Preliminary Study of Sedimentation in Lake Tonle Sap, Cambodia

Shinji TSUKAWAKI, Masafumi OKAWARA, Kim-Leang LAO
and Motohiko TADA

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口絵 1：カンボジアのトンレサップ湖
Lake Tonle Sap, Cambodia

図 1 トンレサップ湖の位置

インドシナ半島最大の湖であるトンレサップ湖（太湖）はカンボジアのほぼ中央に位置する．雨季には増水したメコン河の水がトンレサップ川を通じて湖に流入し，湖の冠水面積は乾季の約3倍（約1万km^2：理科年表）となる．水深は高水位時の最深部でも15m に満たない（同）．有名なアンコール・ワットなどのアンコール遺跡群は湖北部のシェムリアップ周辺に分布する．

写真 1 空から見たトンレサップ湖北部

シェムリアップ（Siemreap）上空より南方にトンレサップ湖北部を見る．雨季の増水で湖畔が浸水しつつある．トンレサップ湖はカンボジア穀倉地帯の中心であるとともに豊富な水産資源を擁し，クメール時代から現在にいたるまでカンボジア国民の文化・生活に密着した存在である．中央に見える丘はシェムリアップの南10km に位置する標高137m のプノム・クロム（Phnom Krom）で流紋岩からなる．山頂にはクメール時代の建造物が残されている．
1991年8月27日撮影．

写真 2 空から見た浸水林（トンレサップ湖中央部北岸）

雨季になるとトンレサップ湖周辺に繁茂する植物群は浸水する．このような浸水林は魚類の産卵場所ならびに稚魚の成育場所として豊富な水産資源を育むもととなる．
1992年8月15日撮影．

写真 3　トンレサップ湖の浸水林（トンレサップ湖北部）

浸水したトンレサップ湖湖畔の植物群．画面左に浮かぶ竹籠は養魚場．雨季の湖水は多量の泥質浮遊物のため茶褐色を呈し，透明度は数10cm以下となる．湖底堆積物の含泥率は90%以上に達し，生物遺骸として珪藻・介形虫・海綿骨針などが含まれる．1992年8月21日撮影．

写真 4　シェムリアップの市場

トンレサップ湖からは200種以上の魚類が報告され，その多くが有用魚類として貴重な水産資源となっている．この湖にはエイやフグなどの海棲魚類の生息が知られ，湖底堆積物に海綿骨針が普通に含まれることもあって，この湖が過去に外洋と密接に結び付いていた可能性が示される．1991年8月21日撮影．

写真 5　雨季の増水で沈水する小河川（プノンペンの西方約20km）

雨季に増水した川水は河道から溢れ出し河川自体も沈水する．画面上部で直線的に流れるのがトンレサップ川，その遠方で緩やかに蛇行するのがメコン河．トンレサップ川はプノンペン東方でメコン河と合流する．1992年8月9日撮影．

（塚脇真二，ラオ・キム・リァン）
(Shinji TSUKAWAKI and Kim-Leang LAO)

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Shinji TSUKAWAKI *, Masafumi OKAWARA **, Kim-Leang LAO ***
and Motohiko TADA **

Abstract

Lake Tonle Sap, the largest lake in the Indochina Peninsula, lies in central Cambodia. Unique sedimentation is expected in the lake due to drastic changes in its water area between the rainy and dry seasons. As the first step to examine the sedimentary processes of the lake, bottom sediments of the lake and the Tonle Sap River, and surface soils of alluvial deposits were collected and examined in order to reveal the origin of the lake bottom sediments.

As the results it becomes clear that clay minerals in the bottom sediments of the northern part of Lake Tonle Sap are derived both from surface soils on the alluvial deposits around the lake, and metamorphic and granitic rock bodies lying in the Mekong River basin. The latter is transported, as suspended sediments by backward current in the rainy season, into the lake from the Tonle Sap River.

The presence of marine creatures in bottom sediments of the lake suggests that the lake was closely connected with the sea during the last sea-level high stand. Furthermore, there is a strong possibility that annual changes due to alternating rainy and dry seasons will be recorded in the lake bottom sediments over the long geological period.

I. Introduction

Lake Tonle Sap, the largest lake in the Indochina Peninsula, lies in central Cambodia. The lake is known as "the elastic water world", because its water area expands drastically in rainy seasons. It is also known as "the mud ocean" which refers to deep brown colour of the water all year round due to a large amount of muddy suspended sediments contained in water. Such settings hold out a promising prospect for investigations of unique sedimentary processes in the lake under the control of seasonal fluctuations in water level due to alternating rainy and dry seasons, characteristics of the tropical monsoon region. In addition, the lake has been closely associated with the lives and culture of the Cambodian people since the Khmer Dynastic periods. Consequently, it is expected that climatic and environmental changes, and their relationships with the rise and fall of various civilization in the Indochina Peninsula can be reconstructed over the period based on analysis of the lake bottom sediments.

Bathymetry, water quality and aquatic re-

* Department of Geology, College of Liberal Arts, Kanazawa University
** Department of Civil and Environmental Engineering, Faculty of Engineering, Iwate University
*** Environmental Center, Japan Quality Assurance Organization

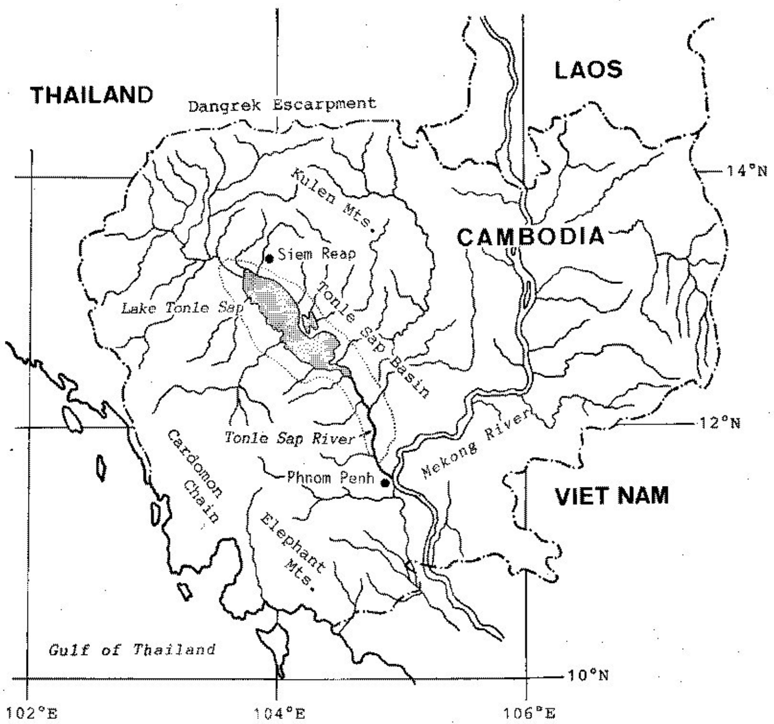


Fig. 1 Lake Tonle Sap and topographic features of Cambodia
Dotted line around the lake indicates flooded areas in the rainy season.

