7. Preliminary study of bottom sediments of Lake Tonle Sap

- Clues to understanding palaeoclimate -

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I Introduction

Active geological research is being carried out at present to study changes in the climate and the environment from bottom sediments of oceans and lakes. Such sediments often contain fossilised micro-organisms which reflect the climate and environment at the time of deposition and their change with time can throw some light on the transition of global and local environments and climates. In particular, the deposits in lakes, which are areas of enclosed water, commonly record environmental and climatic changes which are characteristic to the locality and the sedimentation rate is faster than in the open sea and can be used as material for studying changes over as short a period as several hundreds of years. On the other hand, past occurrences of sudden geological phenomena such as volcanic activity, floods, typhoons, tidal waves, earthquakes can be fixed specifically by soft x-ray analysis of internal sedimentary structures and capturing temporal variations of the mineral composition.

Tonle Sap, the largest lake in the Indochina peninsula, lies in the centre of the Cambodian grain belt and supports abundant aquatic resources. From Khmer dynastic times until the present, it has been closely associated with the people of Cambodia in all aspects such as history, life and culture. Having such an historic background, by investigating the Tonle Sap with geological methods, it should be quite possible to reconstruct climatic transitions and environmental changes over the period from Khmer dynastic times until the present and we can expect to trace their relationship with the rise and fall of various civilizations in the Indochina peninsula. On the other hand, lacustrine sediments in all parts of the world are regarded as important indicators of human environmental pollution and in this regard, the study of environmental pollution of this area is made possible by the long term study of the Tonle Sap lake deposits. Furthermore, Tonle Sap lies in a humid tropical region and the action of sedimentation characteristic of humid tropical regions, which is controlled by the variation in water level due to the repetitive succession of wet and dry seasons, makes this a lake which is of great interest to sedimentology.

Therefore, Tonle Sap should attract the attention of geologists, archaeologists, historians, environmental scientists and others and, while its waters and aquatic resources have been studied (e.g. Lao, 1991), up to now, the bottom sediments had not been studied at all. Consequently, as the first step in answering a number of questions, deposits from Tonle Sap and Siem Reap River, one of the streams feeding the lake, were collected and studied. Then, based on their features, the future extension of the study was considered.

In carrying out this study we have been helped in various ways by Professor Y. Ishizawa of Sophia University, leader of the 8th Survey Mission, and the members of his mission. Mr. Sun Kun of the Phnom Penh Government Ministry of Information and Culture and Dr. Lao Kim Leang of the Machinery and Electronics Inspection and Licensing Corporation provide accommodation and assisted with sampling. We have been helped with identification and assisted with sampling by Associate Professor K. Ishizaki and Dr. T. Irizuki of the Tohoku University in respect of ostracoda and Associate Professor S. Hasegawa of Hokkaido University and Dr. K. Kaiho of the Tohoku University in respect of foraminifera, and Associate Professor T. Maruyama of Yamagata University and Dr. M. Iwai of Tohoku University in respect of diatoms. We wish to express here our deepest appreciation to each of them.

II Tonle Sap

Tonle Sap is located in the western part of Cambodia. Its area expands greatly in the wet season and it is famous as "the elastic water world" (Figure 1). The lake is long and narrow, its northwest-southeast longitudinal axis being about 120 km at high water and the maximum width perpendicular to that axis is about 40 km. The area in the

