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SECTION I

ANGKOR THEN AND NOW

Fig. 1 The old stone bridge shows the stone–paved canal bottom. This bridge is located over the Siem Reap canal east of Angkor Thom.

Fig. 2 The present Siem Reap canal has scoured a channel four feet below the original canal bottom shown by the remains of the bridge footings in the center of the photograph. The terrace on the right shows the original canal bottom.

GEOHYDROLOGY AND THE DECLINE OF ANGKOR

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The vast ruins of the temples of the ancient Khmer Empire at Angkor not only evoke awe because of their solemn other-worldly beauty, but also make one wonder over the reason for their abandonment and decay. Only an aerial view can display the extent and the magnitude of the complex of ruins which constitute the remains of the ancient Khmer capital on the northern shores of the Ton Le Sap (lake). Through the treetops the impressive towers are visible, while the large water reservoir, the West Baray, shimmers in the sunlight.

In the mid-1960s a French geologist asked the question: "L'extinction de la civilisation Khmère est-elle due à un phénomène géologique?" (Escande 1965?). Some archaeologists received this concept with skepticism. Now, however, with the new technology of remote sensing it is clear that the answer will be: Oui!

BACKGROUND

While virtually all previous attention has been centered on the buildings themselves, only a few studies have been conducted on the waterworks, which were the core of the civilization of Angkor. In the early 1990s a comprehensive study of the water management of the Angkor period was conducted by a Hungarian team (Garami and Kertai 1993) of the Angkor Foundation, as part of the Zonal Environmental Management Project (ZEMP). The team measured and identified many of the waterworks which played an important part in the network of canals and reservoirs that maintained the life of the Angkor civilization.

A current explanation of the abandonment of Angkor, which was already troubled by the conversion of its population, mostly slaves, to the more benevolent Buddhist religion from the more demanding religious concept of the Devarāja or god-king (Briggs 1951), holds that it began with the sacking of the city by the neighboring Thai kingdom in 1431.

Scholars seem to be in agreement that this last pillage by Siamese and the following forced exodus of thousands of slaves rendered the city incapable of maintaining itself. There is no doubt that this event was the last drop of water that filled the cup. Ironically, it was the lack of water and the inability to maintain the intricate water system that played a major role in the desertion by the Khmers of their glorious capital. They moved to a more secure and hospitable location further south-east, away from the Siamese borders.

The Landsat images and the aerial photographs used in the ZEMP study made possible a broad analysis of the region as a whole. This method, verified by the detailed field observations of the Hungarian team and additional information from maps and documents, has led to the present explanation of the cause of the decline of Angkor.

From the air, a vast expanse dotted with little rectangular ponds is the trademark of the Khmer civilization. The same pattern repeats itself like an imprint of Khmer dominance all the way throughout Thailand's Northeast. The "*Isān Khiaw*," or Green Northeast Thailand water project, simply repeated the patterns which have existed for a millennium.

These patterns indicate the preoccupation of the Khmers with the need to store water for the long dry season. Each household needed a pond to provide drinking and household water for both man and beast. The barays of Angkor were simply the manifestation of the need of an urban population.

Water was the fountain of life for Angkor; a disruption in its supply would be fatal. The location of Angkor was based on religious views and on the need for a clean perennial water supply. The Khmers harnessed the rivers flowing from Phnom (mountain) Kulen to the north. Even today these streams are still clean and pure in the upper reaches near Banteay Srei, where urbanization has not yet polluted the water course. The rich coastal plain of the Ton Le Sap, inundated and fertilized by the waters of the Mekong, provided multiple crops annually.

The location of the Angkor complex was perfect from a contemporary point of view at the time of its development in the tenth century. From the standpoint of engineering it was laid out on a solid, gently level alluvial apron consisting of sandy material. No laterite was found in the bore holes made below the ancient buildings. The sand and clays lie on top of a thin layer of mudstone, which lies unconformably over bedrock, initially identified as rhyolite, eighty meters below. Was it the sacking of the capital that was the cause of the move away from the sites that had harbored the empire for centuries? Or was it rather that it had become impossible to maintain the waterworks on which the city depended?

PHENOMENON

It seems that the site of Angkor was not as perfect as it was thought to be to support a long settlement over the duration of its existence of five or more centuries. However ideal it may have appeared to be, a geologic phenomenon had condemned the city before it was built. A slow geologic uplift eventually led to the shift of the gradient of the rivers which fed the large water tanks or reservoirs. The city depended on these as a source of water to support it during the dry season. Unlike Bangkok, which has been sinking slowly for many years, the Angkor site rose imperceptibly over the centuries of its life span, affecting the water regime. There was no way that the ancient Khmers could have known about the subsequent changes in the earth's crust which made the maintenance of the city and its complicated water works more difficult as time passed.

