly and effectively, the Committee inscribes the Angkor site on the List of World Heritage in Danger, and requests that the concerned authorities take measures to meet the following conditions:

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- a) adequate protective legislation is enacted
- b) a national protection agency is established and staffed
- c) permanent boundaries are established based on the Zoning and Environmental management Plan (ZEMP) project
- d) meaningful buffer zones, based on ZEMP are defined
- e) monitoring and co-ordination of the international conservation effort are established.

APPENDIX 2: UNESCO/ZEMP EXPERT TEAM

Aderhold, Peter	Tourism Economics
Ashwell, David	Ecology
Belli, Lawrence	Park Management
Box, Paul	Geographical Information Systems
Chim Sumean	Forest and Wildlife
Chrouk Kim Eak	Geographical Information Systems
Csaki, Annamaria	Geographical Information Systems
Csaki, Gyorgy	Geographical Information Systems
Dauge, Veronique	Khmer History
Engelhardt, Richard	Archaeology and Anthropology
Fitzwilliams, James	Forestry Management
Garami, Ferenc	Hydrological Engineering
Gercsak, Gabor	Geographical Information System
Grant, Malcolm	Legislation

Hetreau, Aline	Urban Planning
Ieng Kieth	Structural Engineering
Jacques, Claude	Khmer History
Kertay, Istvan	Hydrology
Khin Vuthy	Logistics
Lek Vuthy	Forest Ecology and Wildlife
Ly, Dek	Geographical Information Systems
Moore, Elizabeth	Archaeology
Om Radsady	Management
Or Kim Song	Geographical Information Systems
Oughton, Gary	Agronomy
Pottier, Christophe	Architecture Conservation
Rogers, Geoffrey	Transport Planning
Rogers, Pamela Rumball	Archaeology
Ros Borath	Urban Planning
Salter, Richard	Ecology
Sam Rithy	Fisheries
Seung Kong	Archaeology
Son Soubert	Archaeology
Suong Leang Hay	Tourism
Thumwimol, Pornthum	Landscape Architecture
Thung Heng	Geography, Geology and Cartography
Uong Von	Cartography
Wager, Jonathan	Environmental Planning
Wilson, Meriwether	Park Planning
Martin, Marie	Anthropology and Sociology