6. The ground and ground water in the Angkor Monuments Complex

- in respect of Angkor Thom and Bayon in particular -

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I Introduction

The monuments of historic stone buildings, their great weight generally supported only by the strength of the ground itself, are often subjected to deterioration and collapse due to changing ground conditions over long periods. The Angkor Monuments are no exception to this. Unlike the pyramids of Egypt, which are built on hard limestone, nearly all buildings are built on alluvium, which is typically weak ground where there is a high probability that causes such as changes in the ground water level will have a serious effect on the deterioration of the construction materials. On this point, it is necessary to carry out adequately detailed studies of the ground and to improve the ground to give it adequate strength before entering on the work of restoration and preservation. But to gain an understanding of the general outline of the problem is an urgent pre-requisite.

Some research has been undertaken by Moriai concerning the ground and the ground water at the Angkor Monuments complex and a summary of the position in respect of Banteay Kdei and Prah Khan has been made fairly clear (Moriai, 1991 and 1992). There is also a conjectural report regarding Angkor Thom (Moriai, 1992). However, surveys so far were mainly carried out in March, which is the dry season, and in the case of each of the monuments the question of changes in the level of ground water in the wet season has been left as before. On that point, in order to gain an understanding of the structure of the ground at Bayon, Angkor Thom, which had only been given some conjectural consideration, in this study many auger samples are taken in the area. At Banteay Kdei and Prah Khan, starting with the results of Moriai's research, several single auger holes were drilled to study changes in the ground water level in August. Some test bore cores received are described from Phnom Penh City which should be data for future research.

In carrying out this study we have been given important assistance by Professor Y. Ishizawa of Sophia University, leader of the 8th Survey Mission, and the members of his mission. In particular, Dr. Lao Kim-Leang of the Machinery and Electronics Inspection and Licensing Corporation has assisted in obtaining boring samples. Various people from the Phnom Penh Government Ministry of Information and Culture and the Angkor Monuments Preservation Office have accommodated us during the actual surveys as well as treating us with warm hospitality. We have had the cooperation of Mr. Koum Sorith and Mr. Seng Soth of the Archeology Laboratory, Phnom Penh University of Fine Arts, in our on-site surveys. We wish to express here our deepest appreciation to each of them.

II Research Methods

The equipment used for auger sampling is the same as in Moriai (1991). In the actual auger drilling, a limit of about 6 m were reached but some holes were stopped shorter than this when weak ground made it difficult to dig deeper or when a hard buried object was encountered. Samples were collected during auger drilling at intervals of 10-30 cm and examined for grain size, mineral composition, contents, colour and pH. Sample colours were recorded in accordance with Goddard et al. (1951) (Table 1). pH measurements were made with a Horiba D-13 pH meter on about one gram of moist sample dispersed in 5 cc of pure water. Eight of the samples taken on the north side of Bayon were subjected to X-ray diffraction analysis to study their mineral composition.

5Y6/1	light olive grey
5Y8/1	yellowish grey
5Y6/2	pale olive
5YR3/4	moderate brown
5YR4/4	moderate brown
5YR6/4	light brown
5YR7/2	greyish orange pink
10R3/4	dark reddish brown
10R4/6	moderate red
10YR2/2	dusky yellowish brown
10YR3/2	dark yellowish brown
10YR4/2	dark yellowish brown
10YR5/2	pale yellowish brown
10YR6/2	pale yellowish brown
10YR7/2	very pale orange
10YR5/4	light brown
10YR6/4	light brown
10YR7/4	greyish orange

Table 1 Goddard et al. (1951) colour codes (abstract)

III Auger Sampling Results

1. Bayon, Angkor Thom

About two kilometres south-southwest of Bayon, which is the central temple of Angkor Thom, lies Phnom Bakheng, one of three sacred mountains of Angkor, and it is assumed that hard bed-rock underlies Bayon. Also, the West Baray reservoir is located to the west of Bayon and the Siem Reap River flows on the east so that it can be said Angkor Thom is surrounded by an environment which has plenty of ground water.

According to Moriai (1992), two auger holes were drilled at Angkor Thom. This time we re-drilled one of these at a site on the south side of Bayon and drilled eight more holes around Bayon. The drilling sites around Bayon are shown in Fig. 1 and the results are shown in Fig. 2 and Tables 2-7.

