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Sedimentation in Erhai Lake, Yunnan Province, China*

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Abstract Erhai Lake in S.W. China is a large, shallow (<20m deep) rift lake. Sediment supply comes mainly from the mountains west of the lake that reach a relative height of 2000m. Supply from the east, a relatively low limestone country, is small. Two rivers supply sediment from north and south. Bottom deposits are predominantly silty mud: coarse material supplied from the mountains has been deposited on broad terraces, deltas, delta-fans, and nearshore in the lake. Deposition rates during the past 13000 years have been low, on the average 0.2 cm a^{-1}, which is equivalent to about 600 t a^{-1}, over the entire lake and is of the same order as the amount of suspended sediment present in February 1992. This points to storage of sediment on land during periods of relatively large supply (period of large rainfall, destruction of vegetation, or earthquakes) and it explains the continuing existence of the shallow lake. Average sediment deposition may have varied by a factor of 2 or 3 at most. Currents redistribute the sediment over the lake floor in flat beds extending over almost the entire lake. There is very little evidence of slumping or sliding. The composition of the sediment reflects the composition of the rocks and soils in the source areas with an additional biogenic component(mainly diatom opal). There is a relative abundance of trace elements, which may be the result of leaching on land, pollution and/or the fine grain of the sediment.

Key Words Erhai Lake, sedimentation

Erhai Lake, the second largest lake on the Yunnan Plateau, southwest China, is located in Dali Prefecture between 25°35′N to 25°58′N, and 100°05′E to 100°07′E(Tab.1). Erhai Lake is a typical rift lake, situated in the Dali basin, which developed along the Yenjiang-Honghe great fault, and has been in existence since the late Pliocene[1]. The west side of the basin is formed by the Diancang Shan mountains, which consist of Precambrian schists and gneisses and Miocene metamorphic limestones: the famous Dali marble[2]. The mountain range is about 50 km long with peaks that are generally 2800 – 3300 m a.s.l., with the highest peak (the Malongfeng) reaching 4112m[2]. The west side of the lake is a relatively fast rising uplift area with a number of large NW-SE trending faults and minor SW-NE faults running through the lake area. One of the main faults cuts through the lake basin. These faults are related to the Himalayan collision zone and are still active as is indicated by the occurrence of earthquakes, as historical records show[3].

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To the east of the lake the hills and relatively low mountains consist of more erosive and soluble material like marine carbonates from the palaeozoic and the Triassic.

There is only one outlet (to the west in the southwest corner of the lake near Xiaguan). From the west and north about 18 rivers and streams flow into the lake(Fig.1); Before entering the lake, the streams are slowed down on a nearly horizontal alluvial plain approximately 5 km wide. It consists of two terraces (at 17 – 22 m and 7 – 11 m) that consist of gravel and loose sands[4]. Along the lake, a series of alluvial fans has been formed with a finger-shaped delta at the mouth of the Miju river (Fig.1), which extends under water down to about 10m.

Tab.1 Basic characteristics of Erhai Lake

Lake area	249km^2
Length	42.53km
Mean width	5.85km
Maximum width	9.19km
Total length of coastal line	128.67km
Mean water depth	10.2m
Maximum water depth	20.7m
Island area	0.38% of whole lake area
Lake volume	2531×10^{6}m^3
Catchment area	2785km^2
Elevation of lake surface	1974m above sea level

The climate in the Erhai Lake area is affected by the southwest monsoon as well as by the southeast monsoon[5]. The annual air temperature is about 15.3℃. The average annual precipitation is 800 mm a^{-1} on the east side of the lake and 1800 mm a^{-1} on the west side[6]. Roughly 85% of the rainfall is concentrated in the period between June and October[7]. Precipitation normally increase with elevation(by 72 mm per 100m). At lake level evaporation is about 900 – 1400 mm·a^{-1} at the water surface and about 716 – 812 mm a^{-1} on land. Wind speeds are normally 5 m s^{-1}(average speed) or less. Winds blow regularly; the maximum velocity measured[8] is 27.9 m s^{-1}.

The water level in lake is 1974m a.s.l. It varies only a few meters during the year, with the lower level in September-November and the higher level in May-July. The lowest level in history (1970, 52m) was measured on 1980-04-30, the highest level (1975, 64m) on 1966-09-07. The volume of lake is 2531×10^{6}m^3 with a mean regulation volume[8] of 813×10^{6}m^3. The maximum discharge from the tributaries into the lake was 1880×10^{6}m^3(in 1966), the minimum 169.3×10^{6}m^3(in 1982). Reservoir construction since the 1950's has decreased the discharge into the lake from 1100×10^{6}m^3 to 900×10^{6}m^3 in 1960 and to (700 – 800)×10^{6}m^3 in 1980. At the same time the sediment discharge increased because of the deforestation in the sorrounding hills and mountains, and of construction work, which both accelerate soil erosion. This caused the deltas and alluvial fans to expand rapidly in a honizontal direction by one to several meters each year.

The distribution of surface currents[8] in the lake shows that along the east side the current is directed to the north, along the west side to the south. The current velocities normally are less than 5 cm s^{-1} and only in 5% of the time above 10 cm s^{-1}. The maximum current velocity measured is 14.6 cm s^{-1}.

