Did earth move to fell Angkor?

From the 9th to 13th centuries A.D., a dozen Khmer kings built successive capitals on a fertile plain between the Kulen Hills and the Tonle Sap Lake in northern Cambodia. With a sophisticated irrigation system, the Khmer civilisation was able to produce sufficient rice for a million inhabitants, and construct a multitude of monuments in laterite, brick and sandstone. What factors contributed to the decline of this 'Angkor empire', and did problems of water management weaken it substantially? Dr Heng Thung, *a geologist who has been studying aerial photographs and satellite imagery, provides compelling intepretations from the perspectives of hydrology, geology and topography*

Original arch of stonebridge, east of Angkor Thom

Water was the fountain of life for Angkor; a disruption in its water supply would simply be fatal. This importance of water to the Khmer empire is borne out in the fact that while the design of Angkor was influenced by religious beliefs, its location was based on the availability of a clean, sustainable water supply for consumption and irrigation. This supported cultivation of rice which was essential to the population, who, in turn, were essential to the demanding maintenance of the many temple complexes.

Seen from the air, little rectangular ponds - a trademark of the Khmer civilisation - are scattered across the vast expanse. The same pattern repeats itself like an imprint of Khmer dominance all the way through Northeast Thailand. Even in modern times, the water projects in "Isaan Khiaw", or Green Northeast Thailand, have simply copied this system which has existed for a millennium.

The Khmer civilisation, at its apex, was an empire devoted to the building of religious edifices that now dot the landscape of more than half a million square kilometres covering the present Kingdom of Cambodia, parts of Thailand, Laos and Vietnam. The Khmers' rich legacy of monuments is unequalled in the world, and reflect a sophisticated society whose architecture and fine arts show an incredibly high degree of technical advancement.

Inundated by the waters of the Mekong, the coastal plain of Tonle Sap Lake provided multiple crops annually. The Khmer harnessed the rivers flowing from the Phnom Kulen mountain in the north, using the flooding caused by the annual rise of the water level of Tonle Sap Lake, and the deluge caused by the seasonal rains to fill their huge water reservoirs (Peng Seang). Laid out on a gentle alluvial apron consisting of mixed sandy material underlain by rocks, the location of the Angkor complex seemed ideal at its time of inception in the tenth century. Laterite for the foundation of many temples was found in quarries east of the site, while the sandstone for the buildings was found along the foothills of Phnom Kulen.

Contemporary historians and archaeologists argue that the sacking of the capital by the Siamese in 1431 caused the sudden abandonment of sites from which the vast and powerful Khmer empire had expanded for centuries. Although this attack forced its inhabitants to scatter into the jungle, never to return, new findings suggest that the civilization had already been weakened by difficulties in maintaining its vital waterworks before the final crippling blow of the Siamese raid.

Many historians have speculated on the rise and fall of the Khmer kingdom, with numerous studies attempting to explain its hydraulic system (Groslier; Garami and Kertai). Scholars have also followed Khmer kings who moved from one city to the next before settling in Angkor in the shadow of Phnom Kulen, and seem to agree that the last pillage by the Siamese and the following forced exodus of slaves was precipitated by the city's inability to maintain itself. There is no doubt that there were several major contributing factors to the decline of the empire, but it was the lack of water, and the failure to maintain the intricate water system that left the Khmers so vulnerable that they could not repel attacks.

Phenomenon

It could be said that the site of Angkor was not as appropriate as it seemed for supporting a long human settlement over five or more centuries. The city might have had been doomed, even before it was built, by a slow geologic uplift that eventually led to a shift in gradient of the rivers, rendering the Khmers' enormous reservoirs useless. Over the centuries, the river which fed the large water reservoirs shifted, and gained a steeper profile than its previously slow, flat, and meandering course. The city depended on these reservoirs as a source of water during the dry season, which coincided with the retreat of the shoreline of the lake. Unlike Bangkok, which has been sinking slowly for many years, the Angkor site may have risen imperceptibly during the centuries of its life span. There was no way that the ancient Khmers could have known about the gradual changes in the earth's crust which made the maintenance of the city and its complicated water works more difficult as time progressed.