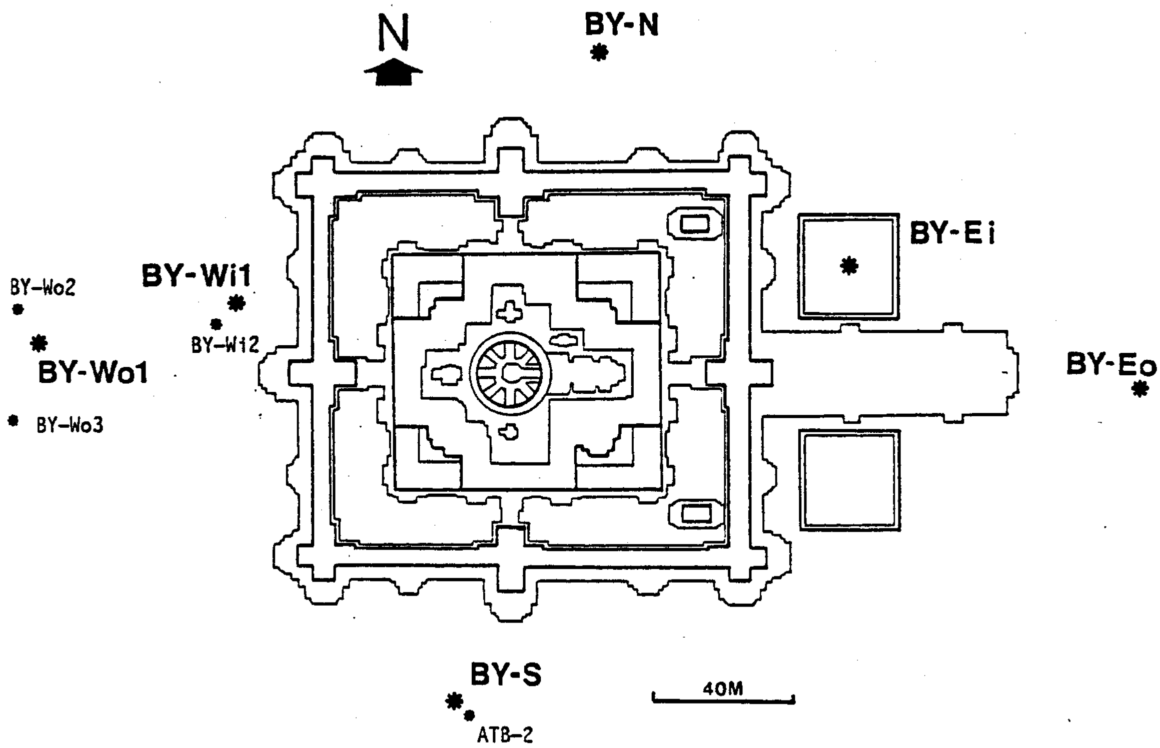

Fig. 1 Auger sampling sites Bayon area, Angkor Thom
(after Ishizawa, 1989 amended. ATB-1: Moriai, 1992

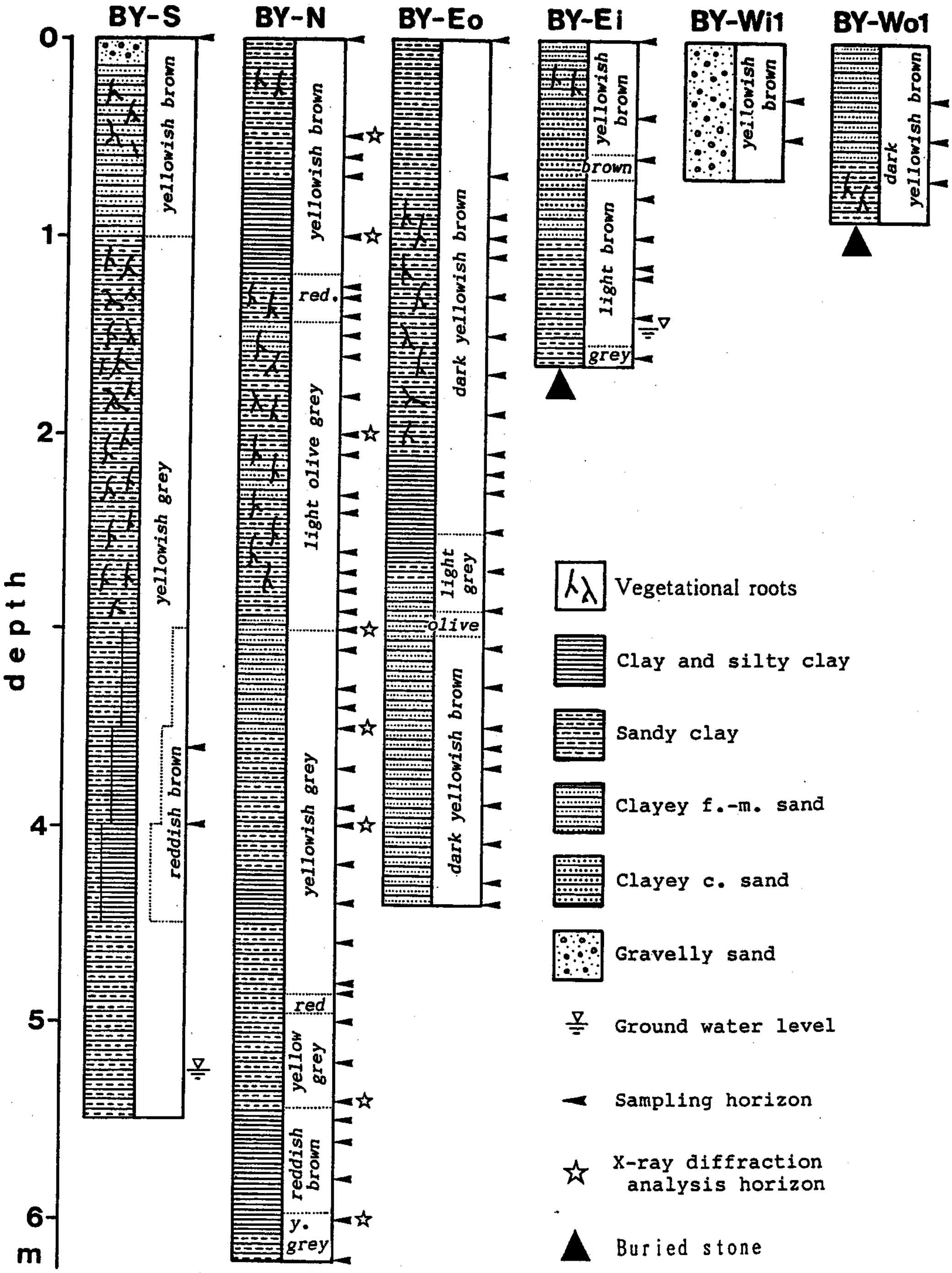

Fig. 2 Core columnar sections Bayon area, Angkor Thom

(1) Bayon South Side (BY-S)

The one hole on the south side of Bayon (BY-S) was drilled in the wet season to re-confirm the sample results obtained by Moriai (1992) in the dry season, so it was located about 4 m to the northeast of hole ATB-2, which is about 40 m south of the First Gallery. The sample results are shown in Table 2. Drilling proceeded to a depth of 550 cm and the ground water level was found at 525 cm. The surface soil is a dark yellowish brown colour, composed of fine gravel accompanied by fine-grained sand but below that the clay content increases gradually, becoming brownish grey sandy clay at a depth of 100 cm. At a depth of 100-300 cm it is yellow grey sandy clay and below that reddish brown clay is occasionally inter-mixed until it once again becomes uniform yellowish grey sandy clay at a depth of 450 cm. Comparatively abundant fine plant roots are inter-mixed around 50 cm deep and again between 100-250 cm deep but below that they are rare. Since this was a re-drilled hole, samples were taken at only four points. The surface pH was 6.2 but at depths of 360 cm and 400 cm is was 7.3 and 7.7 respectively and, at a depth of 500 cm, the pH was comparatively low at 5.4. The ground water pH in this auger drill hole was 6.1. About 50 m south of the drill hole, where the elevation is about one metre higher, the ground water level in a well was 610 cm below ground and the well water had a pH of 5.7.