The water flow in the lake is further complicated by the developmet of a bottom current in a direction opposite to the direction of the surface current, which is the result of the lake surface water being pushed by the wind in a northerly direction, the wind becomes stronger than 6 – 7 cm s^{-1} either from the north or the south. This causes a lowering of the water level of 80 to 90 mm on the windward side. A main seiche with a maximum amplitude of 17.7 cm and an average period of 167.5 min. develops and a secondary seiche with eight antinodes, a maximum amplitude of 16 mm and an average period of 19.5 min. Waves in the lake usually reach a height up to 40-60 cm and a length of about 6m. Maximum waves reach a height of 1.3m and a length of 18m.

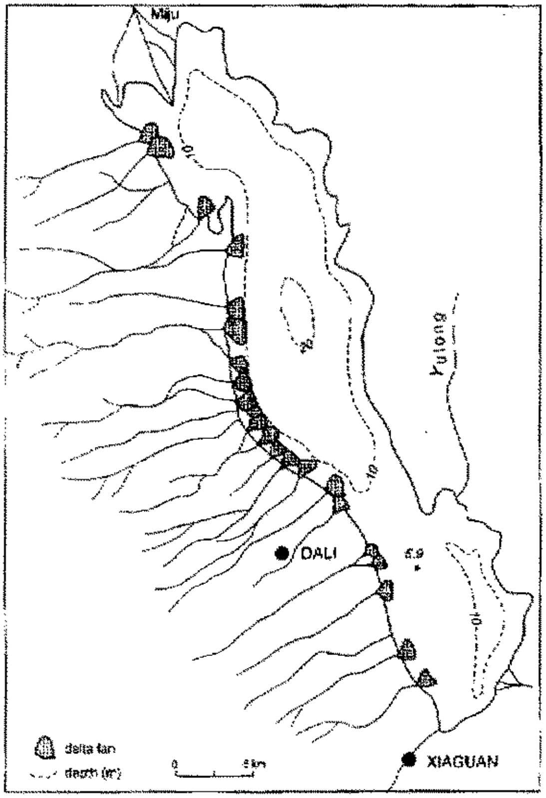

Fig. 1 Stream system and delta fans along the west side of Erhai Lake[4]

This study is concerned with the sediment deposition in the lake. Its position in a valley between relatively high mountains raises the question to what extent seiment supplied from the surrounding land, is deposited in the lake. Many broad valleys in the same region have been (partly) filled in and some valleys are known to be former lakes, as e. g. the Dengchuan basin, north of Erhai Lake, which was parat of Erhai Lake in the Early Holocene but is now land. The alternation of wet and dry seasons suggests a seasonal supply.

Sediment cores were collected in Nov. 1991 and October 1993; suspended matter samples in February 1992 with some additional samples in October 1993. Sediment composition and accumulation rates were determined in the cores as well as the concentration and composition of the suspended matter in the water. During an earlier program (in 1990) several shallow seismic profiles had been made. the results of these programs are presented here.

1 Methods of Sampling & Analysis

Water samples were collected in February 1992 in surface water and at 5 to 10 m depth. The location of the sampling stations is given in Fig. 2. On board 100 to 300 mg of water was filtered over a pre-weighed 0.4μm pore-size Nuclepore filter by suction filtration to determine the total content of organic carbon. For the total concentration of suspended matter the filters were dried for several hour at 70℃ and subsequently weighed on a Metter balance which allows weighing down to 0.02mg. Organic carbon wasdetermined by combustion at 800℃ after removal of the carbonate, or by ashing at 500℃. From each water sample also about 100 mL was filtered over a Nuclepore filter (but not preweighed) for analysis of particles in a SEM in combination with an EDAX microprobe. For SEM analysis the samples were coated with gold/palladium or carbon. The SEM was provided with an automatic stage, developed at NIOZ, which made microprobe analysis less time-comsuming.

Short cores of up to 60 cm length and 3.5 cm diameter were collected with a PVC hand-pistoncorer at the stations indicated on Fig.1. A strong undercurrent made coring in 1992 virtually impossible, but in 1993 12 cores could be collected along two transects. The cores, after transport to the laboratory, were split into two halves and one half was stored, while the other half was described and X-rayed. Subsamples were taken for particle analysis and for the determination of accumulation rates with ^{210}Pb and ^{137}Cs. The stored half of the cores was used for XRF scanning with a core scanner developed at NIOZ[8], which allows measurement of the concentration of a series of elements at 1 mm intervals in the cores. The composition profiles were calibrated for each element by AAS analysis of selected samples.