The difficulties that the Khmer faced in maintaining their water system have been noted by other researchers, some of whom have proposed that the decline could have been due to the impairment of the barays or reservoirs as a result of the vagaries of climate and siltation.

About three decades ago, Escande, a French geologist in search of gold deposits in the Siem Reap region, noted certain geological phenomena and suggested that the decline of Angkor could perhaps have been precipitated by a geologic uplift. These observations were presented in an article, "L'extinction de la civilization Khmere est-elle due a phenomene geologique?" (Escande, 1965).

Some very important clues to the nature of the phenomenon emerged from satellite images and aerial photographs used during the study of the environmental setting of the Angkor complex under the Zonal Environmental Management Project (ZEMP)[1]. The use of remote sensing allowed the scientists a synoptic view of the surrounding area, illustrating the relationships between the different aspects of the land. It was discovered that there were indeed signs of such a geologic uplift, such as the entrenched meanders of streams[2]. In the region north of Angkor, this change of river pattern indicates that a slow upward movement of the earth crust has forced these geologically-old meandering rivers to change their lateral course, becoming far less slow and winding than in centuries past, and creating significant downward erosion cutting into the stream beds. The theory suggests that the river, rejuvenated by its increased gradient, has reached an optimum new gradient by eroding its river bottom to reach the original mature profile.

Evidence

It was necessary to find corroborating evidence to determine the validity of this geologic uplift hypothesis. Further research has revealed much to indicate such an uplift, both in the field and in documentation. Many researchers reported that the actively flowing meandering river channels and canals of Angkor were deeply eroded below their original bottoms. However, none of them attributed the decline of the city to its change of topography, but rather to a change of climate and siltation of the reservoirs.

Aerial photography undertaken by the Cambodian Geology Department in 1998 have shown that the uplift is part of relatively recent geological activities affecting the Tonle Sap basin. Preliminary analysis has revealed a rising in the north-western part of the basin, while the land along the southern shore has subsided, creating wide areas of submerged forest[3]. This is a simple assessment made by viewing recent land form maps, but the structures, such as fault lines, the distribution of entrenched meanders, and other indicators of uplift and subsidence, have yet to be mapped. This final analysis is a major undertaking and will not be completed for several years.

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[1] ZEMP (UNESCO Zoning and Environmental Management Plan for the site of ANGKOR): The purpose of the program was to produce an integrated environmental, resource, and site management plan for the 300-square kilometre Angkor Archaeological Park that was implemented in 1992.

[2] All rivers will attempt to achieve an optimum stream bed profile, which is steep at its origins and slowly flattens out (see profile). When the extent of the land surface over which the river flows is limited, the stream meanders in an attempt to lengthen its reduced profile.

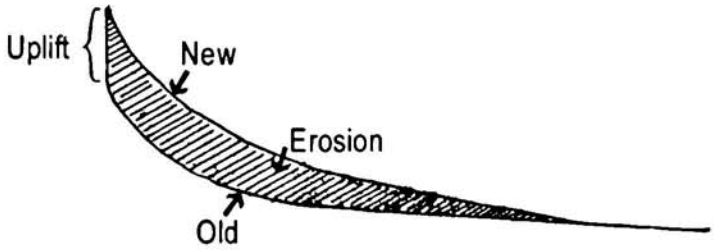
The river is rejuvenated when the equilibrium is disturbed by an uplifting of the land at the upper reaches of the river or a lowering of the water level at the mouth of the river. This effect can also occur due to sediments filling the river bed, but this is often caused by the same geological process as mentioned above or by dramatic climatic changes.

The rejuvenation of the river forces it to adjust its profile to correct for the slow change of gradient by down-cutting its stream bed. The change must occur slowly, since a rapid change, rather than causing downward erosion, would force the river channel to change its course.