BY-S (Angkor Thom, Bayon: 18/8/1992)			
Depth	Colour	pH	Grain size
0cm	10YR4/2	6.2	gravelly f.sand
360	5Y8/1	7.3	sandy clay
400	10R3/4	7.7	sandy clay
500	5Y8/1	5.4	sandy clay
ground water		6.1	

Table 2 Bayon south side sampling - depth, colour, ph, grain size

(2) Bayon North Side (BY-N)

One hole was drilled on the north side of Bayon, about 30 m north of the First Gallery. Drilling proceeded

BY-N (Angkor Thom, Bayon: 19/8/1992)				
Depth	Colour	pH	Grain size	Mineral Composition (%)
0cm	10YR4/2	5.4	sandy clay	
50	10YR4/2	6.2	sandy clay	quartz, kaoline, feldspars
60	5YR4/4	6.2	sandy clay	(70-80) (5-10) (5-10)
70	10R4/6	6.5	sandy clay	
100	10YR5/4	6.2	silty clay	quartz, kaoline
125	10R4/6	6.5	silty clay	(80-90) (5-10)
130	10R4/6	6.0	sandy clay	
140	5Y8/1	6.4	sandy clay	
150	5Y6/1	6.4	clayey f.sand	
160	5Y6/1	6.3	sandy clay	
180	5Y6/1	6.6	sandy clay	
200	5Y6/1	6.8	sandy clay	quartz, kaoline
210	5Y6/1	6.7	clayey f.sand	(80-90) (5-10)
230	5Y6/1	6.9	clayey m.sand	
240	5Y6/1	6.4	sandy clay	
260	5Y6/1	6.5	sandy clay	
270	5Y6/1	6.7	sandy clay	
280	5Y6/1	6.8	sandy clay	
290	5Y6/1	6.4	sandy clay	
300	5Y8/1	6.6	clayey f.sand	quartz, kaoline
310	5Y8/1	6.3	clayey f.sand	(70-80) (10-15)
330	5Y8/1	6.4	clayey f.sand	
340	5Y8/1	6.3	clayey f.sand	
350	5Y8/1	6.2	clayey f.sand	quartz, kaoline, goethite
370	5Y8/1	6.1	sandy clay	(70-80) (5-10) (5-10)
390	5Y8/1	5.6	sandy clay	
400	5Y8/1	5.4	sandy clay	quartz, kaoline
420	5Y8/1	5.6	sandy clay	(70-80) (10-15)
440	5Y8/1	5.3	clay	
460	5Y8/1	5.5	sandy clay	
480	5Y8/1	5.2	sandy clay	
485	10YR5/4	5.4	sandy clay	
500	5Y8/1	5.4	sandy clay	
520	5Y8/1	5.6	sandy clay	
540	5Y8/1	5.5	sandy clay	
550	10R3/4	5.0	clay	quartz, kaoline, goethite
560	10R3/4	5.5	clay	(50-60) (10-20) (10+)
580	10R3/4	5.4	clay	
600	5Y8/1	5.7	clay	quartz, kaoline
620	5Y8/1	5.6	sandy clay	(60-70) (10-20)

Table 3 Bayon north side sampling - depth, colour, ph, grain size and mineral composition

to a depth of 620 cm but the ground water level was not found. Drilling results and X-ray diffraction analysis results are shown in Table 3. The ground at this site is composed of clay, silty clay, sandy clay and clayey sand. At a depth of around 440 cm the clay is a yellowish grey colour and rather thin and a prominent dark reddish brown coloured band is intercalated at a depth of 550-600 cm. Silty clay is intercalated at a depth of 100-120 cm the colour being light brown above and reddish brown below. Whereas the sandy clay and clayey sand which constitutes the major part of this hole is yellowish brown in the upper 100 cm, at depths below 130 cm where it is enclosed by the reddish brown coloured sandy clay its colour changes gradually from light greenish grey to yellowish brown. The sand in the samples is mainly composed of quartz and laterite flakes. X-ray diffraction analysis results of all samples show that quartz predominates with 80%, more or less, with small amounts of kaolin. The top sample has less than 10% feldspar and samples from the 350 cm and 550 cm levels contain 5-10% goethite. The reddish brown coloured layer (550 cm deep) in particular have comparatively large amounts of goethite, up to 10%. Fine plant roots are comparatively common from the surface down to 50 cm, and again between 100-300 cm, but are rare below 300 cm. pH values tend to rise from 5.3 to 6.8 as depth increases from the surface down to 280 cm and to fall again below that, falling suddenly to 5.5 more or less below 390 cm. In particular, at the top of the reddish brown coloured clay the pH has the extremely low value of 5.

(3) Bayon East Side (BY-Ei, BY-Eo)

Auger drill holes were tried at two locations to the east of Bayon. One of these which was in the northernmost of two sacred ponds on the eastern front of Bayon (BY-Ei : Table 4) struck a hard buried object at a depth of 165 cm and could be drilled no further. However it confirmed the presence of water at a depth of 145 cm. The other (BY-Eo: Table 5), beside the path to the Gate of the Dead (about 50 m east of the Bayon eastern front entrance) was drilled to a depth of 440 cm without striking ground water.