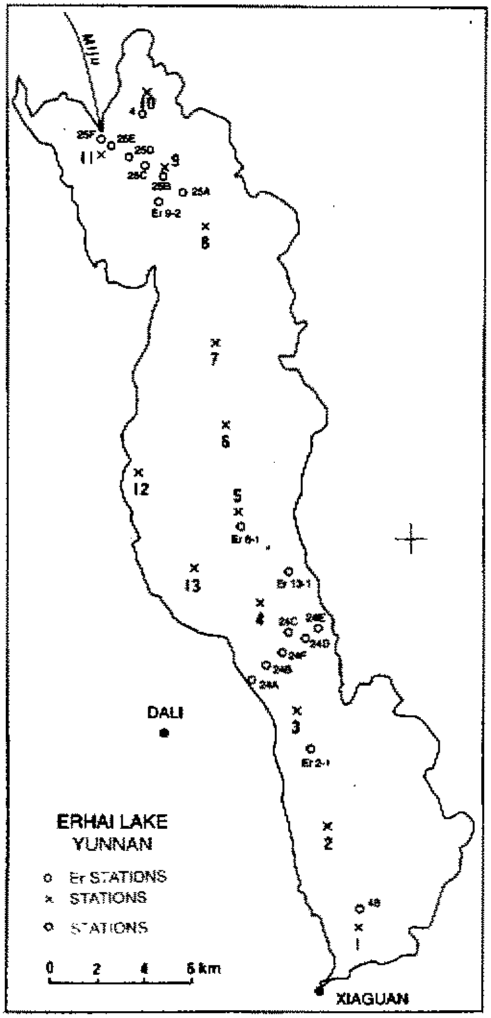

Fig.2 Location of suspended matter sampling and coring stations in 1991, 1992 and 1993

Shallow seismic profiles were obtained with a Uniboom, which has a maximum penetration of 100 m (in mud) and a resolution of 0.1 to 0.2m. Five profiles along cross-sections from west to east and one along a longitudinal section from north to south were obtained.

2 Supended matter

The concentrations of suspended matter were found to be generally low: 0.55 – 1.50 mg L^{-1} in the surface water and 0.43 – 1.68 mg L^{-1} in the bottom water. The highest concentrations were found near to the river mouths at the north and the south, but also in the narrow section near Dali (Fig.3 A & B). Additional samples collected in October 1993 gave similar concentrations in the surface water, although discharges were higher and some streams carried water.

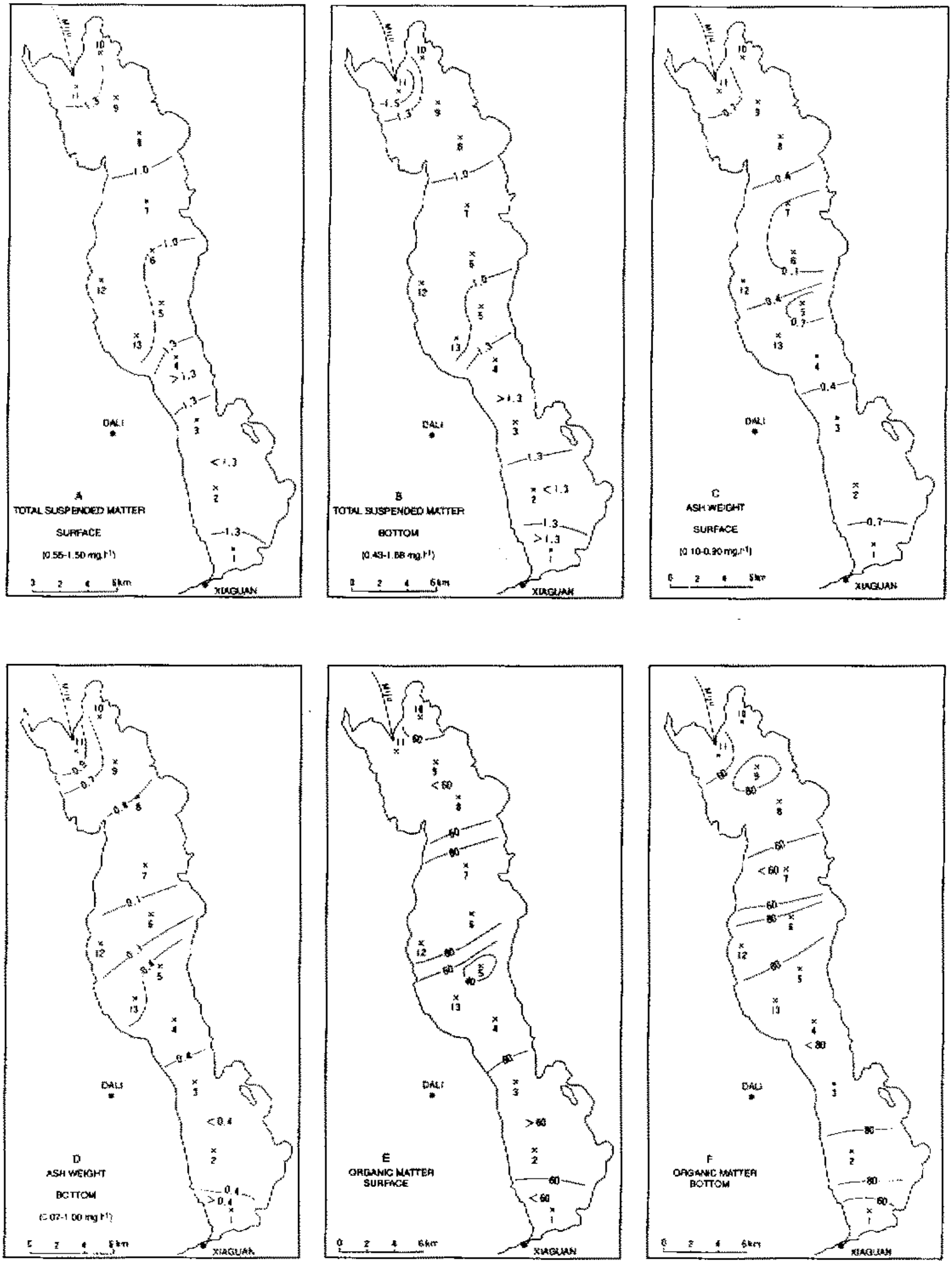

Fig.3 Distributions of total suspended matter, ashweight and organic matter (%) in suspended matter in the surface, bottom water in Feb., 1992