sources of Lake Tonle Sap have been reported (Mitusio *et al.*, 1970; Kottelat, 1985; Lao, 1992, 1993; Matsui *et al.*, 1993). However, no geological and sedimentological investigations have been carried out in the lake, except for brief descriptions of bottom sediments of the lake and adjacent rivers (Tsukawaki and Moriai, 1993 b; Tsukawaki and Lao, 1994). As the Cambodian political unrest has persisted since the 1970's, only a limited survey can be carried out. Therefore, as the first step in a series on pursuing the above-mentioned subjects, the present paper illustrates preliminarily the sedimentary processes of the lake based mainly on the sedimentological and biological properties of bottom sediments in the northern part of the lake and the Tonle Sap River which connects the lake to the Mekong River, one of the largest rivers on the Asian continent, and the surface soils of alluvial deposits in the northern part of the Tonle Sap Basin which seem to be one of the important sources of bottom sediments of the lake.

II. Lake Tonle Sap and Natural Environments of Cambodia

Figure 1 shows topographic features of Cambodia. Lake Tonle Sap lies in the central part of the Tonle Sap Basin, a gentle topographic depression with a NW-SE trend, in central Cambodia. The Cardomon Chain and the Elephant Mountains with the highest peak of 1,744 m above sea level, and the Dangrek Escarpment, 765 m above sea level, all composed mainly of sedimentary rocks of the Upper Indosinias Formation ranging in age from Cretaceous to Palaeocene (Gubler, 1933; Saurin, 1935; United State Geological Survey, 1971; Workman, 1979) form the western, southern and northern boundaries of the basin, respectively. The overwhelming part of the basin is covered mainly with alluvial deposits composed of unconsolidated silt, sand, gravel, laterite (United State Geological Survey, 1971) and a variety of soil types such as acidic lithosoil and lateritic clay which are typical soil types in a humid tropical region (Bridges, 1978; Garami and Kertai, 1993). The thickness of the alluvial deposit reaches more than a few hundred metres at the Mekong Delta in Viet Nam, whereas up to 15 m at Phnom Penh City (Workman, 1979). Several topographic highs such as the Kulen Mountains, Phnom Bakheng, Phnom Bok, Phnom Dei and Phnom Krom are scattered in the northern part of the basin (Pl.-1, 2).

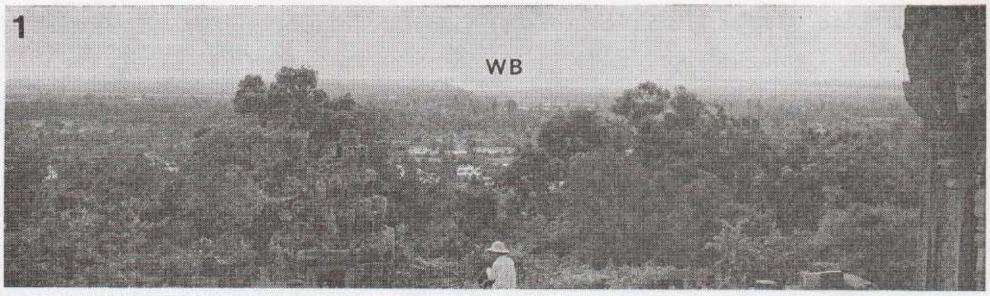
The climate of Cambodia is controlled mainly by the tropical monsoon system influenced by such local topographic highs as the Cardomon Chain and the Dangrek Escarpment. Therefore the dry season (November to May) is clearly distinguished from the rainy season (May to November) with a brief semidry season in July, year in, year out (Fig. 2).

Lake Tonle Sap is long, narrow and gourd-shaped, having a NW-SE longitudinal axis of 120 km and a maximum width of 40 km in the dry season. The water area of about 3,000 km^2 in the dry season swells more than threefold (about 10,000 km^2) in the rainy season (National Astronomical Observatory, 1993), thus the lake lacks fixed coastal lines. At low water level the depth is small wholly (3 to 6 m) (Mitusio *et al.*, 1970) and at high water level the deepest parts are no more than 14 m (National Astronomical Observatory, 1993). Forests in the coastal areas of the lake are inundated during high stands of water level as well as paddy fields (Pl.-3, 4).

There is a network of numerous rivers and streams flowing directly into the lake from its surroundings, but their flow is adequate only in the rainy season, except for a certain number of rivers, such as the Siem Reap River originating in the Kulen Mountains which are a salient topographic high in the northern part of the Tonle Sap Basin. Small rivers and streams around the lake partly flood in the rainy season. Many muddy deltas form in the vicinity of river mouths in the coastal area of the lake in the rainy season (Pl.-5).

Again in the rainy season, the flow of water which contains a large amount of muddy suspended sediment derived from surface soils distributed in the Tonle Sap Basin through this group of rivers joins water of the Mekong River, originating in and bringing much melted snow from the northern slopes of the Himalayas in the western part of China together with the heavy monsoon rain. Therefore, water of the Tonle Sap River flows backwards to the lake in the rainy season, and water level of the river increases more than 8 m in comparison with it in the dry season in Phnom Penh City (Pl.-7, 8). On the other hand, in the dry season, the inflow from the rivers decreases markedly and water flows out from the southeastern part of the lake through the Tonle Sap River to the Mekong River.

