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Characteristics of bottom surface sediments in relation to wind and wave action in Lake Kitaura, central Japan

Tomonori Naya*, Kazuo Amano*, Makoto Okada*, Ryoji Nakazato**, Fujio Kumon*** and Hisashi Nirei**

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* Department of Environmental Sciences, Faculty of Science, Ibaraki University, Bunkyo 2－1－1, Mito 310－8578, Japan
** Center for Water Environment Studies, Ibaraki University, Itako 311－2402, Japan
*** Department of Environmental Sciences, Faculty of Science, Shinshu University, Asahi 3－1－1, Matsumoto 390－8621, Japan

Abstract

In order to reveal sedimentary processes in shallow lakes, we collected samples from 118 points in Lake Kitaura-a shallow coastal lagoon in the eastern margin of the Kanto region, central Japan, and analyzed grain size distribution, TOC, TN and C/N ratio. We propose a new depositional model for shallow lakes controlled by wave action owing to wind. The distribution of sandy sediments is restricted to areas near the perimeter of the lake, and correlates with areas of low contents of TOC and TN. Alternatively, clay-rich sediments are most widely distributed, and show high concentrations of TOC and TN. The TOC /TN ratio is low, about 7 to 8 throughout the basin, suggesting that major organic matter originated from planktons in the lake. High TOC/TN ratios (over 8) recognized in the northern end of the lake evidently suggests the influence of tributary rivers. The bottom sediments of Lake Kitaura are characterized by a predominance of clayey sediments which cover most of the sublacustrine plain and a narrow zone of sandy sediments along the southern coastal area shallower than 2.5m. The former sediments are transported as suspended matter reworked from the shallow and shore areas by wave action. The latter are lag deposits sifted by surface drift generated by prevailing wind. Low topography around the lake and small drainage area of each river appears to be the cause of the very small amount or lack of coarse-grained sediments around the river mouths in the narrow inlets. The sandy sediments in the southern margin of the lake are interpreted as relict sediments deposited during the last high sea-level period.

Key words: grain size distribution, lake sediments, total organic carbon, C/N ratio, shallow eutrophic lake, wind and wave action, Lake Kitaura,

Introduction

Lake Kitaura is a shallow lake (maximum depth: 7m) surrounded by low diluvial uplands and alluvial plains in the eastern Kanto region, central Japan. A northeasterly wind prevails throughout the year except in winter. The steady wind direction is suitable for the study on wind effects in relation to bottom surface sedimentation in Lake Kitaura.

Grain size and chemical components of bottom surface sediments are controlled by water movements such as lake currents and wave action (Inouchi et al., 1989; Inouchi, 1990; Kumon et al., 1993). The dominant factors for lake water movement may average out the nature and distribution of the bottom sediments. Lake sediments can record sedimentary processes of lakes which reflect past environmental conditions. There are many controlling factors of sedimentary process; however, it is thought that wave action induced by wind is the principle controlling factor in shallow lakes (Sly, 1978).

Inouchi et al. (1989) showed the spatial distribution of heavy metals, total carbon and total nitrogen in Lake Kasumigaura, and explained that the distribution was due to reworking and resedimentation by wave and lake current. Inouchi et al. (1989) and Inouchi (1990) also showed the areal distribution pattern of heavy metals, total carbon, total nitrogen and the accumulation rate in Lake Biwa, and put forward a ‘cloud’ model for deep lake sedimentation. Kumon et al. (1993) studied the grain size distribution of bottom surface sediments in Lake Biwa. They pointed out that the geostrophic gyre may be a primary factor controlling the distribution of bottom sediments in the off-shore zone of Lake Biwa, and advocated that the grain size distribution reflected average movements of lake currents. Chikita (1986) is an example of an earlier study discussing the river inflow effect to lake sed-

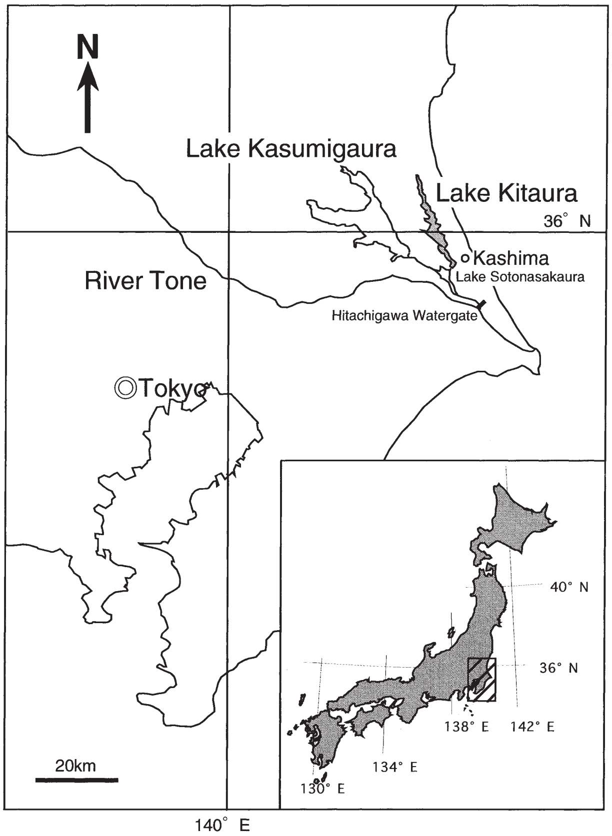

Fig.1. Location of Lake Kitaura

iments. They investigated the distribution of grain size and ignition loss on bottom sediments in Lake Okotanpe, Hokkaido, and revealed that the sedimentary process was controlled mainly by river-induced turbidity currents and sediment dispersion.

The main focus of this study is to discuss the depositional processes of shallow lakes based on bottom surface sediment distributions in relation to wind effect and river inflow.

Materials and methods

1. Geographic features of Lake Kitaura

Lake Kitaura is a eutrophic lake located just east of Lake Kasumigaura (Fig.1), with a maximum depth of 7 m, a mean depth of 4.5 m, an area of 35.2km^2 and a perimeter of 64km (National Astronomical Observatory, 2000). Thermal stratification caused by insolation is weak even in the summer season due to strong winds which intermittently disturb water up to the deepest part of the lake. According to the limnological observation from AD1981 to 1987, the difference of water temperature of the surface and bottom was almost less than 3 ℃ (Kikuchi; 1984, 1985,1986, 1990). The amount of dissolved oxygen may become low on the bottom surface only for a short period in summer. Chlorine ion measurements made from AD1985 to 1987 shows that Kitaura is fresh water with no saline water detected in the bottom part of lake (Kikuchi, 1986, 1990).