The sediment supplied by the streams is probably rather coarse, predominantly transported during periods of high floods and deposited on the delta fans, with mainly the larger rivers supplying fine material to the lake. A high percentage of the suspended matter is organic matter (24% − 81% in the surface water, 38% − 91% in the bottom water). Visual inspection of the suspended particles on the filters indicated that diatom frustules are regularly present but not in large numbers, with the highest numbers in the narrow area off Dali. This makes the contribution (by weight) of detrital minerals even smaller.

The elementary composition of the inorganic particles, measured on the filters by scanning microprobe, allowed to estimate their mineralogical composition. There is a predominance of illite (up to more than 50%), and quartz and chlorite (up to >20%), with lower amounts (<10% − 20%) of montmorillonite, kaolinite, biotite, calcium carbonate, dolomite, iron- and aluminium (hydr)oxides. The highest concentrations of illite occur in the southern part of the lake (Fig. 3); the concentration generally is above 10%. The highest contents of chlorite, calcium carbonate and dolomite occur in the central part, biotite is highest near to the Miju river mouth, while quartz, iron- and aluminium (hydr)oxides are regularly distributed through the lake. This composition reflects the (warm to cold temperate/mediterranean) weathering regime around the lake as well as the presence of primarily metamorphic rock. The presence of the easily weathered biotite indicates the nearness of the source rocks. No planktonic calcium carbonate skeletons were observed in the suspended matter on the filters, so the presence of calcium carbonate (and dolomite) reflects the presence of the cristallyne limestones and marbles in source rocks (the Dali marbles). Some cacium carbonate may have been formed in the lake through extraction of CO_2 by the vegetation, and some is probably authigenic, together with some of the iron (hydr)oxides and some of the quarz[10] for Erhai Lake and several other lakes in Yunnan Province. Extraction of CO_2 by the vegetation is not likely to be a major factor, because of the fact that the calcium carbonate was only found in relatively high quantities in the deepest part of the lake, both in the surface water and the bottom water, where no vegetation is present[11]. About 3% of authigenic calcite in the bottom sediments, with the highest concentrations in the deepest parts and very low contents (less than 0.3%) in the shalllow parts along the coast. Besides by being detrial, the calcium carbonate is therefore likely to have been formed by microbial oxidation and fermentation of organic matter in the sediment[10]. Elsewhere in the lake the percentages of calcium carbonate and dolomite are very low.

3 Bottom Sediments

3.1 Sediment composition

The grainsize distribution of the bottom sediment[8] shows that most of the lake bottom sediments consist of silty clay with along the edges grading into silts, sands with fine gravel and locally coarse gravel. The coarser sediment is present along the west side of the lake as well as on the extreme north side and southeast side, which reflects the origin of the supply. The silty mud is present below 8 m waterdepth, with 60% to 80% clay. Fine sand and silt occur between 3 and 8 m depth, the coarser sands and gravel at about 2 to 3 m waterdepth. The bottom slope along the sides of the lake is in the order of 2% to 3% but in the middle and central parts becomes less than 1%. There is a platform, probably the result of faulting, in the southern part of the lake with a waterdepth of about 5m. On both sides it is bordered by relatively deep channels which on the west side reach 18.8 m depth.

All cores collected in 1993, except one, showed homogeneous, (bioturbated) sediment[12]; only one core (25F) collected off the Miju river mouth, in its lower part (44 – 64 cm from the top) shows parallel and cross laminations. Cores 24A, 24E and 24F show a few thin and vague parallel laminations. The color of the sediment varies from yellowish grey (2.5year 4/1) to dull yellow brown (10year 4/3) and greyish brown (7.5year 4/2). Locally there are black (manganese?) spots. Plant remains and mollusk shells as well as shell fragments are rare and occur mainly in cores 24A, 24B and 25F. Mollusk shells and shell fragments are mainly from (small) gastropods. Plant roots occur in the top 7 to 9 cm of cores 24B and 24F and give the sediment a crumbly appearance. Both cores were collected at 9 to 10 m waterdepth; the vegetation extends to about 12 m waterdepth. Small burrows were very common through all cores except in core 25F below 44 cm from the top. Here, below the heavily burrowed sediment, about 8.5 cm is still burrowed but not so extensive as higher in the core. The well-preserved laminae seen below that part, are less than 1 mm thick with a minimum of about 0.6 mm (5 laminae go into 3 mm). They consist of a coarser part and a finer part: the latter has a thickness which is about one-third of the thickness of the coarser part. The laminae are grouped into bands of coarser grained and finer grained sediment of 2.5 to 2.9 cm thickness. One band may consist of 30 to 40 laminae. In the lowest part some small-scale ripple cross-lamination is present. Crossbedding, indicating an erosion surface, can be seen at 53.5 cm from the top.