It was during the environmental study of the ZEMP Angkor project that aerial photographs were used to analyze the surrounding region of the ancient city. From the air the meandering rivers appeared to be unusual. Meandering streams are a sign of geological old age and would erode laterally with telltale signs of oxbow lakes and meander scars in the river floodplains. These are absent. Instead, the streams are entrenched or incised, flowing from north to south over the alluvial fan terraces and coastal plain of the Ton Le Sap. It was clear that the meandering rivers had frozen into the landscape and had started a vertical erosion to adjust to the new stream gradient and to respond to a gentle but steady geological uplift of the landscape.

EVIDENCE

It was necessary to find corroborating evidence in the field to determine whether or not this hypothesis of uplift was valid. Surprisingly, there was much evidence of the geological uplift visible on the ground. This was described by early researchers. Indeed, many of them reported that the actively flowing, meandering river channels and canals in the area of Angkor were deeply eroded below their original bottoms. However, none of them attributed the decline of the city to the change in topography.

It is almost possible to envision this area as having been crisscrossed by canals, just as Bangkok was until comparatively recently. If water was of such importance to the city, then it seems contradictory to consider that the Khmers designed these canals to be seasonally dry and ugly.

The Hungarian team reported much field evidence, such as the downward erosion of the river bottoms. The process is manifested by the changes in the depth of these bottoms. For instance, east of Angkor Thom there are the ruins of an ancient bridge over a diverted channel of the Siem Reap River (see figs. 1 and 2). The arches are footed on a sandstone ledge 2.5 meters deep over which the water would spill; this shows the sandstone bottom of the original channel. However, during the dry season the water now flows through a breach of some four or five meters below the original depth of the ancient bridge footing. This is a reliable gauge of the amount of down-cutting which took place since the construction of the bridge.

The canals dug by the Khmer slaves thus would have been only two or three meters deep, which is found as the general depth of the abandoned canals and moats around the large temple and city enclosures (Garami and Kertai 1993). It is obvious that the Khmers would not have dug canals six meters deep when only two or three meters would have sufficed. The intakes of the barays are one or two meters below the surface to match the original water level of the canal. The perennial Siem Reap River would continually feed these bodies of water. The availability of water throughout the seasons obviously determined the location of Angkor and governed the building of the waterworks.

Of course the actual time of the collapse of the original bridge is significant and open to debate. The Khmers must have tried to maintain such an important bridge. The river simply undercut the channel below it. A torrential flow of water during the rainy season could easily have breached the bridge at any time after its construction when the river bottom below the bridge had been eroded.

Other bridges which do not span actively flowing rivers or canals, such as the bridges of Angkor Thom and over the original course of the Siem Reap River, do not show evidence of down-cutting or destruction. These did not receive water from the main diversion of the Siem Reap River after the water level fell below the intake.

Rate of Uplift

It is estimated that the diversion of the Siem Reap River took place during the rein of Rajendravarman (944–968) (Garami and Kertai 1993). Thus the down-cutting of four or five meters of this river channel would have taken place over a period of ten centuries, roughly estimated at rate of five mm/year. This means that the canals were at least two meters below the intake level of the barays when the Siamese sacked Angkor in 1431. As the streams and canals slowly deepened their channels, the barays did not. The effect of this discordance between the stream or canal level and the water tanks is that during the dry season the water course is below the level of the intake to the reservoirs. Thus the barays could not be filled during the dry season and water had to be raised up into these tanks through engineering constructions.

Canal Profile

The uplift can best be measured along the profile of the large Prek Thnal Dak canal east of Angkor (fig. 3). During its construction the canal would have been level, not unlike the many canals in the region of Bangkok. The elevation is now twenty–five meters at the terminus of the canal thirty kilometers north of the coastline, indicating an uplift of twenty meters over this distance. This is significantly more than the down–cutting around Angkor. Erosion usually lags behind the uplift of the land; thus this indicates that the erosion of the stream beds is continuing today.

The uplift at Angkor is approximately ten meters, as it is closer to the strike (axis) of the geologic uplift running roughly NW–SE along the shoreline. It may be that the elevation of the area around Angkor was much lower and more level and that many of the canals retained their water longer during the earlier period of their existence.