Based on the AMeDAS data at Kashima local meteorological station, predominant wind direction around Lake Kiaura is NE throughout the year (Fig.2.A). As shown in Fig.2.B, monthly prevailing wind varies seasonally between NW to ESE. Monthly mean wind velocity changes with bimodal peaks around April and Septembe (Fig.2.C).

Lake Kitaura is surrounded by the Kashima upland (elevation: 44−55 m) on the eastern side and the Namegata upland (elevation: 35−39m) on the western side (Ibaraki Pref., 1988,1989) (Fig.3). The great portion of the drainage basin consists of Pleistocene clastic sediments. Permian to early Mesozoic sedimentary rocks are distributed only in a very small area upstream of River Tomoe (Sakamoto et al., 1981; Ibaraki Pref., 1988,1989). Therefore, clastic particles are largely derived from the pleistocene clastic sediments in Lake Kitaura.

There are a total of 22 tributaries including River Tomoe and River Hokota which are the major tributaries. River Wani is the only outflowing river, joining River Tone through Lake Sotonasakaura and River Hitachitone. Lake Kitaura was a lagoon formed along River Tomoe by sea-level rise (Jomon Transgression), and the bay mouth was buried later by dune sand when sea level dropped to near present levels (Ibaraki Pref., 1989, Saito et al., 1990). Lake Kitarura was formally brackish. Hitachigawa Watergate was constructed at the lower part of River Hitachitone (Fig.3) in 1963. Then, the lake changed to a freshwater lake after the complete closure of the gate in 1975 (Sudo, 1994).

The bottom topography in Lake Kitaura can be classified into the littoral shelf, step-off, sublacustrine slope and sublacustrine plain as shown in Figs. 4 and 6. Similar classification of the bottom topography was proposed by Hirai (1987) in neighboring Lake Kasumigaura.

2. Sample collection

Samples of bottom surface sediments were obtained at 118 localities in August 1999 and July 2000 by an Ekman-Birge grab sampler (Fig.4). Typically, the top ten centimeters of sampled sediments were put into plastic bags after documenting sedimentary structures, although the Ekman-Birge grab sampler does not work well for sandy sediments as only the top few centimeters of the sediments can be retrieved for analysis.

In the laboratory each of the samples was stirred well and kept wet for grain size analysis. A part of the sample was dried at 60 ℃ for analysis of total organic carbon

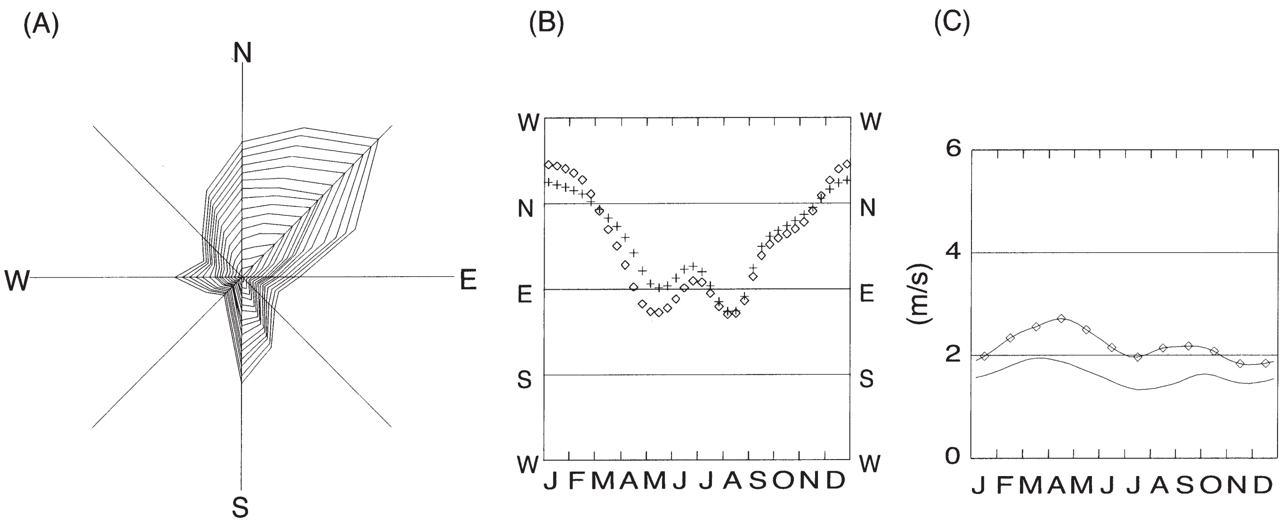

Fig.2. Wind characteristics around Lake Kitaura by Expanded AMeDAS weather data (after Architectural Institute of Japan, 2000). These are based on hourly AMeDAS weather data observed at Kashima Local Meteorological Station from AD 1981 to 1995. (A) Wind rose: integrated annual wind direction frequency (from inner line to outer line AD 1981 to 1995). (B) Annual variation of wind direction (◇: day time ; 9:00 to 20:00, ＋: night time; 21:00 to 8:00). (C) Annual variation of mean wind velocity (m/s) (Line with ◇: day time; 9:00 to 20:00, line : night time; 21:00 to 8:00).

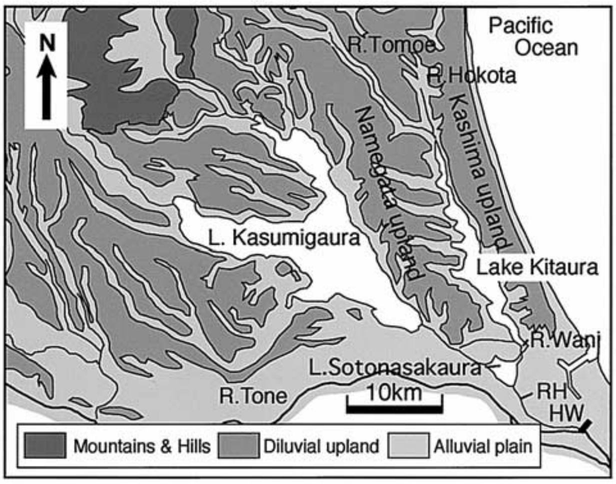

Fig.3. Topography around Lake Kitaura (RH: River Hitachitone, HW: Hitachigawa Watergate) (Ibaraki Pref., 1988)

(TOC) and total nitrogen (TN).