In the case of the Siem Reap canal it is possible that the downward erosion first took place along the lower reaches of the canals below the stone bridge, finally breaching the bridge and then eroding more dramatically upstream.

[3] While the profile shows a simple uplift, it has been speculated that there is a hinge (axis) running east southeast to west northwest cutting from an area south of the Roulos group northwesterly to the West Baray.

The area north of this axis would have experienced this uplift, while the area south of the axis would have lowered. This theory accounts for the fact that the oldest Rolous group is now inundated. One can assume that it was originally built on dry land, and so were the many small temples and barays in the southwestern area which are now immersed.



A diagram showing the original (old) river profile and the result of the uplift. The hatched area indicates the amount of material removed by the waterway to adjust towards the old stable profile.

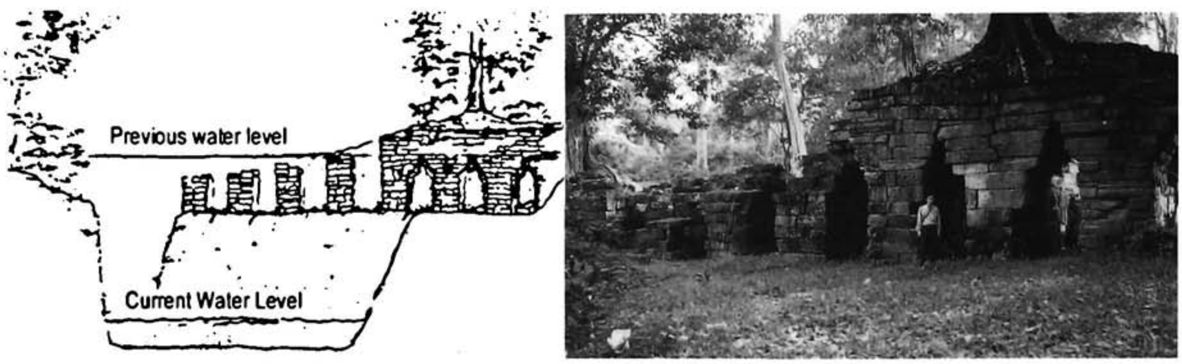
Downward Erosion

As mentioned earlier, the uplift caused the rejuvenation of the river basin. When disrupted by a change in gradient, stream beds will generally start to erode, lowering the stream bottom to achieve the optimum stream profile. This deep cutting is evident along the many streams north of Angkor.

The Hungarian team of the ZEMP project reported much field evidence of deeply eroded river bottoms. They measured the river cross-sections along the north-south diversion canal east of Angkor Thom, which was constructed to provide water to the moats of Angkor Wat. This canal was approximately two to two-and-a-half metres deep when it was dug some eight centuries ago as indicated by the old stone bridge, the footing of which lies two-and-a-half metres below the water surface (over which the water would flow). However, the new river bottom is now about six metres deeper due to erosion, and the canal depth decreases downstream, levelling slowly to the original depth of two metres further down beyond the city of Siem Reap. This is a reliable gauge of the amount of down-cutting which took place since the bridge was breached.

The canals dug by the Khmer slaves would have been only two to three metres deep, as is generally found in the abandoned canals and moats around the large temple and city enclosures (Garami and Kertai). It is obvious that the Khmer would not dig canals six metres deep when only two or three metres would suffice. The intakes of the barays are approximately one or two metres below the surface to match the original water level of the canals.

Of course, the actual time of the collapse of the original bridge is open to debate. A torrential flow during the rainy season could have easily breached the bridge when the canal bottom below the bridge had been eroded. The Khmers must have attempted to maintain this important bridge, and whether they tried to fill the gap or literally bridge it is another question. The lowering of stream bottom and thus the water level during the dry season would render the intakes to the reservoirs useless, with the water level diminished to the



Looking south, this diagram shows the previous dry season water level, the present down-cutting and the breach on the left.

point where it lay below the depth of the intakes. The perennial Siem Reap river was, therefore, not able to replenish the barays just when water was most required.