The material from the sacred pond is composed of clayey sand in the upper 100 cm approximately, with sandy clay below, mainly dark yellowish brown to light brown in colour, the deepest parts only being light yellow brown.

BY-Ei (Angkor Thom, Bayon: 21/8/1992)			
Depth	Colour	pH	Grain size
0cm	10YR2/2	5.3	clayey f.sand
40	10YR4/2	6.1	clayey m.sand
60	5YR3/4	6.2	clayey m.sand
80	10YR2/2	6.1	clayey f.sand
100	10YR4/2	6.1	sandy clay
115	10YR3/2	6.4	sandy clay
120	10YR3/2	5.8	sandy clay
140	10YR2/2	5.2	sandy clay
160	10YR5/2	5.1	sandy clay
ground water		5.2	

Table 4 Bayon east side sacred pond sampling - depth, colour, ph, grain size

BY-Eo (Angkor Thom, Bayon: 22/8/1992)			
Depth	Colour	pH	Grain size
0cm	10YR2/2	7.2	sandy clay
70	10YR3/2	5.8	sandy clay
90	10YR3/2	6.1	sandy clay
100	10YR4/2	5.6	sandy clay
110	10YR3/2	5.9	sandy clay
130	10YR4/2	5.9	sandy clay
150	10YR4/2	5.9	sandy clay
170	10YR4/2	6.0	sandy clay
190	10YR4/2	6.1	sandy clay
210	10YR4/2	6.0	sandy clay
220	10YR4/2	6.2	clay
230	10YR6/2	6.1	clay
250	5Y6/1	6.1	clay
270	5Y6/1	5.9	sandy clay
290	5Y6/1	5.9	clayey f.sand
310	10YR7/2	5.7	clayey f.sand
330	10YR5/4	5.7	clayey m.sand
350	10YR5/4	5.5	clayey f.sand
360	10YR5/4	5.7	clayey m.sand
370	10YR5/4	5.7	clayey m.sand
390	10YR6/2	5.6	clayey m.sand
410	10YR5/4	5.6	clayey m.sand
430	10YR6/2	5.9	clayey m.sand
440	10YR7/2	5.9	clayey m.sand

Table 5 Bayon east side sampling - depth, colour, ph, grain size

The sand is composed mainly of quartz and laterite flakes. Plant roots are detected only near the surface. pH values rose gradually from the surface to a depth of 115 cm then showed a tendency to fall. A pH value of 5.2 was obtained for the water obtained at the 145 cm level.

The outer auger hole material is dark yellowish brown coloured sandy clay from the surface to a depth of 210 cm, mainly light brown to light yellowish brown clayey sand below 290 cm while the top 20 cm of the clayey sand exhibit a light yellow to light green colour. A layer of clay about 80 cm thick enclosed between these two has a yellowish brown coloured upper half and a light brown lower half. Many fine plant roots can be seen in the upper sandy clay. pH values in the upper sandy clay and clay are generally stable and comparatively high at 5.9-6.1. On the other hand, the lower clayey sand had lower pH values of 5.6-5.9.

(4) Bayon West Side (BY-Wi1-2, BY-Wo1-3)

On the Bayon west side, auger holes were drilled beside the road to the west main gate, two on the inside and three on the outside of the perimeter road. Representative results are shown in Tables 6 and 7. The holes on the inner side of the road were drilled immediately after a squall so the ground was weak and drilling was difficult and was abandoned at 50 cm. Outside the road all holes ran into hard buried objects before they were one metre deep and drilling was impossible.

BY-Wi1 (Angkor Thom, Bayon: 22/8/1992)			
Depth	Colour	pH	Grain size
30cm	10YR3/2	4.6	gravelly m.sand
50	10YR4/2	5.3	gravelly m.sand

Table 6 Bayon west side (inner) sampling - depth, colour, ph, grain size

BY-Wo1 (Angkor Thom, Bayon: 22/8/1992)			
Depth	Colour	pH	Grain size
30cm	10YR3/2	5.9	clayey f.sand
50	10YR3/2	5.5	clayey f.sand
70	10YR4/2	5.4	sandy clay
90	10YR4/2	5.1	sandy clay
ground water		5.3	

Table 7 Bayon west side (outer) sampling - depth, colour, ph, grain size

Material from the inner side is a dark yellowish brown colour consisting of fine grained sand accompanying fine gravel. The gravel consists mainly of comparatively well-rounded sandstone and metamorphic rock, the sand is composed of quartz and laterite fragments. Fine plant roots are seen only in the surface layer. The soil at depths of 30 cm and 50 cm has rather low pH values of 4.6 and 5.3 respectively. On the outer side, the colour is generally dark yellowish brown, the upper 50 cm being clayey fine-grained sand with sandy clay below. The sand is composed of quartz and laterite fragments. Fine plant roots are seen only in the surface layer. The pH at the surface is 5.9, gradually falling to 5.1 at a depth of 90 cm.