3. Grain size measurement and chemical analysis

Grain size was measured by a combined method using hydrometer and sieving (Kumon et al., 1993 ; Inouchi and Kumon, 1998). About 100 to 150 g of wet sediments were used for hydrometer analysis after disaggregation by H_2O_2 for a few days. After the analysis the sample was washed out through a 4.5 phi sieve, and the remaining fraction coarser than 4.5 phi were sieved in 0.5 phi intervals to obtain a detailed grain-size distribution of sand fraction. Both data was combined as a whole grain-size distribution by calculation.

Dried samples were grounded with an agate mortar and treated with 2 to 3 ml of diluted HCl (3%) to remove carbonate carbon. The samples were dried and rinsed two or three times with 1 to 2 ml of distilled water to remove any remaining HCl at 110 ℃. Next, TOC and TN amounts were measured by a dry combustion technique using a CHN corder (Yanaco MT−5). About 20 mg material was used for the analysis. The contents of TOC and TN were expressed in weight percentage of dry weight of the original sediments. Sandy sediments were excluded for C/N ratio calculation because they sometimes showed abnormal contents of TOC and/or TN.

Results

1. Grain size distribution

The spatial distribution of grain size represented by a median parameter and a nomenclature based on the ratio of sand, silt and clay are shown in Fig.5, respectively.

The distribution of sandy sediments coarser than 4 phi in median is consistent with that of sand, silty sand and clayey sand. Sandy sediments are restricted within the shore zone, and correspond with areas shallower than the 2.5 m depth, except for the narrow area reaching a depth of 6 m along the sublacustrine slop off Kamaya. Sandy sediments distribute widely south of Tsumugi. On the contrary, the finer sediments distribute in the area shallower than 2.5m near Takada. Apparently there are almost no sandy sediments in the northern part of Lake

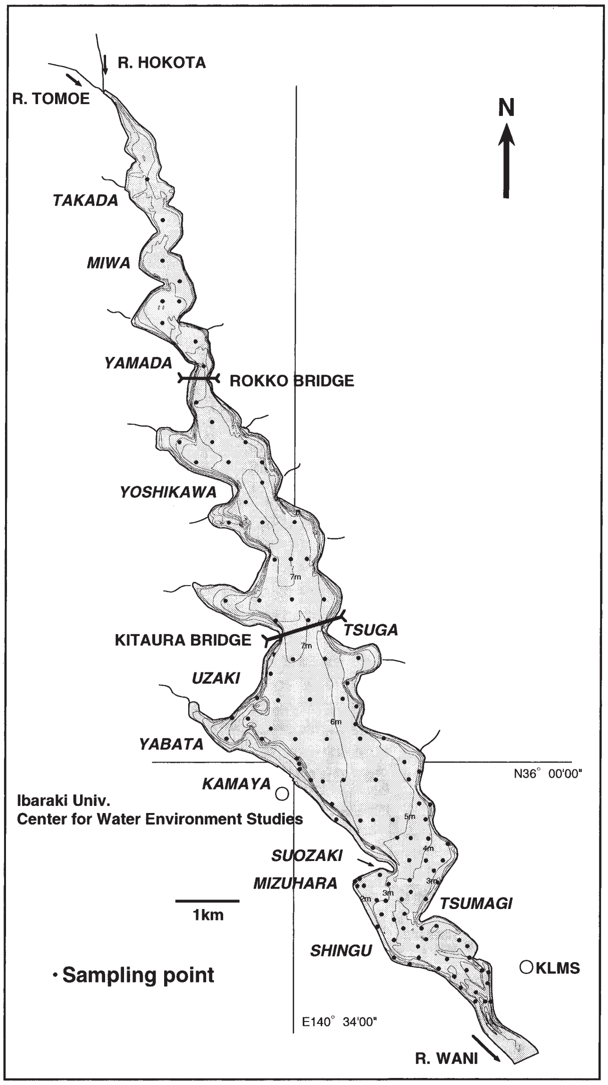

Fig.4. Bathymetry of Lake Kitaura showing contours at 1m interval and sampling points of bottom surface sediments. KLMS: Kashima Local Meteorological Station

Kitaura, especially to the north of Yoshikawa. As sampling density was low near the shoreline and in the inner part of inlet, a small distribution of sandy sediments may occur within inlet areas in the northern part of the lake.

The distribution of silty sediments with a median of 4 to 8 phi are similar with that of sand-silt-clay and clayey silt, and are restricted to a narrow zone just inside the sandy sediment areas. The clay and silty clay with a median of over 8 phi occupy most of the sublacustrine plain of the lake. Silty clay covers most of the bottom plain shallower than 3 m off Mizuhara. The finest sediments (clay) exist only in the central parts of the sub-basins off Kamaya, Yoshikawa and Miwa.

Fig.6 shows the sediment distribution along several cross sections of the lake. The sandy sediments deposit on the littoral shelf and step-off, and clayey sediments on the sublacustrine plain.

2. Distributions of TOC, TN contents and C/N ratio

Fig.7 shows the areal distribution of TOC and TN contents, and C/N ratio in bottom surface sediments. Contents vary from 0.7% to 7.0% and 0.02% to 0.89%, respectively. The TOC and TN contents show a similar distribution, and the C/N ratio is almost the same throughout the lake.

The content of TOC are mostly 5.0 to 7.0%, and that of TN are 0.6 to 0.9%. The contents of TOC and TN are higher in the central and northern parts of the lake north of Suozaki. The contents are always low near the shore line. The contents of TOC show the highest value of over 6.0% off Miwa, Yoshikawa, Yabata and Uzaki. On the other hand, the contents of TOC and TN are low in the southern area, ranging from 1.0 to 4.0% and from 0.2 to 0.6 %, respectively. In most parts of the sublacustrine plain, the C/N ratio is 7.0 to 7.5. These values suggest that most part of the organic matter are planktonic in origin (Sampei and Matsumoto, 2001). The C/N ratio increases to 8.0 in the northern areas to the north of the Rokko Bridge. This may reflect the increased influence of land-drived plant materials. Small areas showing a slightly high value of C/N (over 8.0) are sporadically distributed in some inlets and the southern marginal area of the lake south to Suozaki. Since there is no inflow river in these areas, the influence by river input cannot be considered. In Mizuhara, Tsumagi and some inlets, a littoral aquatic macrophyte zone develops on the shore (Matsubara et al., 1995). Therefore, the high ratios in the southern marginal area of the lake to the south of Suozaki may be due to the aquatic macrophytes.