The canal under study is too wide for irrigation purposes; its use for water transport is supported by other evidence. The canal must have been constructed through a level plain to retain water at the time under consideration; otherwise it would never fill with water as it would drain itself through the lower end. The Khmers would not have built such a wide canal for thirty kilometers if it would have been dry for most of the time. The slow lift of the land in the North rendered the upper reaches dry and shortened the canal length over time. In recent years the population has built cross dikes along the canal to dam the water of the now sloping bottom. They irrigate the rice fields below these retaining dams. The long retaining dikes along the lake shore, used since ancient times, hold water in a similar fashion during the dry season. The farmers let the water trickle through the dikes, irrigating the land down–slope. Thus they are able to have a second crop of rice during the early dry season.

The people of the village at the mouth of the channel believe that the canal was used for shipping in ancient times. Evidence of trade along the waterway was provided by Chinese pottery found in the clay of the dike during excavations for material to make bricks. Furthermore, the villagers mentioned a legend of a ship that sailed north to Phnom Kulen and which ran into the mountain and was shipwrecked. Chou Ta Kuan could have landed in a harbor on this canal in 1291 (Garami and Kertai 1993). It is exactly fifty *li* or thirty kilometers east of Angkor as reported by Jelen and Hegyi (1991).

While the trading port was located near the present Route 6, the canal continues eight kilometers farther north straight towards Mt. Kulen, where the ancient sandstone quarries are located. Thus the suggestion by early archaeologists that the sandstone blocks were transported over water appears to be correct. There was no reason for this canal to extend towards Mt. Kulen unless it had also been dug to transport the heavy sandstone blocks over water to Angkor. Elephants moved the blocks to the existing canal terminal twenty–six kilometers from the lake shore, now in the middle of rice fields. The blocks were floated down the canal, then over the lake and up to Angkor on a now silted–in canal parallel to the Siem Reap River.

The suggestion, however, that the smaller canals supplying the barays also served as transportation routes is difficult to accept. They were much narrower, with sharp angles where they connect with other canals, and thus difficult to navigate.

Norias

Large water wheels along the present Siem Reap River lift up water to irrigate the fields during the dry season (fig. 4). These water wheels, or *norias*, were known to the early Egyptians. These devices, still in use in Cambodia, may be remnants from the past. They were used to raise water from the deepening water level in the main streams to parallel canals along the ancient waterways. Signs of these small parallel channels are visible on the aerial photographs.

Dams

The Khmers may actually have built dams or weirs upstream in the early stages of the erosion when the depth of down–cutting was not too significant, but they obviously did not perceive the problem of a geologic uplift, slow and imperceptible as it was. Thus they focused their efforts on the repair of their original network even though it became more difficult as time went by.

The Khmers did make an effort to build such a dam around the northwest corner of the East Baray, but it failed (personal communication, Christoff Potier 1993). They also did not have a real capability to build large dams and large clay core structures (Van Liere 1980). French engineers, however, had recognized this problem and simply built a dam across the Siem Reap canal. This dam raised the water in the canal to its original level to divert water back into the West Baray for use in irrigation through gates in the southern dike (which had been rehabilitated by the Americans).

Shift of the Lake Shore

The major beach ridge along the north shore of the Ton Le Sap south of Angkor is an indication that the geologic uplift was interrupted, allowing the development of the beach deposit. This land now stands as a bare cultivated ridge. It is higher and becomes dry earlier than the surrounding seasonally flooded lagoon areas. Similar features are found in the Arctic, where the melting of the ice cap has resulted in geologic uplifts creating concentric beach lines. The remnant of a seventeenth–century Dutch whaling station is located on one of these old beach ridges four meters above sea level. The presence of a recent beach ridge means that the uplift at the Angkor site was not continuous and it was likely that the actual rate was more than the five millimeters per year estimated above.

Ancient Lake Area

The Ton Le Sap basin was originally an inlet of the South China Sea that had slowly filled in while the land also rose. The Mekong River broke through the narrow strip of land and

captured the Ton Le Sap and Bassac Rivers some twelve thousand years ago. Phnom Penh is now located at this water gap. The melt water in the Himalayas and the rainwater in the rest of the basin raise the Mekong some eight to ten meters above the dry season level. The water streams into the lower Ton Le Sap River and the river flow reverses. It is the only river in the world that shows this phenomenon. The level of the lake has thus been controlled by the water of the Mekong and rejuvenated by this annual flooding ever since the breakthrough.