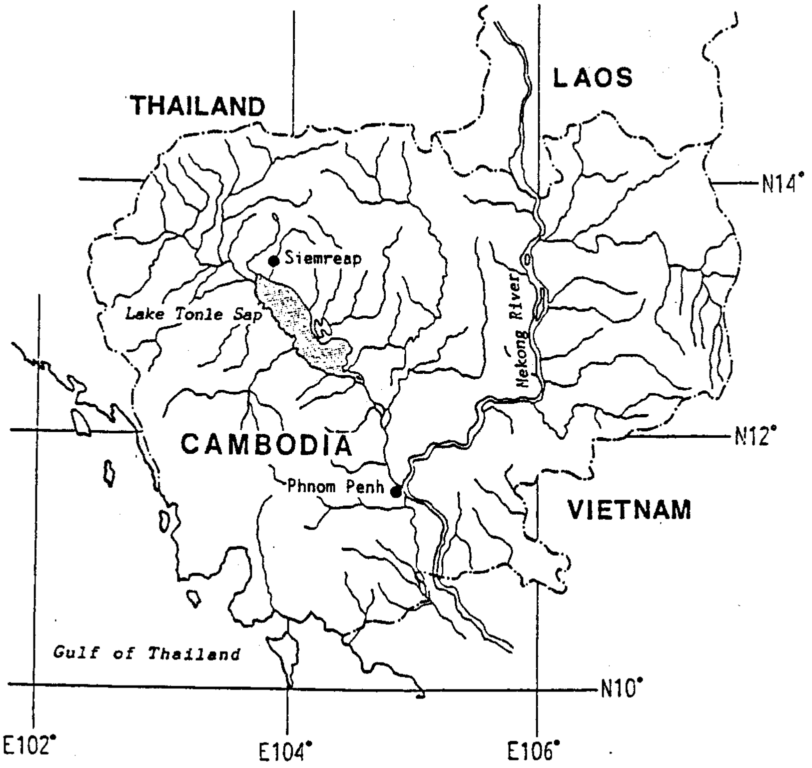

Fig. 1 Tonle Sap Lake location and landform

dry season of about 30,000 km^2 is more than trebled in the wet season to about 100,000 km^2 (Annual Science Report, 1992). However, at low water the depth all over is a shallow 3-6 m (Mitusio et al, 1970) and at high water the deepest parts are no more than 14 m (Annual Science Report, 1992). There is a network of numerous streams flowing directly into the lake from its surrounds but their flow is adequate mainly in the wet season and many silt deltas form in the vicinity of the river mouths (Plate, a). Again in the wet season, the flow of water through this group of streams is joined by water from the south-flowing Mekong River in eastern Cambodia, bringing much water together with detritus into the lake through the Tonle Sap River. On the other hand, in the dry season, the inflow from the rivers is small and water flows out from the southeastern part of the lake through the Tonle Sap River. The lake water exhibits a yellowish brown to reddish brown colour and the transparency of the lake water in the dry season is extremely low at

50-100 cm (Mitusio et al, 1970). The temperature of the surface water is extremely high all year round at 26-30°C and the pH is almost neutral at around 7.5 (Mitusio et al, 1970; Lao, 1992).

The period of formation of Tonle Sap is uncertain but the lake is located almost in the centre of a syncline formed by the Himalayan orogeny of the middle Cenozoic (Workman, 1975) and the region was not subsequently subjected to any great structural movement, so it is assumed that the lake probably started to form no later than the late Cenozoic.

III Survey and Research Methods

The samples used for this report were all collected during the morning of 19 August 1992. The bottom sampling positions in Tonle Sap and Siem Reap River are shown in Fig. 2.

The bottom sampling tool used in Tonle Sap was a cylindrical aluminum can, 6 cm in diameter and 12 cm long, with five 6-inch nails set around the edge. A steel rod of about 1 kg was fastened as a sinker to the rope which was fastened to the mouth of the can (Fig. 3A, Plate, b). The actual sampling was done by throwing in the sampling tool after confirming the depth of the water with a sounding rope. After confirming that it had reached the bottom, 1 m of rope was unreeled and the sampling tool was then retrieved while it scratched the lake bottom deposits (Fig. 3b). On the boat, the samples were quickly checked for colour, temperature and pH and about 1 cm of the reddish brown coloured surface layer and the lower blueish grey coloured part were separated and collected. The recording of sample colours was based on Goddard et al (1951). In the Siem Reap River, about 1 cm of the surface sediment was collected with a scoop.