The distribution patterns of TOC and TN correlate with grain size distribution. The areas of low TOC and TN (below 2.0% and 0.2%, respectively) contents coincide with the areas of sandy to silty sediments. The areas with a high concentration of TOC and TN (over 5.0% and 0.6%, respectively) correspond with the areas of clayey sediments.

Discussion

The primary factors which control lake sedimentation are erosion, transportation and deposition by waves and inflowing rivers (Sly, 1978, Håkanson, 1982). We discuss the effect of wave, river inflow and tide on sedimentation in Lake Kitaura based on the characteristics of the bottom sediments.

The sedimentation rate of surface sediments upper 30 cm in the central part of Lake Kitaura, off Kamaya, is estimated as 0.79 cm/year by ^{210}Pb and ^{137}Cs dating (Horii et al.,2002). The tephra named Asama A (a volcanic ash from

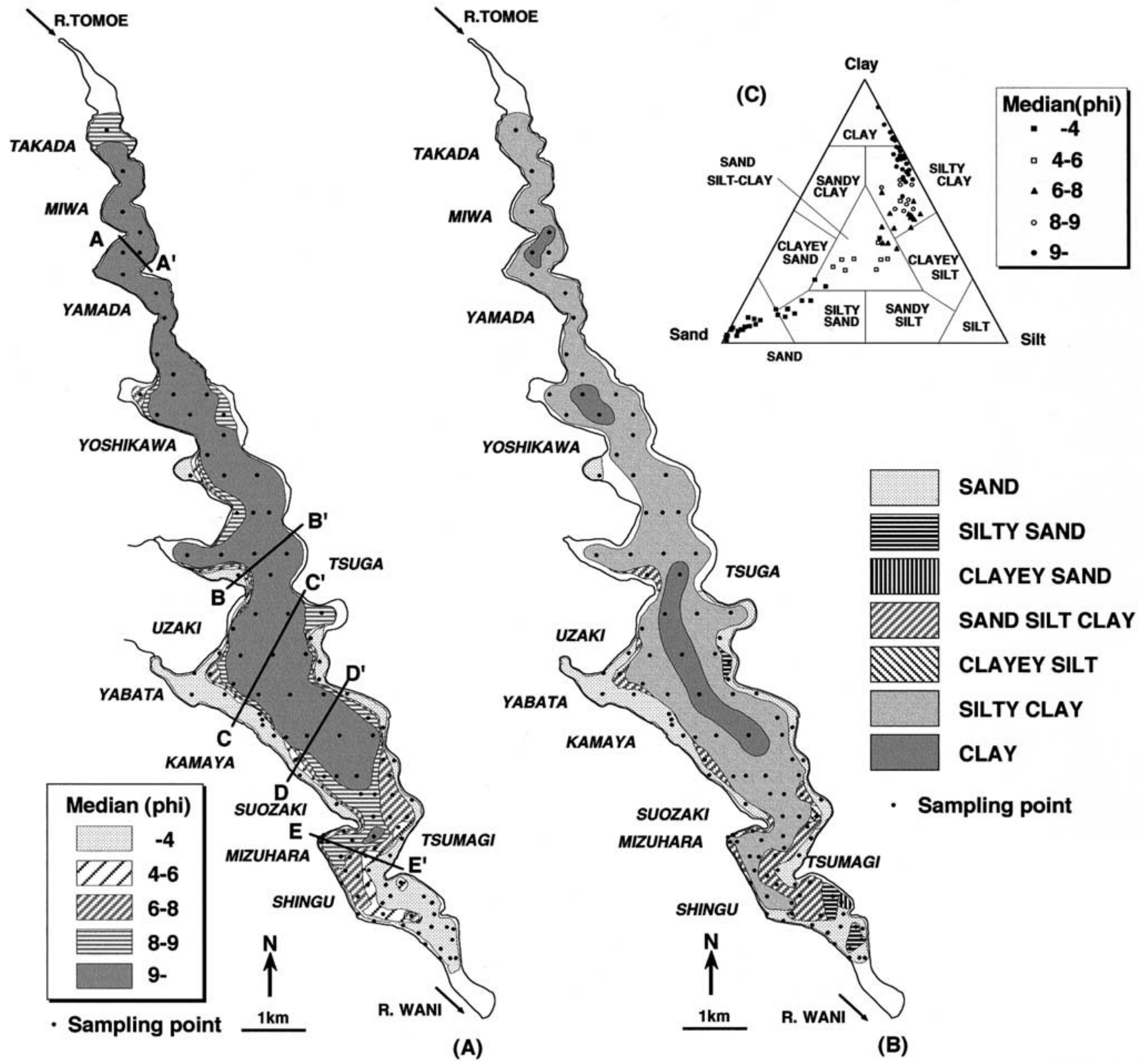

Fig.5. Grain size distribution of surficial sediments in Lake Kitaura. (A) Median diameter distribution shown in phi scale. (B) Distribution of sediments based on the nomenclature shown in diagram C. (C) Plots on a ternary diagram based on sand, silt and clay ratios (Shepard, 1954)

the eruption of Asama Volcano in AD 1783) is commonly identified in the cored sediments at places in Lake Kitaura. The sedimentation rate based on the tephra is from 0.22 to 0.25 cm/year. These facts indicate that the recent sedimentation rate is far greater than that of the past 200 years on average. This tendency is also recognized in Lake Suwa (Saito et al., 1992), and is a general feature of lakes. Although the sedimentation rate varies in place even in the same lake as shown in Lake Biwa by Inouchi et al. (1989), the top 10 cm of the samples can be regarded to represent mostly approximately 20 to 30 years. Therefore, the results show average conditions of the last 20 to 30 years. The influence of saline water before the construction of Hitachigawa Water Gate is very small even if it is included.