The chemical composition of the bottom samples collected in 1991 is given for some major and trace elements given in Table 2. The organic matter content of the sediments was 1.86%, the calciumcarbonate content 3.06%[13]. Compared to the average crustal composition, the concentrations of Ca, Mg, K, and Na are much lower than in the crust, whereas the concentrations of Fe and all trace elements except Ni are higher in the lake sediments, which is the effect of weathering and soil formation as well as, probably, a pollution effect and related to the finer grain size. Within the cores collected in 1993 the elemental composition varies considerably with depth in the core. Some elements, like Mn and P, and to a lesser extent also in some cores K, Fe, Pb, Zn, Hg, Ni, Cr, V, Ba and Cd, show peaks of high concentration but not in all cores and not at the same depth when they are present in different cores. The high concentration peaks are most distinct in the Mn and P profiles (Fig. 4). Some element cnocentrations show an increase with depth in some cores (Ca, K, Fe, Pb, S, Co, V, Ti, Sr, Ba, Cd), some show a decrease (Ca, S, Cu, Sr, Cd). Most element concentrations, although they may be very variable with depth, do not show either an increase or a decrease or marked concentration peaks. Sometimes an increase with depth is followed by a decrease (in core 24D for almost all elements), or a low (decreasing) concentration followed by a high (increasing) concentration (in core 24F below 29 cm: all measured elements except Mn, P and S). The cores collected off the Miju river mouth (25A-F) and those collected in the narrow part of the lake off Dali (24A-F) show a similar variability. One can only speculate on the mechanisms that have caused this, as natural erosion (influenced by rainfall, temperature and vegetation) as well as human interference (causing increased erosion and pollution) may have varied considerably with time during the recent past.

Tab.2 Chemical composition of bottom sediment in Erhai Lake[1)]

Element	Ca /%	Mg /%	K /%	Na /%	Fe /%	Mn /%	N /%	P /%	C_{org} /%	Cd $/10^{-6}$	Hg $/10^{-6}$	Zn $/10^{-6}$	Pb $/10^{-6}$	Cu $/10^{-6}$	Co $/10^{-6}$	Ni $/10^{-6}$	Cr $/10^{-6}$
Ⅰ	1.58	1.60	1.77	1.86	7.87	0.16	0.46	0.163	1.858	0.36	0.136	150	54.8	106.3	26.6	70.8	140.8
Ⅱ	–	–	–	–	–	–	–	–	–	1.2	0.16	103	29	57	30	53	146
Ⅲ	4.15	2.33	2.09	2.36	5.63	0.095	0.02	0.105	–	0.2	0.08	70	12.5	55	25	75	100

1) Ⅰ: Sediment; Ⅱ: Soils of lake area; Ⅲ: Crustal average.

Illite was found to dominate in teh bottom sediments, as was also found for the suspended matter, with chlorite also in percentages up to 25%. The amounts of kaolinite and montmorillonite tend to be higher in the bottom sediments (up to 25% and 30% respectively). This may be related to the difference in method of determination (the mineralogy of the suspended matter samples is based on the elementary composition determined by scanning microprobe, the mineralogy of the bottom sediments on X-ray diffraction) but there may also be a seasonal effect in the suspended matter composition: in the bottom sediments kaolinite is present mostly on the east side of the lake, where during the suspended matter sampling no sediment was supplied. The montmorillonite (smectite) content is lower in the shallower parts nearer to the coast of the lake and higher in the deeper parts. This points to a sorting out and selective deposition of montmorillonite but not to a seasonal supply. Montmorillonite (smectite) is easily overestimated in X-ray diffraction, while some kaolinite may actually have been chlorite, so that probably both seasonal effects and the difference in method of estimation may account for the differences in composition between the suspended matter and the bottom samples.

3.2 Deposition rates

Deposition rates were estimates from ^{14}C- and ^{210}Pb-dating. In cores 4, 48 and X the age of the sediments was determined from mollusk shell carbonate (4, 48) and from the organic matter in the sediment as well as carbonate. Deposition rates were found to be 0.019 cm a^{-1} for the upper 60 cm in core 4, 0.022 cm a^{-1} for the upper 55 cm in core 48, and 0.019 cm a^{-1} for the sediment between 55 cm and 95 cm from the top, also in core 48. This covered a period of about 4800 years (Fig.5). In core X, which is nearly 8 meter long and covers a period of about 13000 years, the deposition rates generally were between about 0.041 and 0.071 cm a^{-1}, but were higher druing two periods: 0.142 cm a^{-1} between 6615 and 7315 B.P., and 0.216 cm a^{-1} between 11500 and 11870 B.P.[14]; these values are averages between two ^{14}C-dates.