For muddy sediments, a smear slide was made and observed by microscope. For sandy sendiments, the entire sample was dried for 24 hours at about 60°C and the dry weight was measured. It was then washed repeatedly to remove the mud and dried and weighed again to obtain the proportional mud content. The remaining material was made into a thin section and examined microscopically as a sand

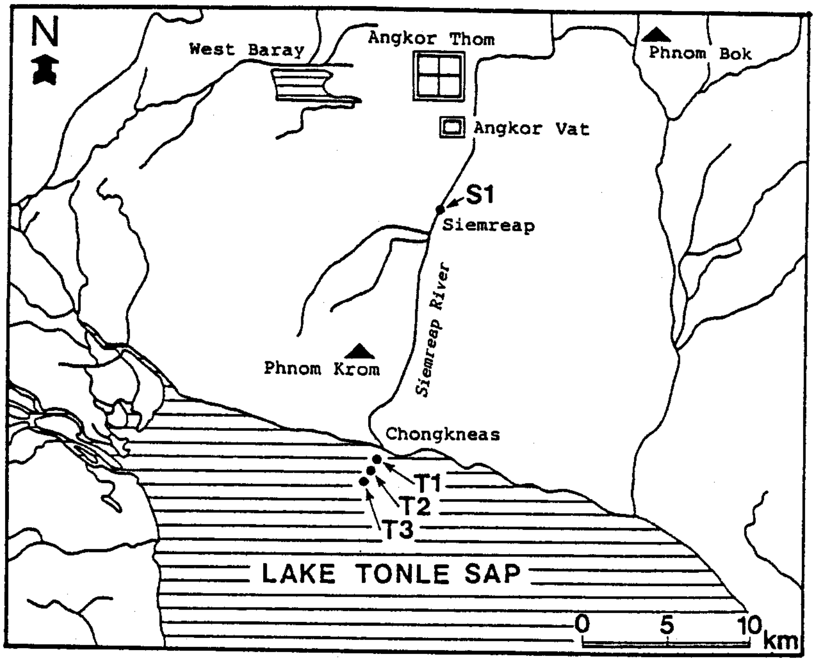

Fig. 2 Tonle Sap Lake and Siem Reap River sampling localities

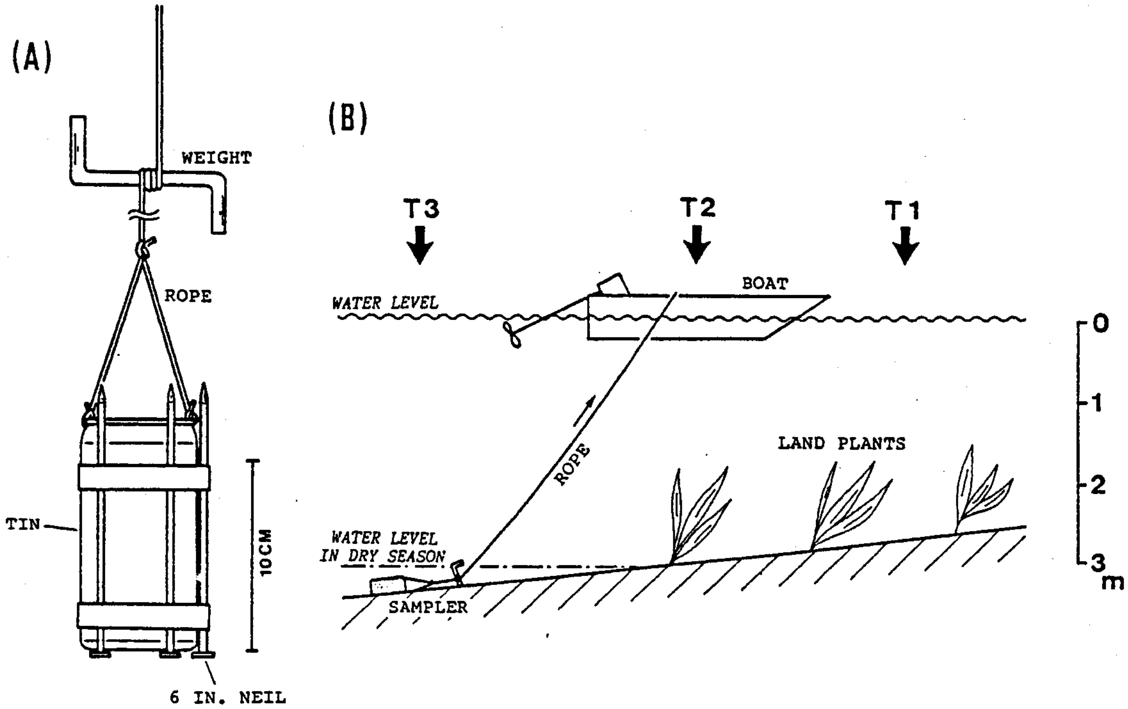

Fig.3 Sampling tool and sampling method

sample. Since there was insufficient sample material for analysis in respect of the remains of micro-organisms contained in the deposits, this aspect was stopped short at a summary grasp.

IV Sediments

1. Tonle Sap

Bottom samples were taken in Tonle Sap at three points (Lat. 13°13'N, Long. 103°49'E) about 2 km offshore to the south of the village of Chongkneas, which lies about 13 km south of Siem Reap city alongside a canal leading to the lake (Fig. 2, Plate, c). However, only the site furthest offshore (T-3) yielded sample material, the other two sites producing only fresh leaves from land plants. The lake water at each of the sites was very muddy and exhibited a yellowish brown colour, the transparency being about 30 cm with pH values of 7.7 and 7.5.