1. Cause of sediment distribution in Lake Kitaura

The clayey sediments with median parameters of more than 9 phi cover most parts of the sublacustrine plain. The sediments on the sublacustrine plain are almost homogeneous, but the finest sediments deposit in the central part of the basin plain. Bottom sediments in shallow areas are often reworked by large waves. A coarser fraction of the reworked sediments settles down in a short time without any transportation. On the other hand, the

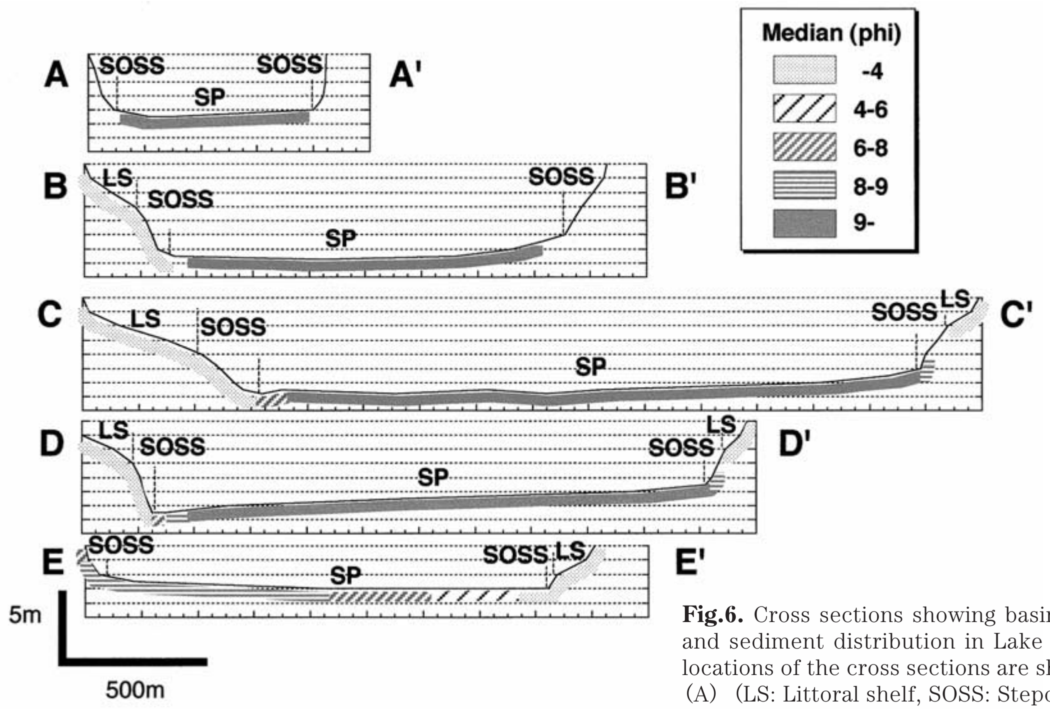

Fig.6. Cross sections showing basin topography and sediment distribution in Lake Kitaura. The locations of the cross sections are shown in Fig.4 (A) (LS: Littoral shelf, SOSS: Stepoff and sublacustrine slope, SP: Sublacustrine plain)

finer parts of the sediments are transported further away as suspended matters by lake current, and deposit in calm conditions in the deeper and remoter areas from the lake shore. The areas with high contents of TOC (>5.0%) and TN (>0.6%) always correspond with areas covered by clayey sediments. The organic matters and the fine particles are thought to have similar behavior, because organic matters such as planktonic detritus sink very slowly. Although organic matters in lakes are basically produced by phytoplanktons in surface water with a small areal heterogeneity, they can settle down more easily under calm bottom conditions. Kobayashi and Kusuda (1984) and Terashima et al. (1991) show high concentration of TOC in a depression where bottom current speed is low compared with the surrounding areas. Anoxic water mass which causes low decomposition of organic matters does not appear frequently in Lake Kitaura, and it is hard to consider the low dilution effect by clastic particles because sedimentation rate in a center of lake may be same. These points suggest that the distribution of finer sediments and TOC in Lake Kitaura indicate the place of weak water movement.

We have also found that the distribution of sandy sediments was restricted to the littoral shelf and the step-off in the coastal zone. Generally, the inner boundary of the shore zone (inner limit of sand distribution) corresponds with the wave-base depth which coincides roughly to a quarter of wavelength (Sly, 1978). A littoral shelf is a flat surface which is formed by coastal erosion and by subsequent transportation and deposition under wave influence (ex., Yoshimura, 1937; Saijyo and Mitamura, 1995). As shown in the cross sections in Fig.6, the littoral shelf along the western side of the southern part of Lake Kitaura is deeper and wider than that along the eastern side. This fact implies that the western coast of the southern part of Lake Kitaura is affected by stronger wave action than the eastern coast.

In a lake, the primary factor causing waves and surface drift is wind, and the magnitude of waves depends on wind velocity, duration and fetch (e.g. Sly, 1978; Håkanson, 1982; Kanenari. 1987; Horne and Goldman, 1994). In Lake Kitaura strong wave action and surface drift occur along the western coast in the southwest part of the lake, where the longest fetch exists in relation to wind directing. We try to estimate the depth of the wave base in storm setting from wind velocity and fetch from D-D' section in Fig.6 using the empirical values shown in Sly. (1978). Maximum mean wind velocity in the past decade at Kashima Local Meteorological Station is used as wind velocity. As a result of this estimation, wave base on the west side of the lake (D side on D-D' section of Fig.6, fetch: 5 km; wind direction: N; wind velocity: 46.8 km/h; 1995.9.) can be estimated to a maximum of 3.5 m depth, and wave base on the east side of the lake (D' side on D-D' section of Fig.6, fetch: 2 km; wind direction: S; wind velocity: 39.6 km/h; 1998.9.) also a maximum of 1.7 m depth. The estimated wave bases are consistent with the depth of the littoral shelf and inner limit of sand distribu-