The Ton Le Sap shoreline once enclosed a much larger lake area than it does today. Part of the land west of Angkor was submerged in prehistoric times as manifested by the lake terraces in that area. A Stone Age population settled along the old shore line (Moore 1994). Dark clay lake deposits are the reason for the fertile soils of the Battambang area.

Many of the major ancient roads leading away from Angkor lie on road embankments several meters in height. It is unlikely that these major structures were constructed for aesthetic purposes alone; the embankments suggest that the flooded land extended far beyond the present area. They would likely have served the purpose of maintaining all–season dry roads to serve the extensive network of the Khmer empire.

Stream Characteristics

The sinuous characteristic of the lower Siem Reap and Prek Thnal Dak canals indicates that there was probably an accretion of the shoreline after the Khmers dug the canals. It was not like the Khmers to leave curved sections between a very straight canal and the lake itself.

CONSEQUENCES OF THE UPLIFT

Thus even during the peak of its existence Angkor was already facing the problem of a decreasing water supply to provide for a large urban population. To maintain the engineering feats of building the temples and to supply the needed water for the population and for irrigation would require a huge labor force to shore up the slowly decaying system. The uplift caused changes in the construction methods of the waterworks. More effort was required to maintain the systems, while the people were also increasingly employed in the building of religious structures. The Khmers must have recognized the problem, but not the cause. Their wars of expansion may have been necessary to obtain more slaves to satisfy the greater demand for labor. The Khmers started to make corrections, as mentioned above, long before the attack on Angkor by the Siamese. This incident removed the majority of the slaves, who changed masters, and deprived the Khmers of the manpower to manage their sophisticated water works, which, through forces beyond their understanding, were slowly weakening.

Studies of maps and aerial photographs indicate clear evidence of different construction methods for the barays. Specifically the early barays, such as the Indratataka and East Baray, were constructed by surrounding the reservoir area with a dike. On the photographs the borrow soil pits for building the dikes are clearly visible as depressed areas along the inside walls of the dikes. These shallow elongated depressions hold much more water during the present dry seasons than the rest of the areas and are now used for dry season rice crops. Even passing across the dike into the East Baray one cannot but notice the rise of the road where one crosses the breached dike. One travels through this depression with rice fields visible on both sides of the road along the dike. The land then rises again to cross over the undisturbed plain, which was the original reservoir floor. Upon measurement of the elevation inside and outside the dikes it is clear that they are in the same plane.

Thus during the earlier period the flood would probably reach the barays and inundate the reservoir, and water would remain in the diked area when the flood retreated. This construction method required fewer people and the Khmers had a smaller population during the early years of the kingdom. During the dry season the two rivers Siem Reap and Roluos maintained the water levels in these reservoirs.

This practice is still being used for making reservoirs to irrigate the rice fields along the lake. On the present flooded plains along the Ton Le Sap we see U–shaped dikes. The highest dikes are on the down slope with two arms. The difference is that after the geologic uplift a complete enclosure of the dike was not necessary. The upper slope of the land is a natural barrier.

On the other hand, the Khmers built the West Baray several centuries later. The flood waters had retreated because of the effect of the uplift. Therefore the reservoir construction required excavation in this case to increase its storage capacity. The height of the surrounding dikes appears excessive now. The Khmers probably used the structures to store the excavated soil. This effort needed a greater number of slaves than during the construction of the earliest barays.

Many observers have mentioned that the exposed strip of land located on the east side of the reservoir near the intake is the result of siltation. It is in fact the original surface of the land. Siltation would show *convex*–shaped alluvial fans; the edge of this soil "terrace" has *concave* excavation marks, because teams of workers would cause such a pattern.

Rather than silting causing the degradation of the barays, most of the filling of the canals and barays is the result of abandonment of the water system and the erosion of the surrounding dikes. Actual silting observed along the edges of the many reservoirs is visible as small recent alluvial fans radiating from the breaches in the dike wall.

CONCLUSION

Art historians have dominated the studies of Angkor. This paper attempts to look at the Angkor region from the physical aspect. Use of the new technology of remote sensing, supported by existing field data, has made possible the discovery of new facts related to the original environmental setting of the Angkor site.

It may very well be that the land surrounding Angkor during its Golden Age was a level area at the end of an alluvial apron or delta deposit. It would have been not unlike Bangkok, built on recent delta deposits. Canals crisscrossed the green fields of rice. Boats full of people plied through these waterways going to and from the markets and fields.

The discovery of the geologic uplift in historic times has far–reaching consequences. It had been generally assumed that the environment of Angkor was the same in the past as it is today. However, it was not. This information has greatly influenced the interpretation of the causes of the decline of Angkor.