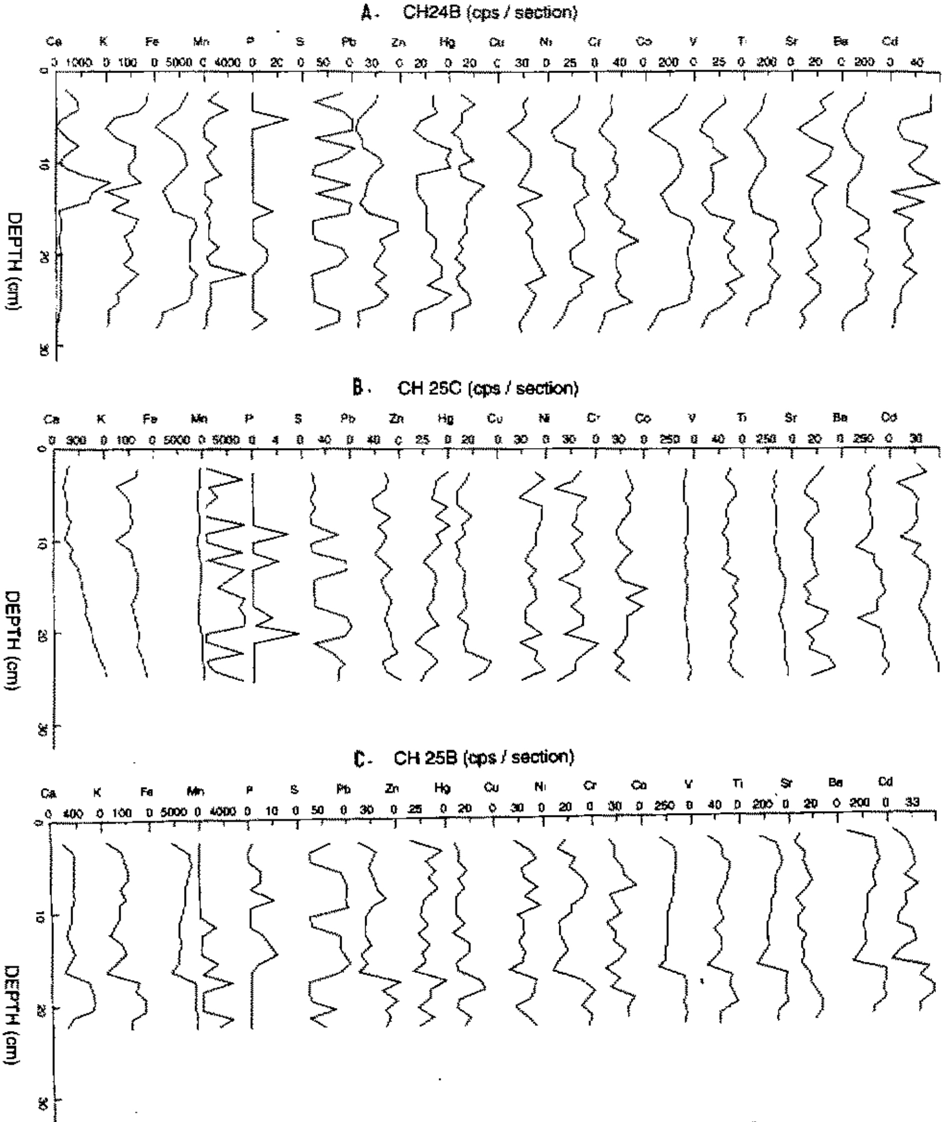

Fig. 4 Core profiles of elementary composition (examples)

^{210}Pb-dates, covering not more than 100 years, gave similar values. They were carried out in four cores collected in 1991 and cores collected in 1993. Two cores from the latter series (24E and 25F which were collected nearshore in shallow water) were found to be very bioturbated and fully mixed; the other cores were all mixed at the top over 2 to 5 cm, as could be seen from the ^{210}Pb-profiles[12]. The deposition rates obtained from the cores except 24E and 25F ranged from 0.03 to 0.482 cm a^{-1}. The mollusk shells (mainly gastropods living on the benthic vegetation or on floating plant debris) were assumed to have remained where they dropped to the lake floor, but bioturbation over at least several cm may have resulted in rather high apparent deposition rates, with the real rates being significantly lower. As will be seen below, there are no indications for horizontal displacement of sediment (slides, slumps or turbidity currents) in the areas that were sam-

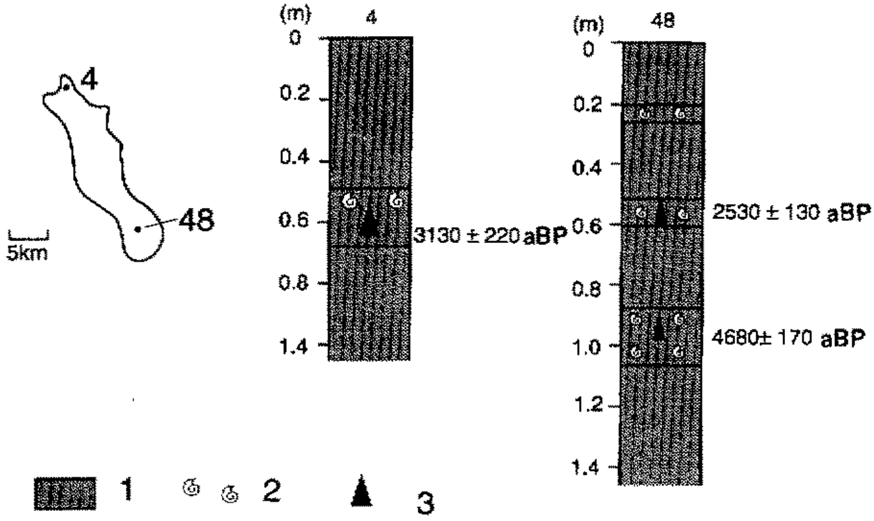

Fig.5 Cores 4 and 48 (1: sediment; 2: mollusk shell; 3: locations of ^{14}C dating)