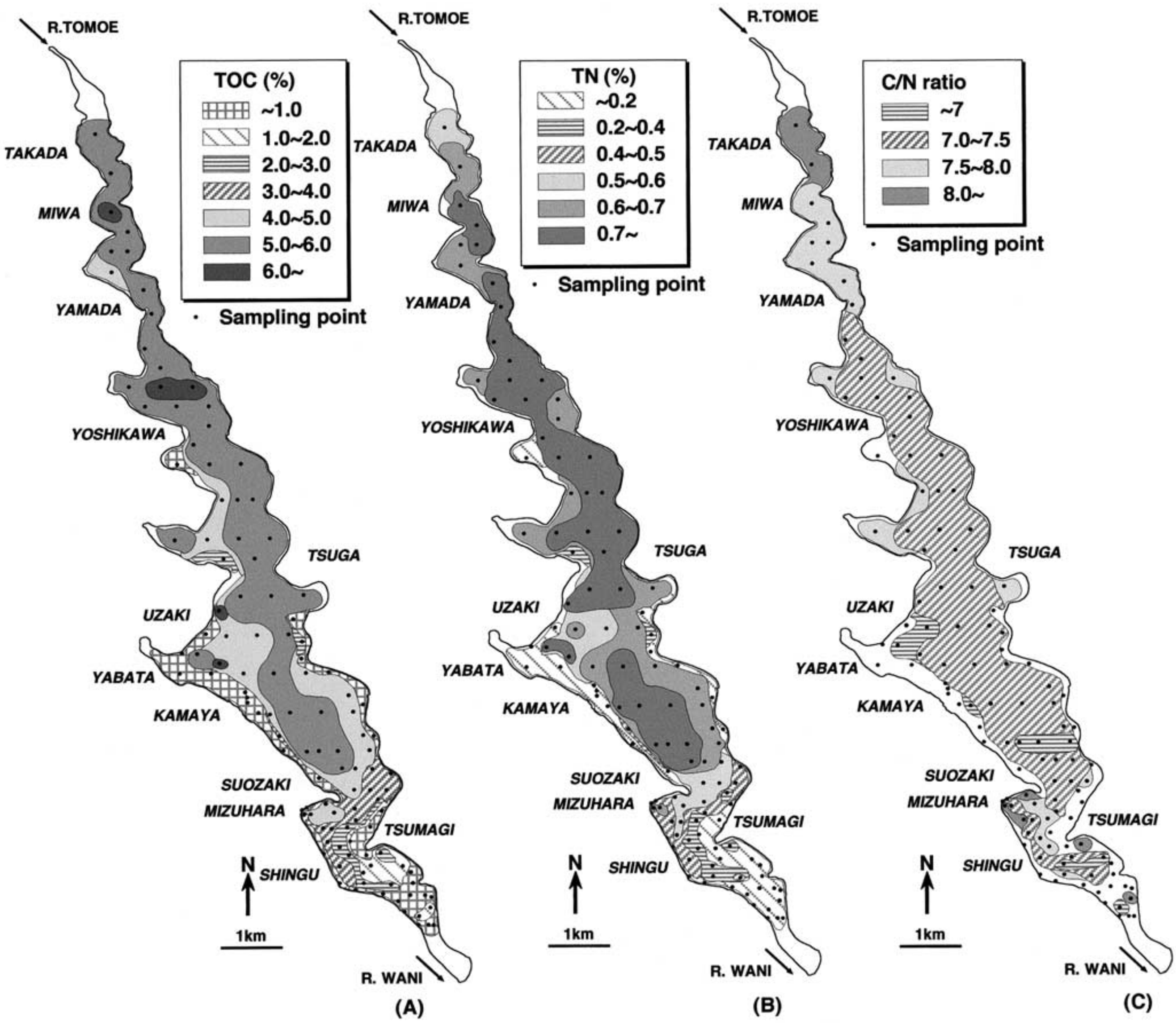

Fig.7. Surficial distribution of total organic carbon content (TOC) (A), total nitrogen content (TN) (B) and C/N ratio (C) in Lake Kitaura.

tion. Fig.8.A is the schematic view of sedimentary process in a storm setting. Although, on both sides the fetch at the shore of Tsumagi may be long, the frequency of NW wind is low (Fig.2.A) and mean velocity is also low (Fig.2.C). As a result the littoral shelf along the Tsumagi coast is not well developed.

The dominant wind direction around Lake Kitaura is NE (Fig.2.A). In usual circumstances (fair weather), dominant northeasterly wind may cause surface drift and vertical circulation of lake water. Due to these currents, the finer fractions of the reworked sediments such as fine silt with a median of 6 to 8 phi and clay sediments may be transported to further offshore especially in southern part of the lake with the longest fetch and probably settle in the area with the weakest water current (Fig.8.B).

The littoral shelf is not observed in the northern part of Lake Kitaura (for example, Section A-A' in Fig. 6). Fine grained sediments such as silty clay and clay distribute on the shallow basin floor less than 2.5 m in depth in the northern part of Takada. This may be due to a short fetch in relation to the prevailing wind direction and a zigzagged topography of the sub-basins because these features decrease wave activity. This is due to a smaller scale of wave and water current because of short fetch in the northern part of the lake. A depositional mechanism in the northern part of Lake Kitaura is the same as that in the southern part. In the littoral area south of Suozaki, clayey sediments are distributed in a shallow bottom of 2 to 4 meters depth (Section E-E' in Fig.6). This fact may be explained by the east-west trending spit which pre-

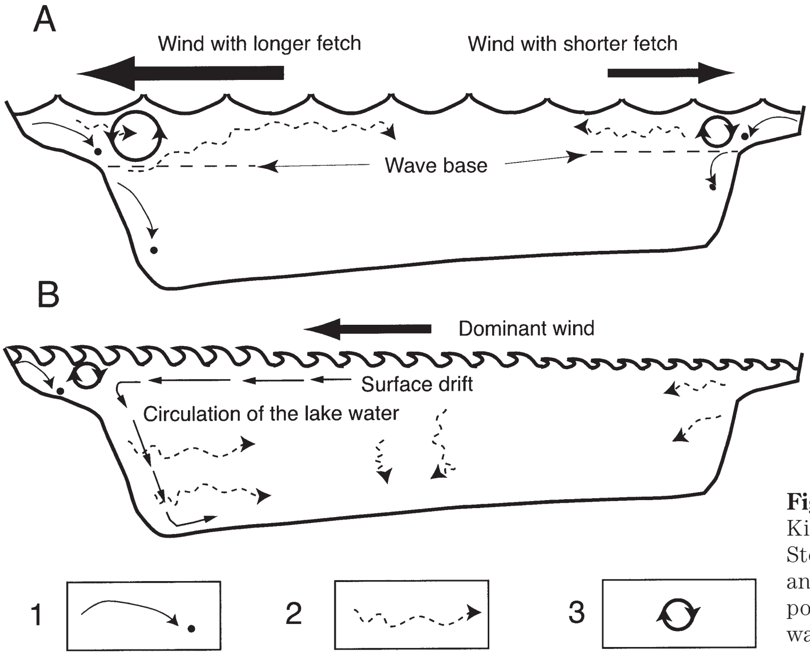

Fig.8. A model of sedimentary processes in Lake Kitaura predominantly affected by wind. A: Storm setting. B: Fair weather setting.1: Erosion and transportation of sandy particles. 2:Transportation of clayey particles. 3: Influence of the wave action

vents the development of waves and surface drift currents from northeasterly wind.

From the points mentioned above, it is suggested that the formation of the littoral shelf and distribution of sandy and silty to clayey sediments in Lake Kitaura is affected strongly by the wind direction and fetch (Figs.8.A and B). This mechanism is different from that of deep lake sedimentary processes typified by a cloud model (Inouchi, 1990) with low impact of wave action for sediment distribution. The novelties of this model are to clarify that the depth of the littoral shelf is dependent upon the length of fetch (Fig.8.A) and the circulation of lake water owing to prevaling wind (Fig.8.B). The wave and the circulation due to the longest wind fetch are the chief factors causing the distribution of sediments in Lake Kitaura.