The lake water is reddish brown to yellowish brown, and extremely low in transparency (50-100 cm) even in the dry season (Mitusio *et al.*, 1970). The temperature of surface water is extremely high (26-30 °C) all year round and the pH is almost neutral (around 7.0) (Mitusio *et al.*, 1970; Lao, 1992, 1993). Two hundred and fifteen species of fishes which come under 127 genera and 47 families including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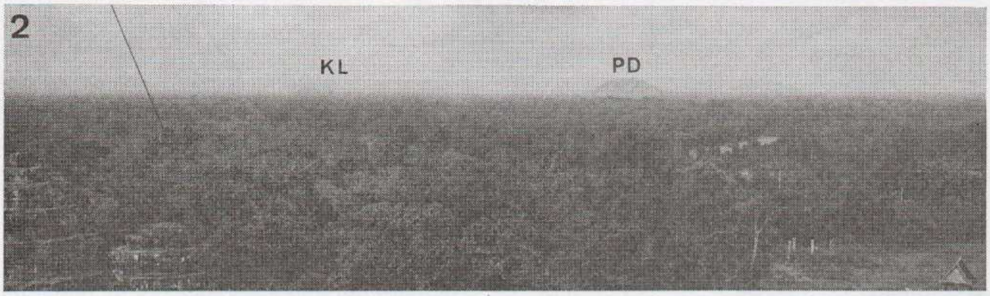
WB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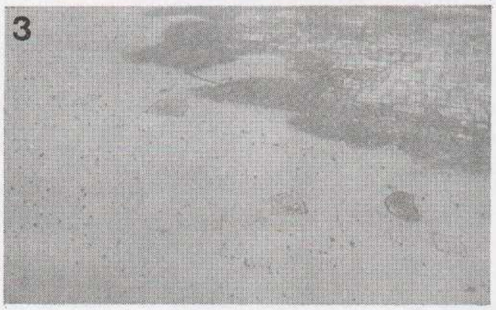
KL
PD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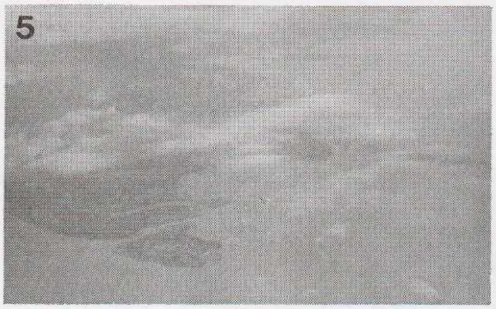
4
TSR
MR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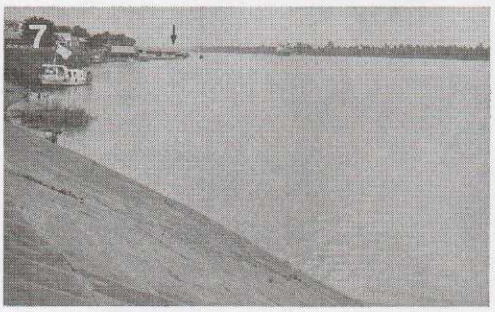
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balloonfishes and rays which are generally marine forms are recognized in the lake, the Mekong River and adjacent rivers in Cambodia (Kottelat, 1985).

III. Sampling Method and Analytical Procedures

The samples used for the present study were collected in August 1992 at the northern part of Lake Tonle Sap and north of Bayon which is the central sanctuary of Angkor Thom, and March 1993 at the Tonle Sap River in Phnom Penh City. Sampling devices were a cylindrical aluminium can, 6 cm in diameter and 12 cm long, with an 1 kg steel weight at the lake, and a Seki-type grab sampler, 500 ml in volume, at the Tonle Sap River. Surface soil samples at Bayon were collected by a 6.5 m long hand auger. Hydrogen ion exponent of the samples was measured made with a Horiba type D-13 pH meter on about one gramme of moist samples dispersed in 5 ml of pure water immediately after collected.

A smear slide was prepared and examined under the microscope for muddy sediments. For sandy sediments, the entire sample was heated over 24 hours at about 60 °C, and its dry weight was measured. Then it was washed repeatedly to remove mud, and dried and weighed again to obtain proportional mud content. The remaining coarse material was made into a thin section and examined under the microscope. Since the contents of micro-organic remains in the samples are insufficient for statistical analysis, the results is short of a preliminary grasp.

For clay mineralogy, samples were first disaggregated in distilled water, followed by ultrasonic procedures for four hours, then clay fractions were concentrated by a centrifuge. Almost pure clay fractions almost free from impurities were dried at room temperature, and prepared for X-ray analysis. X-ray analysis was carried out on oriented powder smeared on a glass slide. X-ray diffraction patterns for each of the samples were recorded with a Mac Science type MXP-3 AHF X-ray powder diffractometer equipped with a graphite monochromator, using Cu-Kα radiation, tube voltage 40 kV, tube current 20 mA, silt system of 0.5 °-0.3 mm and scanning speed of 2 °/min. X-ray analysis was performed for untreated specimens and treated specimens such as ethylene glycol-solvated, glycerol-solvated, HCl-treated, K-saturated, Mg-saturated, and one hour heating treated at 300 °C and 600 °C specimens, respectively.

IV. General Features of Samples and Sampling Sites

General features of the bottom sediments from Lake Tonle Sap, the Tonle Sap River and

Plate 1. A view of the northern part of the alluvium plain in the Tonle Sap Basin looking west from the summit of Phnom Bakheng in August 1992 (WB: West Baray). 2. A view of the northern part of the alluvium plain in the Tonle Sap Basin looking north east from the summit of Phnom Bakheng in August 1992 (KL: Kulen Mountains, PD: Phnom Dei). 3. An aerial view of flooded forests in the southeastern coastal area of Lake Tonle Sap in August 1992. Dark spots in the lake are flooded trees. 4. An aerial view of flooded paddy fields south of the Tonle Sap River (TSR) in the rainy season, about 30 km northwest of Phnom Penh City in August 1992 (MR: Mekong River). 5. An aerial view of developing muddy deltas in the rainy season on the western coastal area of Lake Tonle Sap in August 1992. 6. The auger drilling site north of Bayon, Angkor Thom in Siem Reap Province in August 1992. 7. Tonle Sap River in Penh City in the rainy season (August 1992, arrow indicates Chroy Chanvar Bridge). 8. Tonle Sap River in Phnom Penh City in the dry season (March 1993, arrow indicates Chroy Chanvar Bridge).

surface soils in the Tonle Sap Basin based on Tsukawaki and Moriai (1993 b), Tsukawaki and Lao (1994) and Tsukawaki and Moriai (1993 a), respectively, are as follows.