A vertical aerial photograph of the Prek Thnal Dak shipping canal.

Canal Profile

The degree of uplift can best be measured along a canal profile. In general, canals must maintain a level profile, or they will drain and dry out. The Khmers would not have built a canal that would have been dry at the time they built it. Of course, the canals in the Tonle Sap Lake area could have dried out when the lake level dropped below the bottom of the canals during the dry season. This is not a normal occurence, but Tonle Sap is a unique lake in that its level varies some eight to ten metres between the wet and dry seasons.

The Prek Thnal Dak canal thirty kilometres east of Angkor runs north-south for approximately twenty-eight kilometres from the present lake shore during the dry season. The difference of elevation between the two points is twenty metres, indicating a significant degree of upward shift. This difference in elevation is not necessarily the same as that of Angkor, as there are other factors influencing the change, such as various fault lines influencing the different areas of the region. It does, however, indicate that significant geological upheavals have affected the area since the time the canals were built.

Dams

The Khmers may have actually built dams or weirs upstream to prevent the canals from drying out, some remnants of which are visible from across the Rulous temple. However, according to Van Liere, the Khmers were not familiar with clay core dams and many would have been eroded (Van Liere 1980). The fact that the barays lacked outlets for irrigation indicate that the Khmer practised simple trickle irrigation, which allows water to seep through the dike, forming a very effective, regulated irrigation system. This method can still be seen in use all over Cambodia.

When French engineers rehabilitated the reservoirs, they built a dam across Siem Reap, effectively raising the water level to bring water into the West Baray. This is by far the simplest and most logical method of rehabilitation, but without the knowledge that the French engineers had of clay core dam construction, the Khmers could not have accomplished such a task.

Upgraded French dam raises the water level in the canal to allow the water to enter through the old intake and fill the West Baray, which has been converted to a modern irrigation reservoir.

Norias

Norias (large water wheels) are still in use, in the Siem Reap area, to lift water, and irrigate the fields on both sides of the rivers where the weirs are not able to raise the water sufficiently. There are indications of small parallel canals built along the major waterways which may have been used to supply water to adjacent fields or reservoirs.

Elevated Roads

The construction of raised roadways suggest that the area was flooded regularly. As such an undertaking would demand a massive human effort, raised roadways would only have been built if the environment necessitated their construction.

Shift of lake shore

The lake shore of Tonle Sap shows the geological changes which have taken place. Along the north-western shore, exposed lake beds have been revealed in a recent land form mapping project; while the south-western shore is inundated, showing a distinct tilt. It is interesting to note that a large beach ridge fringes the northern shore, indicating an interruption in the uplift[4].

Stream and canal characteristics

As the shift in landscape was first recognised through interpretations of stream features, these geological activities have obviously taken place in recent history. If these changes were part of a very old phenomena they would be more difficult to interpret from a such a dynamic source as a river system. The fact that the canals were altered by the Khmer implies that such shifts have taken place within the period of Angkor's occupation.

Looking at the general geology of the region, it is very possible that there was volcanic activity in the area, since lava and basaltic deposits have been found in north-east Cambodia. A small volcanic cone was recently discovered in the Cardamon mountains. This would support the hypothesis that the area has been subject to turbulent geological shifts because volcanic regions tend to be much less stable than non-volcanic areas.

A present example of a working Noria used to irrigate the nursery of Angkor Park.

Ancient lake area

The original lake extended far beyond the present shore to the north-west, which was once under water as far as Sisophon some 50 kilometres away — far beyond the demarcation of the present high water mark during the rainy season.

The presently inundated forest (thus lowland) extends in the south-western and north-eastern areas of the lake, indicating a complex structural deformation of the earth crust. It may well be that there is a combined east-west fault tra-

[4] Maps (Cambodia's Department of Geology) showed that the original lake extended some hundred kilometres further west and northwest beyond the existing shoreline, lake beds and deltaic deposits.