2. River inflow effect

In general, bottom sediments of large lakes are also greatly influenced by river input (Sly, 1978; Håkanson, 1982). In Lake Kitaura, sandy sediments were not found at any of the sampling points near the river mouths except in some inlets. However, this may be partly due to the low density of sampling points, and it is possible that the distribution of sandy sediments are limited to small areas in or near the river mouths. Except for River Tomoe, almost no deltas are observed near the inflowing river mouths of Lake Kitaura.

One good indicator of river input effect is C/N ratio, since organic materials derived from land plants have high C/N (Nakai et al., 1982; Nakai and Koyama, 1987; Sampei and Matsumoto, 2001). Organic matters in lake sediments are regarded as a mixture of lake planktons and terrestrial organic matters. Organic matters in lake sediments, which are derived mainly from plankton or terrestrial vascular plants, have C/N ratios of 6 to 9 and 15 to 30, respectively (Sampei and Matsumoto, 2001). The C/N ratio of sediments in Lake Kitaura is 7.0 to 7.5, indicating that the organic matters in sediments mainly originated from planktons in lake. On the other hand, the C/N ratio increases a little in most inlets which are connected to inflowing rivers (Fig.7.C). In particular at the northern end of the lake, the C/N ratio evidently increases toward the mouth of River Tomoe, the main tributary of Lake Kitaura. Although the grain-size distribution does not clearly show the influence of inflowing rivers (Fig. 5), the distribution pattern of C/N ratio suggests a considerable influence of river input associated with supply of fine sediments in the northern part of the lake. The low-relief topography and small drainage area for each inflowing river is probably the reasons for the limited distribution of sandy sediments and terrestrial organic matters around the river mouths and inlets of this lake. Fine sediments are mainly supplied from River Tomoe. The amount of fine sediments derived from other rivers is small as the C/N ratio distribution suggests the inflow effect also small. A clay fraction of fine sediments may be transported widely as suspension by wave action, however, it is unknown how far this is extended.

3. Tidal effect of relict (ancient) sediments

Sandy sediments are widely exposed in the southeastern margin of Lake Kitaura. This distribution is partly due to wave action, because the water depth is shallower than 3 meters. Although the fetch is short, the wave is strong enough to remove fine-grained sediments. But no tributary rivers can supply sandy sediments in the area, and the predominance of sand distribution is difficult to be explained fully under the modern hydrological conditions.

One possible interpretation is that the sandy sediments are relict deposits which were formed by tidal currents under a relative high sea level. Similar sandy sediments are distributed in the southern end of Lake Kasumigaura, and is interpreted as relict sediments formed in the Jomon Transgression in maximum about 6,000 years ago (Suzuki and Saito, 1987; Saito et al., 1990). The relative high sea level continued until 1,000years ago in Lake Kasumigaura (Saito et al., 1990). A similar situation must exist in Lake Kitaura, because this lake connects with the lower portion of River Tone. Brackish conditions existed also in Lake Kitaura before the construction of the Hitachigawa Water Gate in AD 1963. These facts also support the influence of tidal current under a high sea level in ancient time, although precise timing of sand supply is yet unknown.

Conclusions

Wave action owing to wind is the most important factor controlling the bottom sediment distribution in Lake Kitaura. Sandy sediment distribution is restricted mainly to the shore zone. In the area affected by strong wave action, sandy sediments distribute from the shore to deeper parts of the lake. The distribution patterns of the finest sediments correlate with high contents of TOC and TN. It indicates that the finest sediments were transported by suspension and settled in the area where water movement was week. The influence by tributary rivers on the bottom surface sediment distribution is inferred from high C/N ratios, but the influence is low supplying mainly fine sediments only. Based on the distribution of C/N ratios, we showed that the tributary rivers around Lake Kitaura supplied only fine sediments and generally had little influence on the distribution of bottom surface sediments. The clay fraction of fine sediments supplied by tributary rivers may be transported widely as suspension under the influence of wave action. The sandy sediments in the southern end of Lake Kitaura are probably relict sediments transported by tidal current under the last high sea-level (Jomon Transgression) .

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References

Architectural Institute of Japan, 2000, Expanded AMeDAS weather data. Architectural association of Japan, 427p.

Chikita,K., 1986, Sedimentation in an intermounain lake, Lake Okotanpe, Hokkaido. Sedimentary processes derived from the grain size distribution of surficial sediments. *Japan. Jour. Limnol.* , **47**, 53−61.

Håkanson, L., 1982, Bottom dynamics in lakes. *Hydrobiologia* , **91**, 9−22.

Hirai, Y., 1987, Structure and origin of the littoral shelves at Lake Kasumigaura. *Geogr. Rev. Japan.*, **60**, 821−834. *

Horii, Y., Okada, M., Amano, K., Hanari, N., Taniyasu, S. and Yamashita, N., 2002, Analysis of individual polychlorinated naphthalene congeners and dioxin-like compounds in a dated sediment core from Lake Kitaura, Japan. *Bunseki Kagaku*, **51**, 1009−1018.*

Horne, A.J. and Goldman, C.R., 1994, *Limnology (2nd edition)*. McGraw-Hill, New York, 576p.

Ibaraki Prefecture, 1988, Report on fundmental land classification survey Itako, Youkaichiba, Choshi with sheet maps at 1:50,000. Ibaraki Prefecture.**

Ibaraki Prefecture, 1989, Report on fundmental land classification survey Isohama, Hokota with sheet maps at 1:50,000. Ibaraki Prefecture.**

Inouchi, Y., 1990, Sedimentation mechanism of fine materials in Lake Biwa. *Mem. Geol. Soc. Japan*, no. 36, 195−208.*

Inouchi, Y. and Kumon, F., 1998, Methods of grain size analysis for mudy soft sediments *In* Kumon F. and Tateishi M., eds., *Research manual for Analysis of clastic sediments*. AGCJ, Tokyo, pp 284−307.**

Inouchi, Y., Nakano, S., Yokota, S., Saito, Y., Murakami, F., Miyata, Y., Terashima, S., Terashima, M., Takeuchi, S., Yoshikawa, H., Yasuda, A., Saito, E., Watanabe, K., Miyazaki, J., Hoshika, A., Shiki, T., Tokuoka, T., Kumon, F., Nakano, S., Endo, S., Musashino, M., Hisatomi, K., Yoshikawa, S., Maeda, H. and Kondo, Y., 1989, Sedimentation of polluted lake sediment. *Rep. Res. Env. Agency Env. Pres.*, **47**.1−47.30.*

Kanenari, S., 1987, Methods of physical measurement. In Handa, N., Kanenari, S., Inouchi, Y. and Okino, T. *Manual for limnological study*. Kokinshoin, Tokyo, 1−48. **

Kikuchi, H., 1984, Limnological data at the center in Lake Kita-ura from September, 1981 to December, 1982. *Publ. Itako Hydrobiol. Stn.*, **1**, 39−44.