1) Lake Tonle Sap

Bottom sediments were collected in Lake Tonle Sap at three sites (LTS-1, 2 and 3) off to the south of the village of Chongkneas which is located about 13 km south of Siem Reap City alongside the Siem Reap River leading to the lake (Fig. 3). Depths at these sites are about 3 m. Only the farthest site (LTS-3) yielded bottom sediments; the other two sites produced only fresh leaves of land plants which are probably flooded forests existing under the water. The lake water at each of the sites was very muddy and yellowish brown, being about 30 cm in transparency, with pH values of 7.5-7.7.

The bottom sediments at site LTS-3 are composed of the top 1 cm moderate brown mud and lower 2 cm thick dark greenish grey sandy mud. The lower sandy mud is oxidized by exposure to the air, becoming light brown in colour in a few days. The mud contents of the upper and the lower layers are 98 and 84 %, respectively. There is no great difference in sediment composition between the upper and lower layers. Under the microscope, yellowish

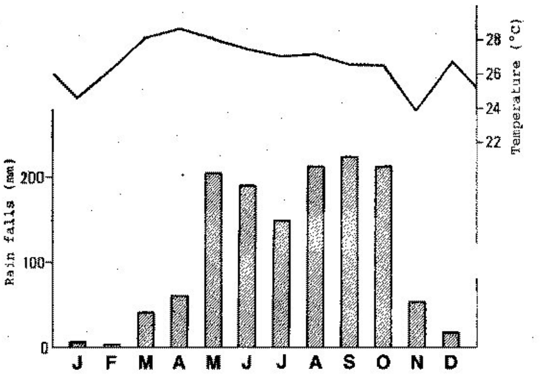

Fig. 2 Average monthly mean temperatures and rain falls during the past 10 years in Siem Reap City in the west of Cambodia (drawn from Garami and Kertai, 1993)

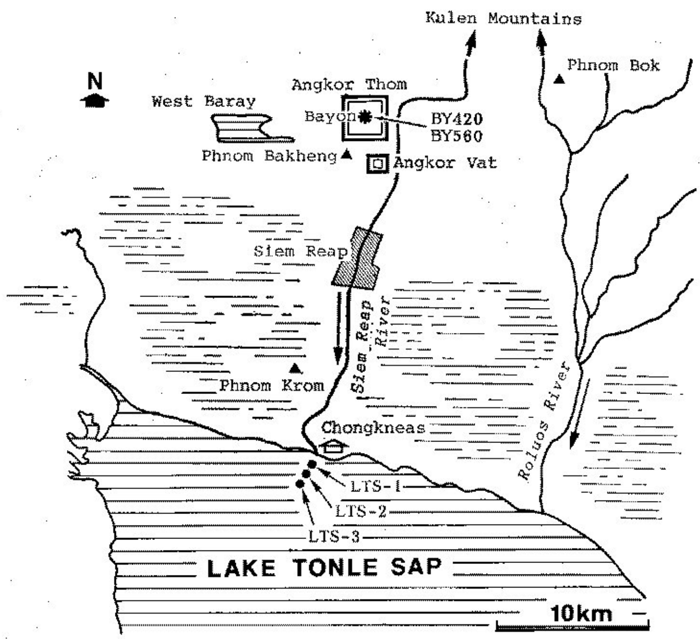

Fig. 3 Sediment sampling sites in the northern part of Lake Tonle Sap off the village of Chongkneas and the surface soil sampling site at Bayon of Angkor Thom

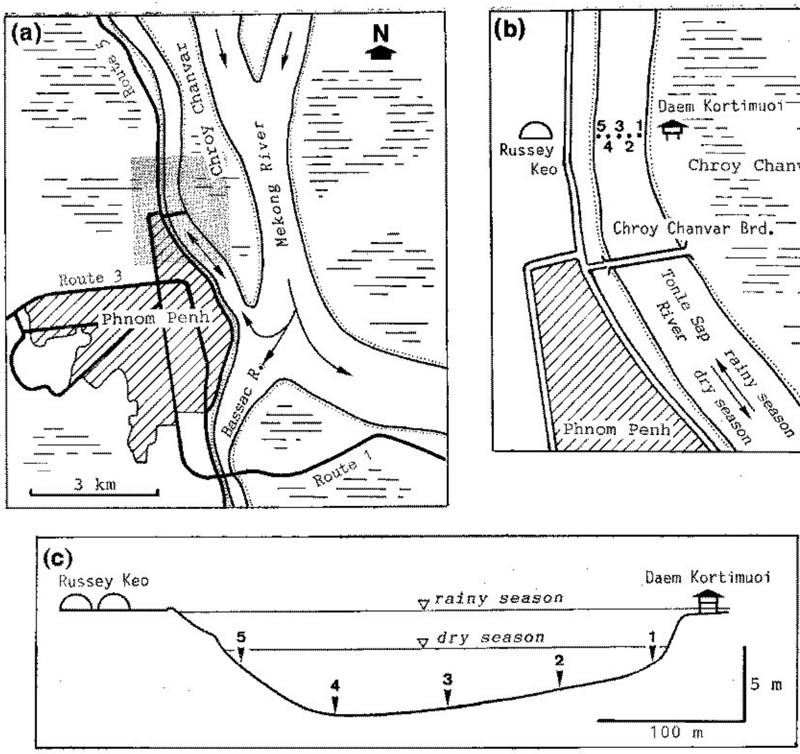

Fig. 4 (a) General features of the junction of the Mekong, Tonle Sap and Bassac Rivers on the east of Phnom Penh City, (b) sediment sampling sites in the Tonle Sap River, and (c) a bottom profile of the Tonle Sap River along the sampling sites

brown clays predominate muddy sediments of both layers, in addition to small amounts of quartz and biogenic materials including diatoms, pollen and sponge spicules. Sandy sediments consist mainly of poorly sorted fine-grained sands, predominantly irregular-shaped quartz and lateritic rock fragments. Biogenic materials include comparatively abundant dark brown plant debris and pale brown insect fragments as well as an incomplete specimen of ostracoda and a fossil planktonic foraminifer.