The upper 1 cm of the collected sample consists of brown coloured (5YR4/4) mud. On the other hand, the lower three centimetres approximately are dark greenish grey (5G4/1) sandy mud which oxidised rapidly on exposure to the air becoming light-brown (5YR5/4) after a few days (Fig. 4). The mud contents in the upper brown mud and the lower greenish grey sandy mud were 98% and 84% respectively, which is rather high, and there was no great difference in the composition of the upper and lower deposits (Table 1).

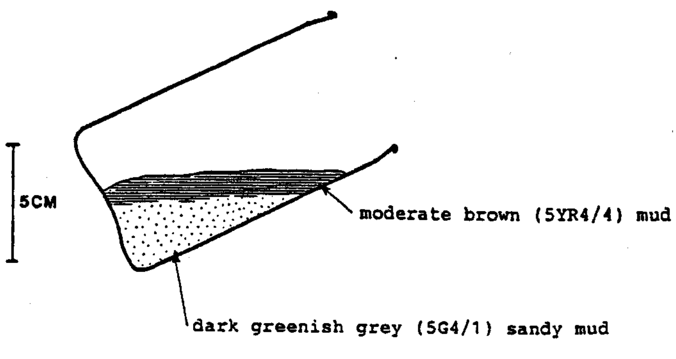

Fig. 4 Sampling results

Station	Sample Weight (dry: g)	Mud Content (%)	Water Depth (m)	Composition										Remarks
				Minerals					Biogenic materials					
				QTZ	PLG	LAT	OPQ	CLY	PLT	IST	OST	DIM	POL	
T-1	-	-	3.0	-	-	-	-	-	A	-	-	-	-	fresh land plants
T-2	-	-	3.0	-	-	-	-	-	A	-	-	-	-	fresh land plants
T-3 (upper)	1.8	98	3.5	A	-	-	-	A	R	-	R	C	R	moderate brown mud
T-3 (lower)	8.1	84	3.5	A	-	R	C	A	C	R	R	C	C	dark greenish grey sandy mud
S-1	57.2	55	0.5	A	R	R	C	A	C	-	-	-	-	light brown sandy mud

(QTZ: quartz, PLG: feldspar, LAT: laterite, OPQ: opaque minerals, CLY: clay minerals, PLT: plant remains, IST: insect fragments, OST: ostracoda, DTM: diatom, POL: pollen; A: abundant, C: common, R: rare, -: absent)