pled. The range found with ^{210}Pb is very much of the same order as found with ^{14}C. This implies that the higher rates found during the two periods in the past may well have been related to local variations in deposition rate and not to different environmental conditions. A comparison with the suspended matter concentrations shows that, while in February 1992 about 1260 to 3800 tons of suspended sediment was present in the water (0.5 to 1.5 mg L^{-1} in a lake volume of $2531 \times 10^6 m^3$), deposition in the lake has been of the same order of magnitude. About 25% to 90% of the inorganic material (average about 1450 tons) of inorganic material was present. A deposition rate of 0.01 cm a^{-1} over the entire lake area of 249 km^2 is equivalent to about 33 t a^{-1} (taking water content of the sediment to be 50% and the density as 2.65). About 10% of this is organic matter so that about 30 tons is yearly deposited equivalent to a deposition rate of 0.01 cm a^{-1}. The estimated deposition rates vary from 0.03 to 0.482 cm a^{-1} (average about 0.20 cm a^{-1}), of which the higher rates are probably lower in reality because of bioturbation. This gives a yearly deposition varying from 90 to 1446t (average 600t). This is somewhat lower but of the same order of magnitude as the amount of inorganic material in suspension in Febr. 1992, which suggests that suspended matter concentrations in the lake have been of the same order of magnitude during the past 13000 years. There is a contribution of authigenic minerals, as mentioned above, but X. Zhang et al.[13] do not give a quantitative estimate of the amounts involved. Fe-oxides and quartz-like minerals occur in low amounts and for the area where calciumcarbonate is present in the largest quantities (the deepest part) no deposition rates are available, and thus were not included in the calculations. The contribution of authigenic minerals is therefore considered to be small. Suspended matter concentrations may have varied by a factor of 2 or 3, but not much more as the higher deposition rates are influenced by bioturbation. A higher sediment supply from the mountains, e.g. during periods of a higher rainfall or destruction of vegetation, or after earthquakes, and resulting in higher sediment transport by the rivers and streams, will have been deposited on the delta-fans without reaching the lake. At present much water from the stream coming towards the lake from the west, is used for irrigation so that large amounts of water, and sediment, are prevented from reaching the lake. The Holocene deposition rates indicate that also before irrigation much sediment did not reach it.

The shallow seismic profiles, although not very detailed, show a regular infill of the lake bottom by flat layers extending across the width of the lake except in one profile. This shows indication for slumping or sliding of sediment along the eastern side, but this occurred before the present flat lake sediments were deposited. As seen above, the cores are rather homogeneous, except core 25F which shows laminations in the lower part. The laminae are regular in appearance and may represent a yearly (monsoon) cycle as their thickness is of the same order as the (present) deposition rates. This also applies to the few faint laminations seen in some other cores. The banding, with 30 to 40 laminae in each band and consisting of lighter and darker bands (as seen on the X-ray negative), then represents 60 to 80 year cycles. During the period of deposition currents must have been strong enough to transport and deposit sand and to form small ripples, which is completely different from the present conditions at that location. The laminated sandy deposit is covered by about 44 cm of the same fine-grained bioturbated sediment as found elsewhere on the lake floor, and is such much homogenized by bioturbation that no deposition rates could be determined. If the same range of deposition rates applies here, the laminated sediment must have been deposited 150 to 200 years ago at the latest, possibly earlier, but not much later. The transition from the laminated deposit to the upper silty mud layer is gradual over about 8 cm which represents several decades. A sudden change, such as subsidence during an earthquake or a sudden shift in the Miju river mouth is therefore not likely to have caused the change, but a gradual shift of the river mouth, or a slower subsidence of the river mouth area, may have caused it.

4 Conclusions

Erhai Lake, situated in a faulted vallely on the eastern side of the Himalayas, has low concentrations of suspended matter, which for a considerable part (up to 90%) consists of organic matter. The composition of the inorganic material reflects the composition of the surrounding rocks and their weathering products. The bottom sediments in the lake have a somewhat different composition: not only is the content of roganic matter much lower but there is also more kaolinite and montmorillonite. This can be caused by both a difference in the analytical technique that was used, and seasonal variations in the supply (in particular of kaolinite). Compared to the land surface, there is a higher percentage of trace elements in the lake sediments, which is partly the result of weathering, partly of pollution, partly of the fine grain size. The sediments on the lake floor are mostly silty muds with in the shallower parts along the shore coarser material: silt, sand, and gravel. Most of the sediment supplied from the mountains on the west side through a series of streams flowing towards the lake is stored in delta-fans; the two larger streams that flow into the lake from the north and south form small deltas. Supply from the east is small, as the area east of the lake consists largely of limestone. The low deposition rates during the past 13000 years, determined with ^{14}C- and ^{210}Pb-dating, are in agreement with the low suspended matter concentrations; on the average sediment supply may have varied by a factor of 2 or 3, but not much more and it is likely that storage of sediment on the fans and deltas has been a regular process during the Holocene. The regular sedimentation in the lake is reflected in the presence of flat beds that extend across the entire width of the lake, and the sediments may have been almost entirely deposited from suspension except nearshore, but bioturbation over up to 5 cm depth in the sediment probably has resulted in apparently higher deposition rates than actually occurred.