2) **Tonle Sap River**

Bottom samples were taken in the Tonle Sap River at five sites (TSR-1, 2, 3, 4 and 5), about 700 m above the Chroy Chanvar Bridge (Japan Bridge) between the village of Daem Kortimuoi and Russey Keo Oil Preserver in Phnom Penh City (Fig. 4(a) and 4(b)). The river flows together with the Mekong River about 4 km below the sampling sites. The width of the Tonle Sap River at the sampling sites is about 300 m and water depths are up to 5.8 m (Fig. 4(c)). Around the sampling sites, the east bank of the river shows natural topography, but the west bank has artificially been embanked. The water at each of the sites was pale greenish grey, being about 2 m in transparency, with pH values of 6.7–7.0. No distinct internal structures were observed in these samples.

The sediments at all sites, about 4 cm thick, are moderately brown mud or sandy mud. The mud contents of these samples are high in the range of 71–99 %. Moderately brown clays predominate muddy sediments, in addition to small amounts of quartz and biogenic materials such as diatoms, pollen and sponge spicules. Nearly all sandy sediments are very well sorted fine-grained sand, predominantly irregular-shaped quartz, feldspar, muscovite and biotite, with a small amount of magnetite and lithic fragments. Biogenic materials include comparatively abundant black and brown plant debris and insect fragments. A complete carapace of the ostracode *Candonocypris*? sp. was detected from sample TSR-5.

3) Surface sois of Bayon, Angkor Thom

Surface soil samples of the alluvial deposits in the Tonle Sap Basin were taken at an auger hole about 30 m north of Bayon of Angkor Thom in Siem Reap Province (Fig. 3 ; Pl.-6). Angkor Thom, constructed in the beginning of the 13 th century (Khmer Dynastic times), is one of the largest Angkor monuments. The Siem Reap River which flows southward into Lake Tonle Sap along the embankment of the eastern moat of Angkor Thom, and a network of numerous watercourses connects the moat with the river and ancient water reservoirs such as West Baray and moats of Angkor Vat (*e. g.* Lao, 1992). Tsukawaki and Moriai (1993 b) mentioned that surface soils, particularly clay fractions, are washed out by surface and ground waters due to heavy rainfall in the rainy season and driven into the Siem Reap River.

Auger drilling proceeded to a depth of 620 cm, above the ground water level at that time. The soil at the drilling site is composed of yellowish grey clay, silty clay, sandy clay and clayey sand with thin intercalations of reddish brown clay (Fig. 5) which indicates a probable surface of temporarily static ground water (Tsukawaki and Moriai, 1993 b). Samples for the present study were taken from the yellowish grey sandy clay layer at a depth of 420 cm (BY 420) and the reddish brown clay layer at a depth of 560 cm (BY 560).

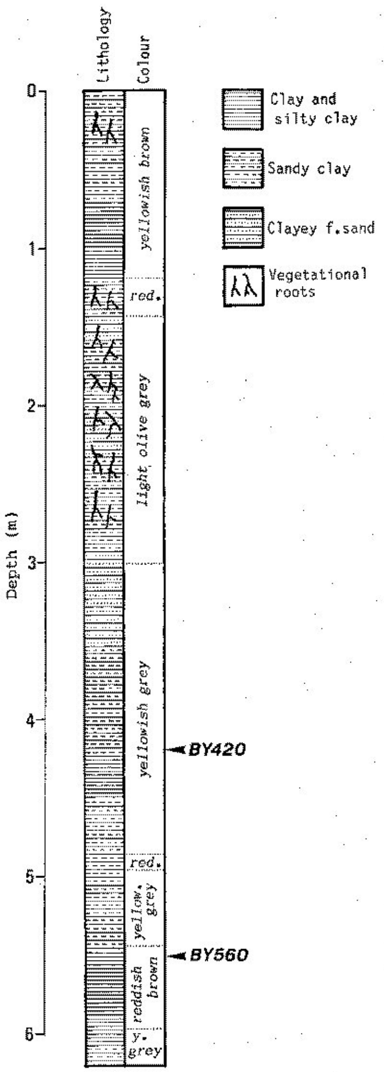

Fig. 5 A soil columnar section at the auger hole north of Bayon of Angkor Thom on the Siem Reap River in the Tonle Sap Basin
The location of Bayon is indicated in Fig. 3. Arrows indicate sampling horizons of BY 420 and BY 560 (simplified from Tsukawaki and Moriai, 1993 b).

The mud contents and pH values of the samples BY 420 and BY 560 are 91 % and 98 %, and 5.6 and 5.5, respectively. Pale brown clays predominate both samples, in addition to small amounts of quartz. Sandy sediments consist mainly of fine-grained quartz and lateritic rock fragments. No biogenic materials are recognized in the samples except for fine vegetational roots.

V. Clay Mineralogy

1) Lake Tonle Sap

Figure 6 shows X-ray diffraction patterns for untreated and treated specimens of the lower greenish grey layer of sample LTS-3 from the northern part of Lake Tonle Sap. The untreated specimen has a broad reflexion peak around 14.3 Å and sharp peaks at 10.0, 7.1, 4.25 and 3.35 Å. The sharp peaks at 4.25 and 3.35 Å are attributed to impure quartz. Broad peak shifts to about 17 Å by ethylene glycol-solvation and also by glycerol-solvation of Mg-saturated specimen indicates that the broad peak is attributed to montmorillonite. However, a small peak at about 14 Å observed in untreated, ethylene-solvated and glycerol-solvated specimens suggests the presence of a small amount of chlorite. The sharp peak at 10.0 Å and its high order reflexion do not change by glycolations and 300 °C heating, indicating that the peak at 10.0 Å is attributed to illite. The basal peak at 7.1 Å which is not affected by HCl-treatment is attributed to kaolin.

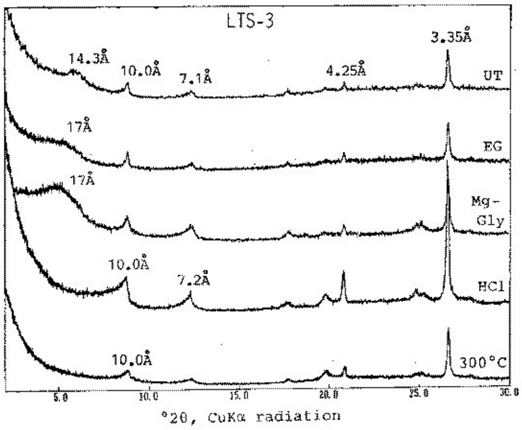

Fig. 6 X-ray diffraction patterns for oriented aggregates of sample LTS-3 from the northern part of Lake Tonle Sap
UT: untreated sample, EG: ethylene glycol-solvated sample, Mg-Gly: glycerol-solvated sample after Mg-saturation, HCl: HCl-saturated sample, 300 °C: thermally treated sample at 300 °C for 1 hr.