Table 1 Mud content, mineral composition and composition of biological remnants in Siem Reap River and Tonle Sap Lake deposits

Yellowish brown coloured clay minerals predominate in both upper and lower layers of the muddy sediments and, in addition to small amounts of quartz, the biogenic materials include fresh water diatoms (Table 2, Plate, e-g), pollen and fresh water sponge spicules (Plate, d). Among the three diatom species recognised, Aulacosira granulata and Suriella splendida are both fresh water species, the former being typical of species having a floating habit whereas the latter are bottom dwelling species. On the other hand, most of the Actinocyclus cf. normanii or Thalassiosira sp. are typical floating marine types but the ones which have been detected on this occasion are thought to be floating types which live in fresh water (T. Maruyama, pers. comm.).

Nearly all sandy sediments are well sorted very fine-grained sand, predominantly irregular shaped quartz with a little magnetite. Biogenic sediments include comparatively abundant black and brown coloured plant debris and insect fragments as well as complete specimens of ostracoda and a fossil planktonic foraminifera. The ostracoda which were detected are fresh water types with chitinous tests and although damage to the tests makes species identification impossible, since the flexibility of the tests can be recognized it is highly probable that they are recent species.(K. Iwazaki, pers. comm.). On the other hand, since the calcareous tests of planktonic foraminifera have been distorted by sealed pressure, it is possible that they are reworked fossils (S. Hasegawa, pers. comm.).

2. Siem Reap River

The Siem Reap River samples were collected at a place in the city where the water was 50 cm deep (Fig. 2, Plate, h). The flow velocity at the time of collection was about 1 m/sec. and the water, which was carrying abundant light-brown mud, had a temperature of 28^{o}C and pH 6.2. The river bottom sediments which were collected were light brown coloured (5YR5/6) sandy mud in which numerous slender roots of aquatic plants could be seen. The mud content in the samples is 55%. The mud consists mainly of yellowish brown clay minerals with a little quartz. The sand is well sorted very fine to fine-grained sand, predominantly irregularly shaped quartz, usually accompanied by rounded or elliptical laterite fragments and magnetite. Biogenic sediments are composed of a small quantity of plant remnants and insect fragments (Table 1).

V Discussion

1. Provenance of Sediments

In the upper reaches of the Siem Reap River there are small isolated mountains such as Phnom Bok, Phnom Dei, Phnom Kuhlen, etc. consisting of sandstones and conglomerates of the Indochinia Formation (Permian - Palaeogene) (US Geological Survey, 1971; Workman, 1975). Sandstone produced from this area was used as the principal building material for monuments at Angkor (Ishizawa, 1989). From the results of studying the sandstone blocks at these monuments, the rock bodies near the source of the Siem Reap River are assumed to contain metamorphic minerals such as mica, etc. (Tsukawaki and Moriai, 1993a). Considering the particularly active erosion by the streams in the source region, such metamorphic minerals should be present in the deposits in Tonle Sap and Siem Reap River. However, in each case the samples contained abundant quartz but no metamorphic minerals could be recognized. From the colour and shape of the clay minerals contained in the Tonle Sap lake deposits, they are probably kaolin and, combined with the coarse fraction in which quartz predominates, they are the same as the alluvium which forms the base of the Angkor monuments (Tsukawaki and Moriai, 1993b). The Siem Reap River deposits also have much the same composition, showing that the lake bottom sediments in Tonle Sap offshore from Chongkneas village are composed of alluvium distributed in the middle and lower reaches of the Siem Reap River which is eroded mainly in the wet season and transported to the lake where it is deposited. In other words, in Cambodia, which is an uplifted peneplain, if there is erosion it is slight and it seems that almost all of the detritus supplied to the northern part of Tonle Sap is derived from the alluvium surrounding the lake. However, whereas quartz predominates in the alluvium around the Angkor monuments, which comprise 70-90% quartz and 20% kaolin (Tsukawaki and Moriai, 1993b), in Tonle Sap and Siem Reap River sediments, as shown by the mud content, there is an extremely content of kaolin which forms the muddy sediments. Compared with the kaolin, the comparatively large grained quartz is more difficult to transport but the flow rate in the Siem Reap River in the wet season is adequate for the transportation of sandy sendiments. The reason for this sort of difference is thought to lie not only in the fact that the work of erosion by the river is simply the mechanical erosion of the river bed and river banks but that the kaolin is selectively washed out from the ground by the eluviation of ground water.