Kikuchi, H., 1985, Limnological data at the center in Lake Kita-ura in 1983 and 1984. Publ. Itako Hydrobiol. Stn., **2**, 67−75.

Kikuchi, H., 1986, Limnological data at the center in Lake Kita-ura in 1985. Publ. Itako Hydrobiol. Stn., **3**, 13−19.

Kikuchi, H., 1990 Limnological data at the center in Lake Kita-ura in 1986 and 1987. Publ. Itako Hydrobiol. Stn., **4**, 29−37.

Kobayash, S. and Kusuda, T.,1984, Bottom sediments of Lake Teganuma −sedimentation and property of polluted sediments−. Data of the Chiba Pref. Lab. Wat. Poll., no. 49, 1−49.

Kumon, F., Kamitani, T., Sutoh, K. and Inouchi, Y., 1993, Grain size distribution of the surface sediments in Lake Biwa, Japan. *Mem. Geol. Soc. Japan*, no. 39, 53−60.*

Matsubara, N., Sotooka, T. and Sasaki, M., 1995, The state of littoral vegetation in Lake Kasumigaura and Lake Kitaura. *Bull. Ibaraki Pref. Fresh. Fish. Exper. St.*, **31**, 36−48.**

Nakai, N., Ohta, T., Fujisawa, H. and Yoshida, M., 1982, Paleoclimatic and sea-level changes deduced from organic carbon isotope ratios, C/N ratios and pyrite contents of cored sediments from Nagoya harbor, Japan. *Quatern. Res.*, **21**, 169−177.*

Nakai, N. and Koyama, M., 1987, Reconstruction of paleoenvironment from the viewpoints of the inorganic constituents, C/N ratio and carbon isotopic ratio in the 1400 core taken from Lake Biwa. *In*: Horie, S. (ed) History of Lake Biwa. Kyoto Univ. Contrib. **553**, 137−156.

National Astronomical Observatory, 2000, Rika Nenpyo (Chronological scientific tables 2001). Maruzen Co.,Ltd.,Japan.**

Saijyo, Y. and Mitamura, O., 1995, *Manual for limnological study*. Kodansha, Tokyo, 238p.**

Saito, Y., Inouchi, Y., Katayama, H., Ishihara, T., Miyata, Y., Inazaki, T.,

Terashima, S., Terashima, M., Yasuda, S., Saito, E., Watanabe, K., Miyazaki, J., Takeuchi, S., Yoshikawa, H., Okino, T., Kumon, F. and Kawamura, M., 1992, Removal method of polluted lake sediment. *Rep. Res. Nat. Inst. Polu. Prev.*, 47.1－47.17. *
Saito, Y., Inouchi, Y., Yokota, S., 1990, Coastal lagoon evolution influenced by Holocene Sea-level changes, Lake Kasumigaura, central Japan. *Mem. Geol. Soc. Japan*, no.36, 103－118.*
Sampei, Y. and Matsumoto, E., 2001, C/N ratios in a sediment core from Nakaumi Lagoon, southwest Japan － usefulness as an organic source indicator －. *Geochem. Jour.*, **35**, 189－205.
Shepard, F.P., 1954, Nomenclature based on sand-silt-clay ratios. *Jour. Sediment. Petrol.*, **24**, 151－158.
Sly, P.G., 1978, Sedimentary processes in Lake. *In*: Lerman, A., ed, *Lakes - chemistry, geology, physics*－. Springer-Verlag, New York, 65－89.
Sakamoto, T., Aihara, T. and Noma, Y., 1981, Geology of the Ishioka district. Quadrangle series, Scale 1:50,000. Geol. Surv. Japan, 50p.*
Sudo, S., 1994, Salt damage of Lake Kasumigaura. *In* Kasumigaura Academic circle ,ed, *Relationship between people and the lake*. STEP, Tsukuba, 46－48.**
Suzuki, T. and Saito, Y., 1987, Heavy mineral composition and provenance of Holocene marine sediments in Lake Kasumigaura, Ibaraki, Japan. *Bull. Geol. Surv. Japan*, **38**, 139－164.*
Terashima, S., Inouchi, Y., Saito, Y., Miyata, Y., Katayama, H. and Terashima, M., 1991, Vertical variation and chemical characteristics of elements in bottom sediments from dredged hollows of Lake Biwa and Lake Kasumigaura, Japan. *Bull. Geol. Surv. Japan*, **42**, 387－407.*
Yoshimura, S., 1937, Limnology. Sanseido, Tokyo, 426p. **

* in Japanese with English abstract
** in Japanese

（要　旨）

Naya, T., Amano, K., Okada, M., Nakazato, R., Kumon, F. and Nirei, H., 2004, Characteristics of bottom surface sediments in relation to wind and wave action in Lake Kitaura, central Japan. *Jour. Geol. Soc. Japan*, 110, 1－10.（納谷友規・天野一男・岡田　誠・中里亮治・公文富士夫・楡井　久，2004，風・波浪との関係からみた茨城県北浦湖底堆積物の特徴．地質雑，**110**，1－10.）

浅い湖沼における表層堆積物堆積過程を明らかにすることを目的として，浅い海跡湖である北浦の118地点で，粒度，全有機炭素量（TOC）そして全窒素量（TN）の分析を行った．それに基づいて風による波浪の影響の強い浅い湖沼における堆積モデルを提唱した．北浦湖底堆積物は，湖底平原の大部分を粘土質堆積物が占めることと，沿岸域の2.5m以浅に砂質堆積物が狭く分布することにより特徴づけられる．この特徴は，本モデルによれば，以下のように説明できる．粘土質堆積物は波浪によって浅部または沿岸部から懸濁物として運ばれたものであり，砂質堆積物は卓越風によって生じた吹送流に淘汰された残留堆積物となる．北浦周辺地域の地形は低く流入河川の流域面積も小さい．このため，湾入部の河口における粗粒堆積物の分布が狭く限定されている．なお，南端部に分布する砂質堆積物は，高海水準期における潮汐の影響により堆積したものであると解釈される．