2) Tonle Sap River

Figure 7 shows X-ray diffraction patterns for untreated and treated specimens of 2 cm thick surface sediments of sample TSR-2 from the Tonle Sap River in Phnom Penh City. The untreated specimen has reflexion peaks at 14.4, 10.1, 7.2 and 3.34 Å. The peak at 3.34 Å is attributed to impure quartz. After ethylene glycol-solvation, the peak at 14.4 Å separates into weak peaks at 17 and 14 Å, thus the diffuse peaks are attributed to montmorillonite. The weak peak at about 14 Å increased its

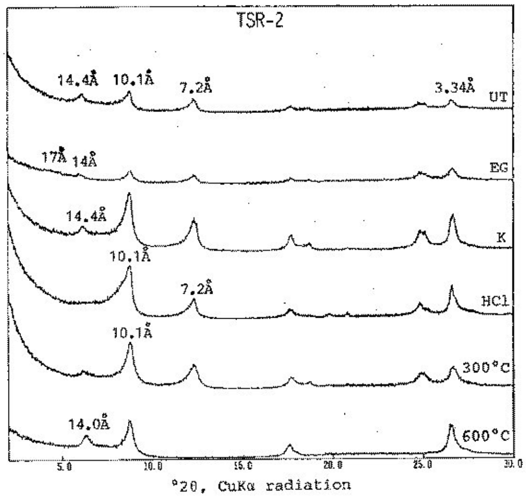

Fig. 7 X-ray diffraction patterns for oriented aggregates of sample TSR-2 from the Tonle Sap River in Phnom Penh City
UT: untreated sample, EG: ethylene glycol-solvated sample, K: K-saturated sample, HCl: HCl-saturated sample, 300°C and 600°C: thermally treated samples for 1 hr. at 300 °C and 600 °C, respectively.

intense, and its spacing is slightly contracted to 14 Å after heating at 600 °C, while higher order reflexions disappeared. In addition, the peak at 14.4 Å does not change by K-saturation, indicating that the peak is attributed to chlorite. The basal peak at 7.2 Å is not affected by HCl-treatment although the intensity weakened slightly. Therefore, the basal reflexion peak at 7.2 Å is attributed to chlorite overlapping with kaolin. The 10.1 Å reflexion peak does not change by HCl-treatment and 300 °C heating, indicating that the reflexion peak is attributed to illite.

3) Surface soils of the Tonle Sap Basin

Figures 8 and 9 show X-ray diffraction patterns for untreated and treated specimens of samples BY 420 and BY 560, from surface soils at Bayon, Angkor Thom locating on the alluvial deposits in the Tonle Sap Basin.

The untreated specimen of BY 420 shows a broad reflexion peak from 14 to 10 Å, strong peaks at 7.2 and 3.58 Å, and weak peaks at 4.97, 4.19, 3.35, 2.39 and 2.00 Å. After ethylene glycol-solvation, the broad peak separates into 17 and 10 Å. The diffuse peak at 17 Å is attributed to montmorillonite. The reflexion peak at 10 Å does not change by glycolations, and heating at 300 °C and 600 °C, thus the 10 Å reflexion and its higher order reflexions are attributed to illite. The strong peak at 7.2 Å does not change by HCl-treatment, but collapses after heating at 600 °C, indicating that the 7.2 Å reflexion peak and its higher order reflexion are attributed to kaolin.

X-ray diffraction patterns of BY 560 are very similar to those of BY 420. The untreated specimen shows a broad peak from 10 to 14 Å, strong peaks at 7.2 and 3.58 Å, and weak peaks at 4.97, 4.18, 3.35, 2.38 and 2.00 Å.

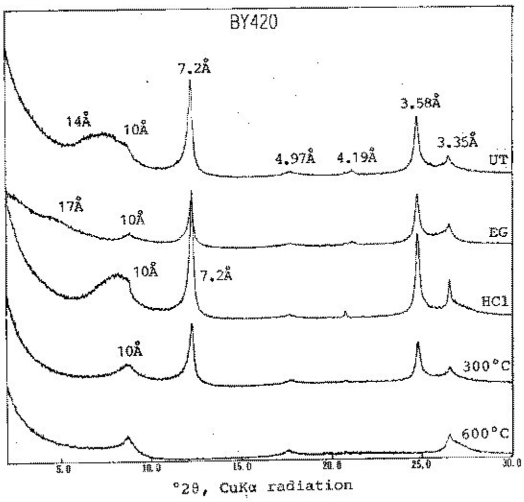

Fig. 8 X-ray diffraction patterns for oriented aggregates of sample BY 420 from surface soil at Bayon
UT : untreated sample, EG : ethylene glycol-solvated sample, HCl : HCl-saturated sample, 300 °C and 600 °C : thermally treated samples for 1 hr. at 300 °C and 600 °C, respectively.

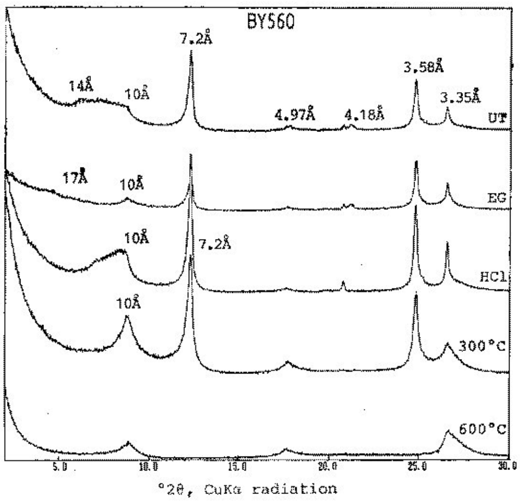

Fig. 9 X-ray diffraction patterns for oriented aggregated sample BY 560 from surface soil at Bayon
UT : untreated samples, EG : ethylene glycol-solvated samples, HCl : HCl-saturated samples, 300° C and 600° C : heated samples for 1 hr. at 300° C and 600 °C, respectively