2. Banteay Kdei

In March 1991, seven auger holes were drilled at Banteay Kdei (Moriai, 1991). In this study, hole No. 3 was re-drilled in a location to the northeast of the front colonnaded pavilion (Fig. 3). The results are shown in Fig. 4 and Table 8. Drilling at this point reached 480 cm and the ground water level was found at a depth of 455 cm. The ground is mainly sandy clay and clayey sand, from the surface down to a depth of 120 cm there is reddish brown sandy clay, from 120-250 cm it is greyish white sandy clay with a reddish brown clay layer enclosed at a depth of around 150 cm. At a depth of 250-270 cm reddish brown clay mixes gradually with the yellowish grey clay and the ground below that is greyish white but at 340 cm it again becomes

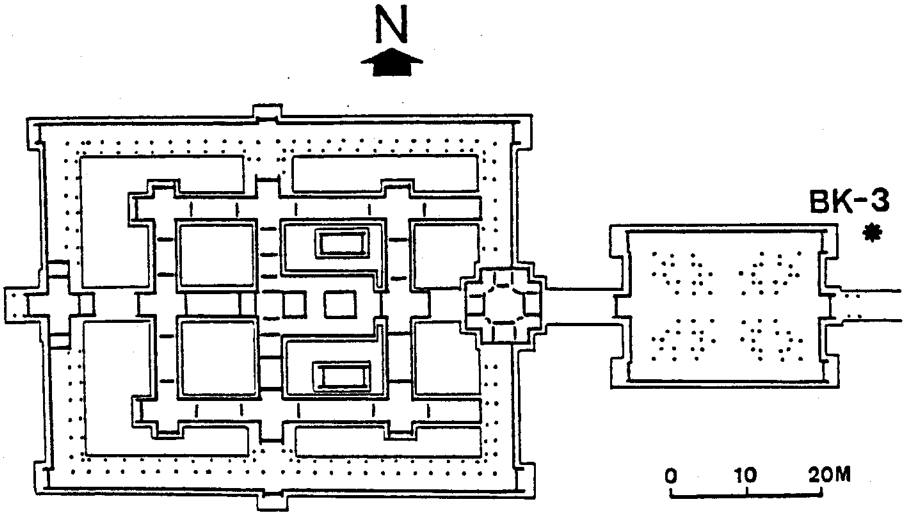

Fig. 3 Auger sampling sites at Banteay Kdei
(after Delvert, 1967 amended)

BK-3 (Banteay Kdei: 17/8/1992)			
Depth	Colour	pH	Grain size
70cm	10YR5/4	5.8	gravelly f.sand
150	10YR5/4	6.2	clayey f.sand
ground water		5.9	

Table 8 Banteay Kdei Hole 3 sampling - depth, colour, ph, grain size

mixed with reddish brown clay. Because this is a re-drilled hole, sampling was confined to material obtained from two points. In both cases the material is light brown clayey sand with small amounts of fine gravel. The ph is more or less 6, which is not noticeably different from the ground water pH of 5.9.

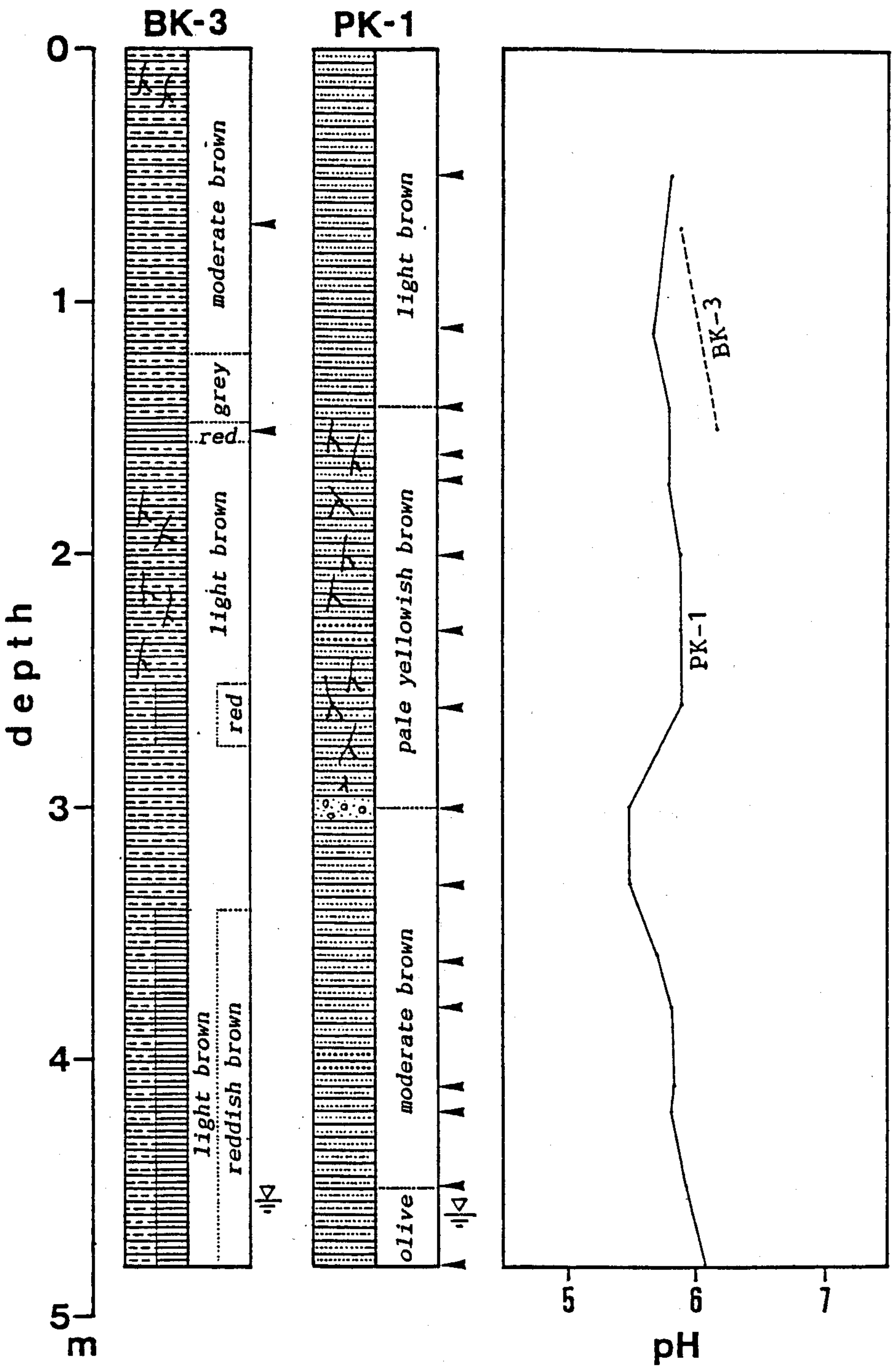

Fig. 4 Core columnar sections and vertical distribution of pH values in Banteay Kdei Hole 3 and Prah Khan Hole 1 (Legend as for Fig. 2)