2. Annual Changes Recorded in Lake Bottom Deposits

In the approximately 4 cm thick Tonle Sap Lake deposits collected on this occasion, it was confirmed that there is a lower dark greenish grey coloured sandy mud covered by about 1 cm of light brown coloured mud. The lake water at the time of collection in the rainy season was thick with abundant yellowish brown mud particles and, since the upper light brown mud had hardly any sand detritus, it is clear that it is this muddy layer which has settled to the bottom of the lake. On the other hand, the lower dark greenish grey sandy mud containing comparatively abundant plant fragments, its colour indicating that the deposit has been in a reducing environment for a certain period of time, is possibly material deposited during the dry season when the rate of deposition is low. From these observations it is concluded that deposits whose characteristics are different in the dry season and the wet season, form layers several centimetres thick on the bottom of Tonle Sap.

3. Micro-organisms

(1) Ostracoda, diatoms, pollen

In the Tonle Sap Lake samples, detritus of biological origin which can serve as environmental indicators include ostracoda, diatoms and pollen. Ostracoda are arthropod, with body length ranging from 0.5-4 mm, which live in all waters and some land areas, their habitats differing as to water quality, bottom material and water depth to suit the various species. The calcareous or chitinous carapace which encloses the soft body parts is preserved in the deposits after death and the fresh water species often reflects the environment at the time it was living, in particular the water depth and bottom materials (Ishizaki, 1976). Diatoms are single cell plants which live in all waters, reacting sensitively to salinity, pH, temperature, mineral salt type, etc. The diatom's protoplasm is enclosed within siliceous test so that the test is often preserved in the deposits after death. Apart from the influence of water temperature and pH, fresh water diatoms in particular are strongly controlled by currents and scarcity or abundance of nourishment and the quality of the water at the time of life can be determined from the distribution of species (Koizumi, 1976). On the other hand, physically and chemically, pollen is made of extremely tough material so that there are many opportunities for preservation in deposits and the plant life at the time deposits were formed can be inferred by examining the conformation of the pollen contained in the deposits (Soma, 1976).

In this study, extant ostracods, diatoms and pollen were detected in the lake bottom sediments from Tonle Sap. The ostracods and diatoms reflect the environment of the water and bottom material. Since they were not detected in the Siem Reap River deposits, it is practically clear that they were lake dwellers. Also, the plant life of the lake environs can be taken indirectly from the pollen. The existence of these micro-organism remains is confirmed from the present lake bottom sediments, in particular the detection of three species of diatoms including bottom dwellers and floating species can be said to have provided a handle to understanding the historical environment and climatic variations of the lake and the region surrounding the lake.

(2) Sponge spicules, planktonic foraminifer

Sponge spicules are usually present in the Tonle Sap Lake samples. Sponge spicules are bone fragments of the siliceous or calcareous skeletons of sponges, often contained in marine deposits such as reefs and banks (Iwabuchi, 1977). They are extremely rare in fresh water (T. Maruyama, pers. comm.). However, this discovery shows clearly that sponges are living in Tonle Sap, which is a fresh water lake. Apart from sponges, it is known that there are various marine fish species living in Tonle Sap (Lao, 1991). The presence of such marine creatures suggests that there was a period in the past (probably in the interglacial epochs) when Tonle Sap was closely connected with the sea. Also, with extended research in the future, it is feasible that fresh water sponges can be used in the same way as other micro-organisms as indicators of environmental changes.