Therefore, the construction of the beautiful structures we so admire was not the only agony facing the population. Life was more difficult than assumed. The empire required more resources to maintain itself. At the end the efforts led to the weakening of the country. Over the centuries the channels had run increasingly dry and finally were never to fill with water again as the land slowly tipped, draining the canals southwards into the lake. The Thais attacked to take advantage of the weakness of Angkor. The removal of the labor force rendered Angkor uninhabitable. Naturally the water system further deteriorated after the abandonment of the city; then siltation started to fill these dry reservoirs and canals.

Wisely enough, the Khmers decided that perhaps moving the capital to another site would leave behind the bad spirits that haunted these buildings after the sacking of the city. Another move would not have been different from earlier actions: Khmer rulers had moved to create better and greater cities in the past.

Left
Fig. 3 The dikes of the Prek Thnal Dak shipping canal are clearly visible, while rice is growing in the canal bottom. A linear village is parallel to the ancient canal and has developed along a new road.

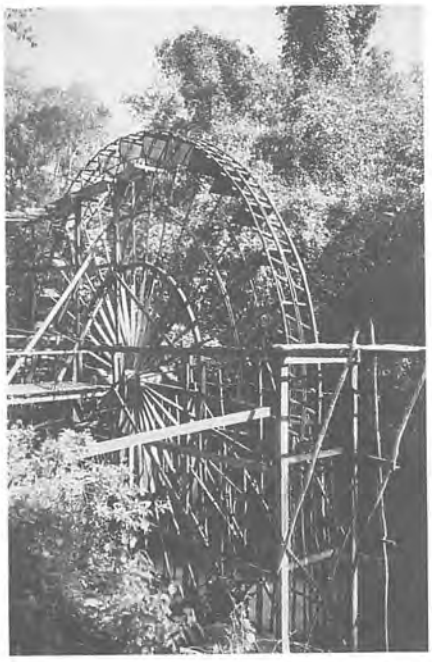

Fig. 4 A replica of the many ancient *norias*, or water wheels, is still used today to water the forestry nursery at Angkor.

Fig. 5 A Pol Pot period canal further east of Angkor is a modern version of the ancient Khmer shipping canal.

Fig. 6 Ancient field patterns show through the new rice fields because of the different soil textural conditions caused by ancient disturbances of the soil.

Ironically, another civilization vanished for the same reason as Angkor. This was the civilization of the Chimu, with Chan-Chan as its capital, which flourished on the coastal plain of present-day Peru. Another similar slow geologic uplift devastated an analogous subtle irrigation system halfway around the world from the Khmer empire.

This new evaluation concurs with the findings of that French fellow geologist who in the mid-1960s suggested a geologic uplift as a plausible cause of the decline of Angkor.

RECOMMENDATIONS

This paper is not a final thesis, but rather provides an opening to a new chapter on Angkor and the rise and decline of the majestic city; hopefully it will give other scholars of Angkor new ideas to contemplate. Many more measurements are still needed. The above discussion is a simplification of a more complex process in which there would be localized variations showing anomalies. Many scientists can investigate the details of each of the aspects mentioned in this paper. Perhaps they will further untangle not only the secrets kept in the mute structures of past grandeur but also the mystery of the land with the hundreds of canals, where hundreds of thousands of people lived and died.

We always say that if the stones could speak they would have much to tell; the land has opened its pages, but much is still to be discovered. However, the *concept* of a changing slope has a far-reaching impact on the modern rehabilitation method at Angkor. It is necessary to coordinate efforts before the rehabilitation of Angkor is started. A proper master plan has remained elusive, not only because of the great cost it would entail. Perhaps the tremendous human resources and funds expended at Angkor should be applied according to a new system. We could assign the various interested groups to select topics which together would provide the necessary data to set priorities for the reconstruction of the total environment of this magnificent group of monuments:

1. Survey the area to determine the topography and slope. This must be the first task.
2. Make a survey of the condition of the canals.
3. Divide the sloping land into sections of equal slope.
4. Select dam locations in order to control the water level on the terraces.
5. Ensure that the canals and barays selected for rehabilitation are interconnected through a series of terraces, but in a more limited water system.

The perennial water flow can be harnessed again, although it will not be adequate to fill the original system. Furthermore, restorers of the complex must bear in mind that Angkor was designed according to very rigid geometric lines, following very precise religious guidance. Any peripheral tourist complex that is being planned should be in harmony with the rigid ancient environment.

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