3. Prah Khan

Three auger holes were drilled at Prah Khan in March 1991 and March 1992 (Moriai, 1991 and 1992). In this survey, a new hole was drilled about two metres west of No 1 hole, which was near the West Entrance (Fig. 5). The hole reached the ground water level at a depth of 460 cm after

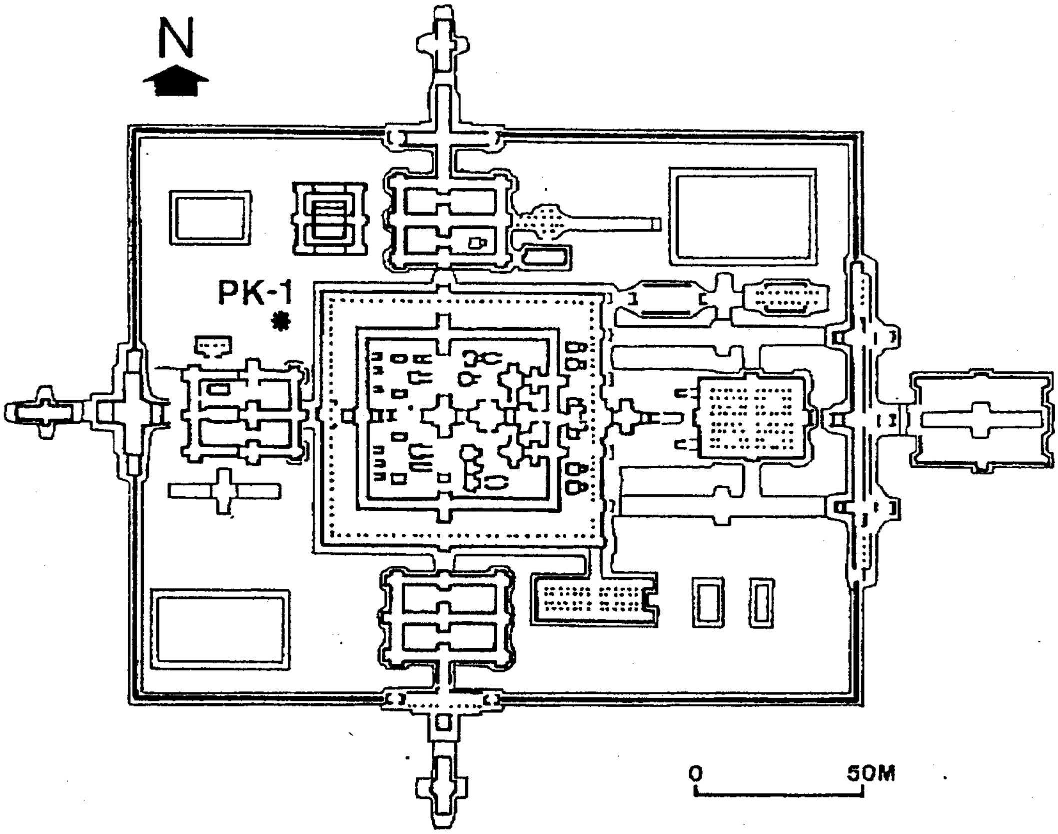

Fig. 5 Auger sampling sites at Prah Khan
(after Chihara, 1982 amended)

which the drilling became difficult and was stopped at 480 cm. The results are shown in Fig. 4 and Table 9. The ground consists mainly of fine sand in clay. Coarse-grained sand is included at depths of about 230 cm and 400 cm and at around 300 cm there is also fine to small gravel. The sand is composed mainly of quartz accompanied by a small quantity of laterite flakes. The colour from the surface down to a depth of 140 cm is light brown, the upper 50 cm approximately being tinged with red. From 140 cm to 300 cm down it is light yellowish brown and to 450 cm it is brown after which it becomes light greenish grey. The pH values are a more or less uniform 5.8, falling a little to 5.5 at about 300 cm down but in any case these values are higher than the ground water which has a pH of 5.1.

PK-1 (Prah Khan: 21/8/1992)			
Depth	Colour	pH	Grain size
50cm	10YR5/4	5.8	clayey f.sand
110	10YR7/4	5.7	sandy clay
140	10YR6/4	5.8	clayey f.sand
160	10YR6/4	5.8	clayey f.sand
170	10YR6/2	5.8	clayey f.sand
200	10YR6/2	5.9	clayey f.sand
230	10YR6/2	5.9	clayey m.sand
260	10YR6/2	5.9	clayey f.sand
300	10YR6/2	5.5	clayey f.sand
330	5YR4/4	5.5	clayey f.sand
360	10YR7/2	5.7	clayey f.sand
380	5YR4/4	5.8	clayey m.sand
410	5YR4/4	5.8	clayey c.sand
420	10YR5/4	5.8	clayey f.sand
450	5Y6/2	5.9	clayey f.sand
480	5Y6/2	6.1	clayey f.sand
ground water		5.1	