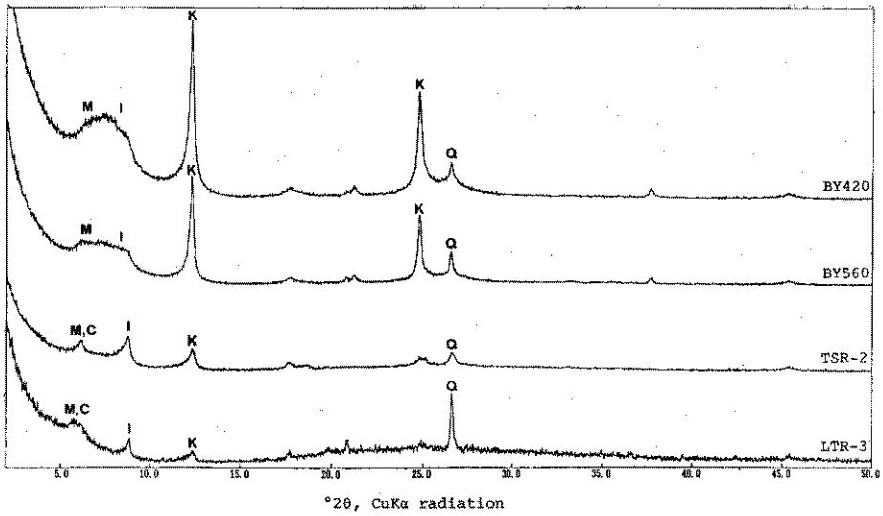

Fig. 10 X-ray diffraction patterns for oriented aggregates of untreated samples from Lake Tonle Sap (LTS-3), the Tonle Sap River (TSR-2) and surface soils at Bayon (BY 420 and BY 560)
M : montmorillonite, I : illite, K : kaolin, C : chlorite, Q : quartz

These peaks show behavior coincident with those of BY 420, following a variety of chemical treatment. Therefore, clay minerals of BY 560 consist mainly of montmorillonite, illite and kaolin.

VI. Discussion

1) Provenance of lake bottom sediments

The X-ray diffraction patterns of all the analyzed samples are summarized in Fig. 10. Illite, kaolin, montmorillonite and chlorite were determined as clay minerals in the samples. Kaolin and illite were commonly observed in every sample, and were particularly abundant in surface soil samples from the northern part of the Tonle Sap Basin. Montmorillonite was frequently detected in surface soil samples from the Tonle Sap Basin. It was also determined as minor expansive clay mineral in the samples from the Tonle Sap River and Lake Tonle Sap, and was rather abundant in the sample from the lake than the river.

Chlorite characteristically occurred only in the samples from the Tonle Sap River and Lake Tonle Sap. They generally do not ascribe chlorite to the products by natural weathering even under acid conditions in humid tropical region (Shirozu, 1969 ; Sudo, 1974 ; Nishiyama, 1985 ; Kodama, 1986). Therefore, considering sediment transport in water systems in Cambodia, it is highly probable that the chlorite detected in the lake sediments is the derivative of river sediments. Tsukawaki and Lao (1994) demonstrated that the sediments of the Tonle Sap River in Phnom Penh City are those derived mainly from Precambrian to Palaeozoic metamorphic and granitic rock bodies distributed in the Mekong River basin in Viet Nam and Laos transported through the Mekong River into the Tonle Sap River by a strong back current in the rainy season. Matsui *et al.* (1993) noted that there is no great difference in water quality among Lake Tonle Sap, the Tonle Sap River and the Mekong River, and concluded that the Mekong River water with muddy suspended material flows into Lake Tonle Sap through the Tonle Sap River in the rainy season. Consequently, the chlorite detected in the bottom sediments of the lake should be derived from metamorphic rock bodies distributed in the Mekong River basin through the river by strong back currents in the rainy season.

Taking all these factors into consideration, it becomes clear that clay minerals of the bottom sediments in the northern part of the lake are those derived both from the surface soils lying in the northern part of the Tonle Sap Basin and rock bodies distributed in the Mekong River basin through rivers such as the Siem Reap River and back currents of the Tonle Sap River during the rainy season.

On the other hand, the composition and grain size of sandy sediments of Lake Tonle Sap are widely different from those of the Tonle Sap River. Muscovite and biotite derived from rock bodies in the Mekong River basin were not detected in the sample of the lake, accordingly it is expected that the sandy sediments transported by back currents of the Tonle Sap River in the rainy season do not reach to the northern part, but to the southern part, of the lake.

2) Seasonal changes recorded in lake bottom sediments

In the approximately 3 cm thick sediments collected in the northern part of Lake Tonle Sap, it was confirmed that the lower dark greenish grey sandy mud layer is covered by an 1 cm thick moderately brown mud layer. The lake water at the time of sampling (the rainy season) was thick with muddy suspended sediments showing the same colour with the upper layer of the bottom sediments. Thus, it is clear that the upper layer consists of mud particles settled from the lake water. On the other hand, the lower sandy mud layer containing comparatively abundant plant fragments, and the colour indicative of deposits under reduced conditions for a certain period of time, suggests a possible deposit during the dry season when the sedimentation rate was markedly low. From these observations, there is a possibility that seasonal changes due to the alternating rainy and dry seasons are recorded in the modern and ancient bottom sediments of Lake Tonle Sap.

3) Marine creatures in Lake Tonle Sap

Three and eight diatom species were recognized in the sediments from Lake Tonle Sap and the Tonle Sap River, respectively (Tsukawaki and Moriai, 1993 a ; Tsukawaki and Lao, 1994). Among these diatom species are typical fresh water species, having floating or bottom dwelling habits. However, *Actinocyclus* cf. normanii or *Thalassiosira* sp. recognized in the sediments from the northern part of Lake Tonle Sap are typical floating marine forms. In addition, sponge spicules were usually present in the samples from the lake and the river. This discovery shows clearly that sponges, being rare in fresh water, do exist in the lake and the river. Apart from sponges, it is known that there are a certain number of marine fishes such as balloonfishes and rays living in the lake (Kottelat, 1985). The presence of such marine creatures suggests that there was a high stand of the global sea level which closely connected Lake Tonle Sap to the sea, and these marine creatures have been kept in the inland water since then.