One specimen of a planktonic foraminifer fossil was detected in a Tonle Sap Lake sample. Foraminifera are marine dwelling, single cell animals with calcareous tests. Since the planktonic species having evolved rapidly, they are used as important index fossils for separating geological ages (Takayanagi, 1976). It is clear from the traces of transformation due to diagenesis remaining on the test that the specimen detected on this occasion is not one which is living in the lake at present but is a fossil which has been washed out of the upper Indochinia Formation at the upper reaches of the Siem Reap River and transported to the lake. However, this discovery is evidence of the presence in Cambodia of rocks containing planktonic foraminifera and, considering the geological effectiveness of planktonic foraminifera, we can expect that this will be a great help to future geological surveys and prospecting in Cambodia.

VI Subjects for the Future

1. Tonle Sap deposits contain an abundance of clay minerals compared with Alluvium around the lake which suggests that fine grained material is being eluviated of the ground in the Siem Reap River by ground water. This eluviation is one cause of deterioration of the strength of the ground and, although it explains ground subsidence at the Angkor monuments, it is a serious problem. In future, the water

system in the vicinity of the Angkor monuments, in particular the water and sediments of the Siem Reap River, should be studied systematically and periodically to gain a quantitative understanding of the extent of the removal of fines by eluviation.

2. It is highly probable that the deposits in the Tonle Sap Lake, which have different characteristics in the wet and dry seasons, are deposited in layers which will enable time to be read from the lake bottom deposits in annual units. It is important to confirmation that this is so, not only to debate climate transitions and environmental pollution problems but also to clarify the sedimentation rate in the lake and provide a clue to understanding the question of the lake becoming infilled, which would affect agricultural land development. This should be done by using the most convenient Phleger core sampler (Phleger, 1951) to take a column of bottom sediments about one metre in length to confirm the presence or absence of a layered structure as well as its thickness.

3. Ostracods and diatoms which reflect the nature of the lake bottom and its water are contained in the Tonle Sap Lake sediments and they can be used to understand the present state of environmental pollution. Surface sampling should be carried out over the whole of the Tonle Sap Lake and its surrounding waters to clarify the distribution of ostracods and diatoms.

4. The detection of ostracods, diatoms and pollen in material which is now being deposited in the Tonle Sap Lake shows that there is a strong probability that remnants of these are also contained in past deposits. By investigating the composition of suites of these items contained in past deposits collected by core sampling, expectations of looking back and recreate the age of environmental changes in the lake and its surrounding areas can be done. In addition, it is possible to shed light on past events such as typhoons and floods by core sampling and to clarify the relationship between the rise and fall of various civilisations in the Indochina Peninsula and palaeoclimate and sudden geological phenomena. Also, unless they have been dredged, the same investigation could be made in respect of the western Baray and eastern Baray, which are artificial lakes of the same age as the Angkor monuments.

5. The sponge spicules usually found in Tonle Sap Lake samples are extremely rare in fresh water and may be the key to unravelling the history of the lake. Biological investigative research in this regard is expected.

VII Conclusions

1. Bottom deposits in the Tonle Sap Lake and the Siem Reap River have been collected and their conformations discussed.

2. The removal of fines by eluviation from the grounds of the monuments has been demonstrated.

3. The feasibility of elucidating palaeoenvironments and palaeoclimates using ostracods, diatoms and pollen contained in the Tonle Sap Lake sediments has been discussed.

4. The existence of fresh water sponges living in Tonle Sap Lake has been indicated.

5. The existence in Cambodia of rocks containing planktonic foraminifera has been indicated.

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- e: *Aulacosira granulatae* (Ehrenberg) Simonsen
- f: *Suriella splendida* (Ehrenberg) Kutzing
- g: *Actinocyclus* cf. *normanii* or *Thalassiosira* sp.

h: Near a Siem Reap River sampling site.