Table 9 Prah Khan Hole 1 sampling - depth, colour, ph, grain size

IV Discussion

1. Ground water levels in the wet season

No. 3 hole at Banteay Kdei, No. 1 hole at Prah Khan and the drilling on the Bayon east side at Angkor Thom all reached ground water. In March, 1991, which was the dry season, the ground water at Banteay Kdei and Prah Khan was 360 cm and 410 cm below ground, respectively (Moriai, 1991). Comparing these with the results obtained this time shows ground water levels in August in the wet season which are 50 to 100 cm lower. On the other hand, with the drilling at the Bayon south side, the ground water was found 525 cm below the surface. This is about the same as the ground water level of 620 cm measured in the well near the drill site. From observations of the drilling and at the same well in March 1992, Moriai (1992) estimated the ground water level at this point as being 430 cm below the surface so that here also, as with the two monuments mentioned previously, the results gave a lower ground water level in August. As to reasons for the wet season ground water level being lower than in the dry season, one can infer that the auger drilling was done at the start of the wet season and the rainfall in the 1992 wet season was comparatively low (Mr. Koum Sorith, Phnom Penh University of Fine Arts, pers. comm.), and one can suppose that perhaps the ground water levels in these areas, after reaching a maximum level from the end of the wet season and the start of the dry season, gradually fall until the start of the next wet season. It is known that in the Southeast Asia belt, including Cambodia, a little dry season begins in August (Delvert, 1967) and this is also a possible reason.

No great differences were observed in the vertical variations in the nature of the ground, and colour changes in particular, from the results of surveys conducted about a year and a half earlier at Banteay Kdei and Prah Khan and about half a year earlier at Bayon (Moriai, 1991 and 1992), so the ground neither changes seasonally nor during the passage of this amount of time.

2. The ground in the vicinity of Bayon

(1) Composition of the ground

With the exception of the west side, auger drillings of more than four metres were done at three points in the vicinity of Bayon. Of these, the south side and the north side reveal similar profiles. In both places from the surface to a depth of about one metre the ground consists mainly of yellowish brown clayey sand and sandy clay. Below this it is mainly yellowish grey or light greenish grey sandy clay and clayey sand with enclosed or intercalated layers of reddish brown clay some tens of centimetres thick. The ground on the east side is different, consisting of dark brown sandy clay from the surface to a depth of about two metres and dark yellowish brown clayey sand from three metres down with yellowish brown or greyish white enclosed between these two. As to reasons why the ground in the east should be different from that of the north and south at Bayon, at the time Bayon was constructed, the surface may have been excavated to about a metre below the original surface of the ground near the south and north auger drilling sites and it is possible that about a metre of surface layer which exhibits a yellowish brown colour is accumulated material which was later back-filled over this. By contrast it is highly probable that the original surface remains at the auger drill site to the east. Another point is that abundant plant roots can be seen in the upper half of the ground at all of the drilling sites but, whereas there are only little shrubs growing nearby at the south and north drilling sites, in the west there is a large banyan tree about 10 m away, more or less, and it is possible that the different vegetation has been influenced by the composition of the ground.

(2) Weathering of the ground and depth of ground water

Eight samples obtained from the auger drilling at the Bayon north side were examined by X-ray diffraction analysis. Samples at all horizons, except the 350 cm and 550 cm samples, have predominant 70-90% quartz accompanied by 5-20% kaolin. 10% feldspar is present only in the sample from 50 cm deep. Quartz is a mineral which is extremely resistant to both chemical and mechanical weatherings and kaolin comes from aluminosilicates, feldspar in particular, which have disintegrated due to weathering and hydrothermal alteration. With the auger drilling depths used this time, the possibility of hydrothermal alteration cannot be entertained so the kaolin which was detected can be considered to have been derived mainly from the weathering of feldspar by ground water. This is supported by universal predominance of quartz, the fact that kaolin content increases with depth and the fact that feldspar, which is susceptible to weathering, is found only in a sample 50 cm deep. The sample from 550 cm deep is derived from reddish brown clay and only in this material is the quartz content comparatively low at 50-60%, the kaolin 10-20% and goethite 10%. Goethite is a mineral with a yellowish brown or red colour and the goethite is the reason for the reddish brown colour at this horizon. Goethite is formed mainly by the oxidation of iron minerals due to weathering and is soluble in hydrochloric acid (Sudo, 1977). In other words, the layers rich in goethite being formed by iron dissolved in oxidising ground water being concentrated in certain specific level by the movement of the ground water and this reddish brown clay layer as being indicative of a surface where the ground water was temporarily static (the lowest level). The material from 350 cm deep is comparatively rich in sand and exhibits a yellowish brown colour but it also contains 5-10% goethite and it is highly probable that this horizon also indicates a surface of temporarily static ground water (the highest level).

At the Bayon south side, ground water was found 525 cm below the surface of the ground. In consideration of the results of auger drilling at the same place and observations of a nearby well by Moriai (1992) in the dry season, and the presence of reddish brown clay 600 cm under the ground which indicates the surface of temporarily static ground water on the Bayon north side, therefore this water level indicates the lowest ground water level. On the other hand, by this auger drilling the inter-mixing of reddish brown clay in yellowish brown sandy clay is detected at a depth of 300-450 cm and, since the ground above this level is almost homogeneous, it is highly probable that the uppermost level of the ground water is near 300 cm.

The auger drilling on the east side has revealed no reddish brown clay layers indicative of static ground water surfaces but a clay layer exhibiting greyish white colours is enclosed at a depth of 220-270 cm and it is possible that this clay layer indicates one of the static ground water surfaces.

(3) pH

Fig. 6 shows the vertical distribution of pH values in samples obtained by auger drilling in the vicinity of Bayon. pH values are low throughout all horizons, typical of iron-aluminum soils (Bridges, 1978). At the north and west of Bayon, where the auger drilling was comparatively deep, pH showed a tendency to rise gradually from the surface to around the 250 cm level, and to fall gradually below the 300 cm level. On the south side, the pH values measured in auger samples and in the ground water in the nearby well were 6.1 and 5.7 respectively and, from the depth of the auger sample having a pH close to the value indicated, therefore the ground water is exerting a direct influence of the ground at a depth of 250-300 cm. The pH value of the surface soil is generally low. Presumably, this is due to the sparse vegetation at the auger drilling site and the scarcity of bases supplied by fallen leaves, etc. By contrast, it is only at the outer Bayon east side that the pH of the surface soil is almost neutral at 7.3 but this could be because there is a large banyan tree near here, from which plenty of bases are supplied, or perhaps the influence of rain which fell immediately before.