VII. Conclusions and Open Subjects

1. Clay minerals in the bottom sediments of Lake Tonle Sap are derived both from the surface soils of the alluvial deposits in the Tonle Sap Basin and rock bodies in the Mekong River basin. They are those transported

into the lake through the Tonle Sap River with flooding waters in the rainy season. Since, only one sample from the lake was examined in the present study, systematic sediment sampling and examinations should be carried out over the whole lake.

2. There is a large possibility that seasonal changes due to the alternating rainy and dry seasons are recorded in the bottom sediments of Lake Tonle Sap. The presence of marine creatures such as marine diatoms, sponges and fish suggests that Lake Tonle Sap was closely connected with the sea in the past. A long core sampling should be carried out in the central part of the lake in order to develop the history of the lake.

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References

Bridges, E. M. (1978): *World Soils, 2nd ed.* Japanese translation by Nagatsuka, S. and Urushibara, K. (1990): *World Soils.* Kokon Shoin, Tokyo, 200 p.

Garami, F. and Kertai, I. (1993): *Water Management in the Angkor Area.* Angkor Foundation, Budapest, 109 p.

Gubler, J. (1933): Traits généraux de la structure du Cambodge nord-occidental. Sa position tectonique dans le bati de l'Indochine du Sud. *Bull. Soc. Géol. France 5e ser.*, **3**, 583-596 (in French).

Kodama, H. (1986): Experimental vermiculitization of mica and chlorite minerals. *Nendo Kagaku (J. Clay Sci. Soc., Japan)*, **26**, 67-77 (in Japanese with English abstract).

Kottelat, M. (1985): Fresh-water fishes of Kampuchea. A provisory annotated check-list. *Hydrobiologia*, **121**, 249-279.

Lao, K.-L. (1992): The inland water environment of the Angkor region —Preliminary survey of water quality—. *Renaissance Culturelle du Cambodge, Sophia Univ., Inst. Asian Cult.*, **6**, 109-128 (in Japanese), 200-213 (in English) and 347-362 (in Cambodian).

Lao, K.-L. (1993): Current status of water environment in the Angkor Region. *Renaissance Culturelle du Cambodge, Sophia Univ., Inst. Asian Cult.*, **8**, 128-136 (in Japanese) and 363-369 (in English).

Matsui, S., Kawaguchi, H., Doi, A. and Matsuda, T. (1993): A report on the environment and water resources of Lake Tonle Sap. *Soc. Civil Eng., Japan, Ann. Meet. Abstract*, 139-145 (in Japanese with English abstract).

Mitusio, H., Ohno, M. and Meas, S. A. (1970): Limnological study of the Mekong water system, Cambodia. *Res. Rep. Kochi Univ., Nat. Sci.*, **16**, 59-68.

National Astronomical Observatory ed. (1993): *Chronological scientific tables (Rika-nenpyo).* Maruzen, Tokyo, 1037p. (in Japanese).

Nishiyama, T. (1985): Clay minerals produced by weathering and their properties. *Nendo Kagaku (J. Clay Sci. Soc., Japan)*, **25**, 101-106 (in Japanese with English abstract).

Saurin, E. (1935): Etudes géologiques sur l'Indochine du sud-est (Sud Annam, Cambodge oriental). *Bull. Surv. Géol. Indochine*, **22**, 1-419 (in French).

Shirozu, H. (1969): Genesis and chemical composition of chlorite. *Sci. Rep., Fac. Sci., Kyushu Univ., Geol.*, **9**, 105-111 (in Japanese with English abstract).

Sudo, T. (1974): *Clay mineralogy.* Iwanami Shoten, Tokyo, 498 p. (in Japanese).

Tsukawaki, S. and Moriai, T. (1993a): The ground and ground water in the Angkor Monuments Complex —In respect of Angkor Thom and Bayon in particular—. *Renaissance Culturelle du Cambodge, Sophia Univ., Inst. Asian Cult.*, **8**, 95-114 (in Japanese) and 263-286 (in English).

Tsukawaki, S. and Moriai, T. (1993b): Preliminary study of bottom sediments of Lake Tonle Sap —Clues to understanding palaeoclimate—. *Renaissance Culturelledu Cambodge, Sophia Univ., Inst. Asian Cult.*, **8**, 115-127 (in Japanese) and 287-301 (in English).

Tsukawaki, S. and Lao, K.-L. (1994): Bottom sediments of the Tonle Sap River in Phnom Penh City, Cambodia. *Renaissance Culturelle du Cambodge, Sophia Univ., Inst. Asian Cult.*, **10**, 82–93 (in Japanese, English and Cambodian).
United State Geological Survey (1971): *Geological map of Cambodia showing location of lithologic sections, scale 1 : 1,000,000*. United State Department of the Interior, Geological Survey.
Workman, D. R. (1979): Geological structure of the Indochina Peninsula. *Reg. Conf. Geol. Mineral Res. Southeast Asia* (Jakarta). *In* Miyashiro, A. ed.: *Chikyu kagaku* **16**. (Japanese translation by Sato, T.) Iwanami Shoten, Tokyo. 385–398.
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トンレサップ湖の堆積作用に関する予察的研究

塚脇　真二*　大河原正文**　ラオ　キム　リァン***
多田　元彦**

カンボジア中部に位置するトンレサップ湖は，雨季と乾季とでその冠水面積が3倍以上にも変化し，季節的水位変動に支配された特異な堆積作用の存在が予想される。また，同湖はインドシナ半島最大の湖であり，湖底堆積物には同半島における地域的気候・環境変動が記録されている可能性がある。そこで，トンレサップ湖研究の第一段階として，湖の北部，同湖とメコン河とを連絡し雨季に同湖へと逆流するトンレサップ川，ならびに湖の周辺に分布する沖積層の堆積物組成から同湖における堆積作用の予察的検討を行なった。

その結果，粘土鉱物組成にもとづき，トンレサップ湖北部の湖底堆積物は，沖積層ならびにメコン河水系に分布する地質岩体の双方を起源とし，堆積物はおもに雨季に湖に流入することが判明した。また，同湖での存在が確認された海洋性レリックから，過去の高海水準期における同湖の南シナ海との連絡が推定された。さらに，湖底堆積物に雨季と乾季との季節変化記録の可能性が示された。

* 金沢大学教養部地学教室
** 岩手大学工学部建設環境工学科
*** (財) 日本品質保証機構環境計画センター