The low suspended matter concentrations and low deposition rates are observed in a lake situated in a rift valley with recent faulting accompanied by earthquakes and a sediment supply from mountains that have a relative height of over 2000 meter directly west of the lake. The sediment is stored, however, on delta-fans along the west side and two small river deltas at the northern and southern ends of the lake. This storage, that took place throughout the Holocene, and the fact that most of the organic matter produced in the lake is largely remineralized, are the reasons that the lake still exists and has not been filled in.

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References

1 Duan Y X. Development of Erhai Lake. In: Collected scientific work on Erhai Lake in Yunnan. Kumming: Yunnan People's Press, 1989. 212－213

2 Zhang Y. Geology of the Erhai region. In: Collected scientific works on Erhai Lake in Yunnan. Kunming: Yunnan People's Press, 1989. 201－212(in Chinese)

3 Ni H, B Yao, C Gong, *et al*. Neotectonics and paleogeography of Erhai lake. In: Collected scientific works on Erhai lake in Yuunan. Kunming: Yunnan People's Press, 1989. 186－190(in Chinese with English abstract).
4 Feng M, B Yao, C Gong, *et al*. The deposits of fan delta in the west shore of Erhai Lake. In: Collected scientific works on Erhai Lake in Yunnan. Kunming: Yunnan People's Press, 1989. 191－200(in Chinese with English abstract)
5 Qian D. Investigation on aquatic vegetation in Erhai Lake. In: Collected scientific works on Erhai Lake in Yunnan. Kunming: Yunnan People's Press, 1989. 45－67(in Chinese with English abstract)
6 Cao C H. The hydrographic characteristics of drainage basin of Erhai Lake. In: Collected scientific works on Erhai Lake in Yunnan. Kunming: Yunnan People's Press, 1989. 136－152(in Chinese with English abstract).
7 Yuan J, Y Wang. Water level in Erhai Lake. In: Collected scientific works on Erhai Lake in Yunnan. Kunming: Yunnan People's Press, 1989. 291－296(in Chinese with English abstract)
8 Zhu H. The environments and sedimentation of fault lakes, Yunnan Province. Beijing: Science Press, 1989. 310
9 Jansen J H F, S J vanda Saast, B. Kosten, *et al*. CORTEX, a shipboazd XRF-scanner for element analysis in split sediment coses. *Marine Geology*, 1998, **151**: 143－153
10 Zhang X, Y F Wang, H Lei. Authigenic mineralogy, depositional environments and evolution of fault-bounded lakes of the Yunnan Plateau, south-western China. *Sedimentology*, 1996, **43**: 367－380
11 Li H. A review of the aquatic vegetation of Erhai Lake. In: Collected scientific works on Erhai Lake in Yunnan. Kunming, Yunnan People's Press, 1989. 31－44(in Chinese with English abstract)
12 Thomasse E. Monsoon cycles preserved in lacustrine sediments of lake Erhai, S.W. China. Report NIOZ, Texel, 1995, 21
13 Sui G R. Chemical composition of Erhai Lake sediment. In: Collected scientific work on Erhai Lake in Yunnan. Kunming: Yunnan People's Press, 1989. 131
14 Song X L, Wu Y A, Jiang Z W, *et al*. Paleolimnological studies on the limestone district in central Yunnan, China. Res Rep Yunnan Inst Geol Sciences, 1991. 80

云南洱海现代沉积研究

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提　要　洱海是位于云南省境内较大的但相对较浅的断陷湖泊(水深小于 20m). 根据 1990－1993 年对该湖现代沉积的研究，结果表明,湖泊沉积物主要来自西部相对高 2000m 以上的山地,东部为低矮石灰岩山地,物源较少,南北两条入湖河流亦是重要的物源供应区.湖区沉积物主要是由粉砂质粘土组成,来自山地的粗碎屑物质则大量的堆积于此地,三角洲、扇三角洲及滨湖地带,沉积速率在过去 13000 年中平均为 0.2cm a^{-1},相当于全湖平均每年堆积约 600 t a^{-1},这个量也相当于 1992 年 2 月湖中悬浮物总量. 这也表明丰富的陆源供给(雨季降雨,植被破坏和地震等),并说明了持续浅水湖泊的存在. 湖泊沉积作用也受到内部因素影响而复杂化,如湖流作用使沉积物重新分布并扩展至整个湖底在现代沉积物中,水下滑坡和滑塌尚少见.对沉积物化学分析表明,其反映了周边岩石和土壤组成,包括生物成因的成份(主要是植硅石). 沉积物微量元素相对较丰，可能系土壤渗漏、污染或细粒沉积物携带所致.

关键词　洱海　现代沉积
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