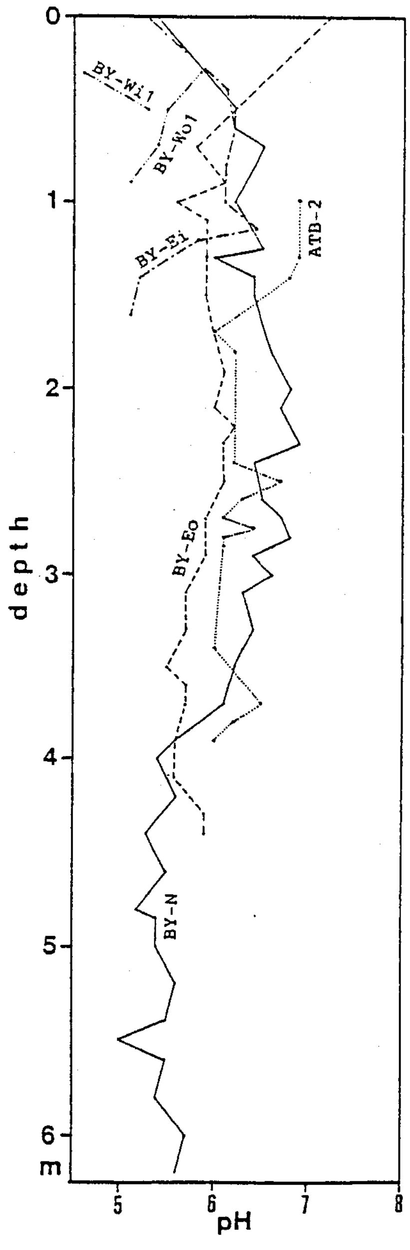

Fig. 6 Vertical distribution of pH values Bayon area, Angkor Thom (ATB-1: draw after Moriai, 1992).

3. The possibility of buried buildings near Bayon

The auger drilling in the sacred pond at the front of Bayon encountered a hard buried object at a depth of 165 cm which prevented further progress. The sound of the auger bit scraping the buried object was comparatively small and the resistance on the handle was slight, suggesting that the surface of the buried object is flat. This depth is about the same as the height of a man; there is water present at the deepest part, the level of which is clearly higher than the ground water level measured at the Bayon south side; the bottom of the pool at Srah Srang, the famous sacred bathing pool, is paved with laterite (Ishizawa, 1989). Considering these facts, the existence of pavement on the bottom of the sacred pond can be imagined similar to that at Srah Srang.

Auger holes were drilled at three sites on the outside at the Bayon west side but at each of the sites drilling could not be continued because of hard buried objects at a depth of 70-90 cm. Considering that these drill sites were all about 10 m apart from each other, and the drilling was stopped at a comparatively uniform depth, it is possible that there is some sort of building buried under the ground in this area.

V Subjects for the Future

1. The auger sampling at Banteay Kdei, Prah Khan and the Bayon south side has produced results contrary to expectations in that the ground water level in the 1992 wet season (August) is lower than that in the dry season (March). As to the seasonal rise and fall of ground water, the eluviation of fine material has a major affect in reducing the strength of the ground and with regard to the restoration and long term preservation of the monuments, this is something which must be clarified urgently. On that point, in respect of these three monuments, it is essential to undertake regular ground water level measurements and match them to regular rainfall measurements in order to grasp the relation between rainfall and the variation in ground water levels during the year.

2. From the result of auger sampling in the environs of Bayon, an outline of the structure of the ground in the environs of the monuments and the growth in the amount of clay minerals due to weathering have been clarified. However, knowing the details of the structure of the ground which forms the foundations of the monuments, both the

number and depth of auger samples are inadequate for solving the various important problems such as ground subsidence. In future these problems should be solved by many tests with mechanical boring in addition to hand augering, together with geophysical approaches such as electrical exploration and micro-tremor exploration.

3. The existence of objects buried under the ground at the Bayon sacred pond and to the west of Bayon have been assumed. It would be good if a future archeological excavation could verify this.

VI Conclusions

1. The ground water levels at Banteay Kdei, Prah Khan and Angkor Thom (Bayon) were measured in August 1992.
2. An outline of the ground structure in the vicinity of Bayon clarified.
3. The bottom of the sacred pond in front of the northwest side of Bayon may be paved.
4. A buried structure to the west of Bayon may be existent.

VII Postscript

Some portions of samples from boring conducted in July, 1992 in Phnom Penh city were obtained. The location of the drilling sites is unclear but the depth of the samples is certain. Since up to now there has been only the brief mention by Workman (1975) concerning the thickness of the alluvium at Phnom Penh, therefore the description in detail was done for the benefit of future research.

The material is eight samples from four sites. Table 10 shows the depths from the which the samples were collected as well as their colour, pH and lithofacies. The colours shown by the samples are light yellow and greyish white and, on examining the samples from bores CKB-3 and CKB-4, any great variation is not seen in the vertical direction. In all cases the pH values were comparatively low at 4.9-5.4.

PHNOM PHEN				
St.	Depth	Colour	pH	Grain size
CKB-1	14.0m	10YR7/2	5.1	clayey m.sand
CKB-3	4.0	5YR7/2	5.4	clayey m.sand
	7.5	5YR7/2	5.0	clayey m.sand
	13.5	5YR7/2	5.2	clayey m.sand
CKB-4	1.5	5YR6/4	4.9	clayey m.sand
	13.5	10YR7/2	5.4	clayey m.sand
	16.5	10YR7/2	5.1	clayey m.sand
CKB-8	14.0	10YR7/2	5.2	clayey m.sand

Table 10 Phnom Penh city bore sampling - depth, colour, ph, grain size

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