The extensive lake bed deposits are permeated by deltaic deposits, indicating that erosional material was deposited into the lake bed surrounding the ancient lake area. However, along the north shore where Angkor is located, the sediments bordering the lake beds appear as alluvial fans. The fan shape deposits demonstrate that they were deposited on land and not in water. Thus, those deposits represent rapid erosion and put forth the case of an uplift because the land was much steeper than other shores abutted by deltas.

A more extensive research is planned to study the geological processes which created the lake and the dynamics of the lake's changes. It is obvious that the level of the lake was previously much higher, but there exist doubts as to whether this process influenced the foundations of the Angkor complex.

versed by north-south faults separating the two halves of the lake.

For the geologist, this is a very exciting investigation as it has much wider ramifications on the study of the lake's origin. Since much of the evidence of this uplift has been found in the alluvial deposits, it is possible to speculate that these changes to the lake's geology took place in the Pleistocene era, or during the last million years.

Consequences of the uplift

Thus, even during the peak of the Angkor settlement, the area was already facing a diminished water supply, making it difficult to provide for a large population. To maintain and build temples and provide water for the population and irrigation, a huge labour force would be required to shore up the slowly decaying system. Inevitably, the uplift caused changes in the construction methods of the water works.

More effort was required to maintain the systems while the people were increasingly employed in the building of religious structures. The war of expansion noted by historians may have been necessary to obtain more slaves to satisfy the greater demand for labour. It is possible that the Khmers recognised the problem but not the cause, because of the imperceptibly slow movement of the earth's surface. It might have appeared to them as some change in the weather, the way we now blame any adverse climatic effect on El Niño.

Long before the attack on Angkor by the Siamese, the Khmers must have started to make corrections; but eventually the Siamese invasion removed the majority of the slaves and deprived the Khmers of the manpower needed to maintain their water works, consequently rendering the site uninhabitable.

Similar geological activities occurred at almost the same time in the coastal plain of Peru, where a slow geologic uplift also destroyed the delicate equilibrium necessary to maintain the irrigation system of the Chimus. In their case, however, the civilisation simply continued to decline into oblivion, without the sudden impact of a hostile raid. The canals were eroded, the water supply dropped, and food production fell. Recent excavations showed a general decrease in the size of human skeletons due to starvation during this period as their fields disappeared, leading up to the eventual collapse of An-An, the capital city of the Chimus' empire.

Studies of aerial photographs, maps of the Angkor site, and subsequent field visits to the area revealed that different methods were used to construct the barays. The early barays were derived from the original agricultural system of impounding flood waters within diked enclosures. This system is still practised throughout the areas that are flooded annually by the waters of the Mekong river, including those surrounding Tonle Sap Lake.

Originally, these enclosures in the Siem Reap area were rectangular but due to the increased slope along the lakes, they were later constructed as U-shaped dikes (because the dike at the upper part of the reservoir was not necessary as the slope formed a natural wall).

The larger dikes built around the large barays required more material, as evidenced by the numerous depressions adjacent to the structure from which the soil was excavated to raise the dike. Today, water accumulates in the depressions, allowing the local farmers to cultivate a rice crop in the dry season. This less labour-intensive method was observed by Grolier earlier.

In contrast with the dike construction of the East Baray, the West Baray was excavated. The digging of the West Baray was not yet completed when Angkor was abandoned. Extensive excavations were required to fill the reservoir since the flooding had receded due to the continuing uplift, leaving the surrounding land dry for the majority of the time. The exposed land area at the Eastern side of the reservoir consists not

The technique of flooding the dike-enclosed reservoirs during the rainy season is currently still being practiced along the north shore of the Tonle Sap Lake and the Mekong River floodplain north of Phnom Penh.

of sedimentation as thought by earlier researchers, but of original land. This fact is easily proven as the elevation is the same both inside and outside of the baray. Furthermore, the edge of the remaining land shows concave patterns indicative of excavations. Sedimentation would be shown as convex outlines of small deltas, which is not the case. Silting, observed in many of the excavated moats or reservoirs such as Srah Srang, occurred when the protecting dikes or laterite walls collapsed; from these breaches, small deltas or alluvial fans developed and filled these water bodies[5].

Conclusion

During the early period of settlement, the lake level reached further inland. The rainwater would flood the area more rapidly from the north because of its lower elevation and more gentle slope. This flow would collide with the flood waters of the Mekong, raising the water level of Tonle Sap Lake. The resulting cresting would cover the land and fill the empty reservoirs much more rapidly than simple replenishment from the river. Such activities still occur at present, albeit in less dramatic way, as studied on radar imagery by Peng Seang (1997).

It was the decreasing lake water supply which necessitated the ever-increasing construction of extensive dikes eastwards from Angkor to capture the waters from the different streams draining from the Kulen mountains and beyond.

The discovery of a geologic uplift in recent time has far-reaching consequences. It has been generally assumed that the environment of Angkor was as it is today, despite the fact that some researchers have noted that the shoreline was previously much further inland. However, it was the more level land that allowed the irrigation systems to function, and provide the Khmers with the water to grow rice. Additionally, the estimates of earlier research on rice production in the area may well be inaccurate; it is only recently that satellite remote sensing offers a detailed survey

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[5] Alluvial deposits are unconsolidated sediments deposited by water. In the case of deltas and alluvial fans, the finer material is carried farther away from the source.

In deltas, the material consists of silts and clays, creating excellent areas for agricultural land. The alluvial fans, however, are near rocky escarpments and the apex usually contains course boulders, decreasing in size to pebbles and sands at the edge of the fan-shaped land form.

Prehistoric villages, however, have been mapped along the lake shore northwest of Angkor and southwest of Batdambang (Moore), indicating that it is possible that the lake level has receded within recent times.

of these large areas that were once cultivated by the Khmer people.

The difficult construction of the beautiful structures we so admire was, therefore, not the only challenge the Khmers encountered. The empire required more resources to maintain itself, and might have deforested parts of Cambodia to provide for their capital. With aerial photographs, ancient fields and the evidence of ancient sites can be seen in many areas that are, once again, forested.

Over the centuries, the channels gradually dried out as the land tipped, draining the canals. In 1431, the Siamese attacked, taking advantage of a vulnerable capital city, sacking the city and removing the Khmer slave labour force. As in the past, the Khmer leaders decided to abandon their capital in favour of a safer location, leaving a once glorious empire to the encroaching jungle. They fled to the southeast, to a more secure and hospitable site, far from the Siamese borders.

This is surely not the final word on this intriguing subject. Many questions are left unanswered and more detailed studies must be conducted. This treatise lifts only a corner of the shroud which covers the past. It is an opening to a new chapter of research on the rise and decline of Angkor. New techniques and technologies that researchers had no access to only a few decades ago, are available to us now. It is hoped that this general discourse will encourage researchers to further unravel this mystery of the past.

One fruitful line of investigation may be to examine more carefully the chronology of the construction of the various canals and irrigation systems. This research may indicate how urgently the Khmers were trying to address the problem of their dwindling water supply. If the Khmers were indeed struggling against a steadily growing problem, we may see longer, more extensive and sustained periods of canal-building toward the end of the period of habitation. If such an increase coincides with an overall decrease in the rate of temple-building, then it may prove that the Khmer were forced to divert increasing portions of their labour force toward a problem that was demanding more of their efforts. Also, much more can be deduced from the analysis and interpretation of aerial photography and satellite. An extensive study of the changing

Photographs by Nicolas Urban

drainage patterns of the area may shed more light on this compelling subject. With continuing efforts and new methods of research, this area of inquiry will undoubtedly yield many new findings for years to come.

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The author would like to thank Ean Lee, Eric Seifert and Colin Dunne for their assistance and layout design of the above article.

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