Quantitative Assessment of Chemical Characteristics of the Sediments in Lake Biwa, Japan, by Cluster Analysis

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Chemical characteristics of the sediments in Lake Biwa were analyzed by a concentration correlation matrix method and by a hierarchical cluster analysis. The sediment core samples were collected from 18 sites of the North Basin and the South Basin in Lake Biwa. The chemical constituents in the sediments were determined by an X-ray fluorescence analysis. The correlations among the sampling sites were described using the analytical concentrations of the major six elements, Si, Al, Fe, Ti, K and Mg, in the sediments. The result of the concentration correlation matrix showed that high correlations were observed for each of the neighboring sites, whereas relatively low correlations were found between the sediment in a northern site (C10) of the North Basin and the sediments of the South Basin. Low correlations were also found between the sediments from the northeast sites (E4, E5) and those other sites in the South Basin. The correlations among the samples in these sites were more clarified by the cluster analysis. The clusters for sampling sites of the sediments were almost classified into five regions. The generic correlations among the sampling sites of the Lake Biwa sediments could be explained by the physical and chemical redistribution of the components during the processes in which the sedimentary materials are transported through the lacustrine water currents.

(Received on August 9, 2001; Accepted on September 13, 2001)

Materials and Methods

Site Description and Sample Collection
Lake Biwa is a largest lake in Japan, which is in the middle of Japan’s main island. It has been composed of two basins called North Basin and South Basin. The North Basin has an average water depth of 44m and a surface area of 616km², but the South Basin is only 3.5m deep on average and a surface area of 58km². A catchment area is surrounded by mountain ranges about 1000m above sea level, and is 4.7 times as wide as the lake itself. Some 460 streams of various size flow into Lake Biwa, but the water outlet is only one in a southern end of the lake. There are only a few cities of moderate size in the drainage basin. The areas surrounding the South Basin have recently become popular suburbs of Kyoto City and Osaka City, and there has been a steady increase in population since the mid-1980s. Now, some 150 million persons are supplied with the lake water as drinking and daily life water. The quality of an aquatic environment in the lake has been profoundly influenced by transition of the environmental conditions.

Sediment cores collected from Lake Biwa, Japan, were used to assess lake’s environments and the effects of recent changes of the environmental conditions. Sediments have been composed of many chemical compounds, and are partly of artificial materials, but large amounts are discharged by natural origin. Therefore, the properties of chemical characteristics of the bottom sediment are reflected on an aquatic environment in the lake. The present work concerned with lake bottom sediment for which techniques were sought to demonstrate sediment-flow patterns in Lake Biwa and discover the origins of the sedimentary materials. The concentrations of major elements (Si, Al, Fe, Ti, Na, Mg, K, Ca, S, P) and minor elements (Cl, Cr, Mn, Ni, Cu, Zn, As, Rh, Sr, Ba, Hg, Pb) were measured in the North Basin and the South Basin of Lake Biwa. The sediments accumulated more than 80 years during which the environments changed from rural area to urbanized area. Since the sediments of Lake Biwa do not receive the contamination of major elements from industrial effluents, the analytical concentrations of the major elements in the lake sediments were used for analysis of the correlation among the water systems in Lake Biwa. In this study, the correlations among the sediments were obtained by two approaches: a concentration correlation matrix method and a hierarchical cluster analysis. The results of statistical analysis revealed that the chemical characteristics of the sediments in Lake Biwa are controlled in the sedimentary processes of the sediments.

Analytical Method
An X-ray fluorescence analyzer (XRF) RIGAKU RIX2000 (Rh cathode: 50kV-50mA) was used for the determination of 21 elements in the sediments. Standard reference material NIST1646 (Estuarine Sediment) and NIES No.2 (Pond Sediment) were used as a standard sample for XRF analysis.
The sample disks for the XRF measurements were prepared as following. The base disk of 4cm diameters and 0.3cm thickness was made in the cellulose powder (ADVANTEC No.A). The sediment of 1.2g was uniformly put on the desk, and then it was molded by press at 1600kg/cm². The standard samples were also prepared in the same way. The relative standard deviation was estimated to be within 3% for major elements in the Lake Biwa sediment.

Statistical Analyses

Many workers statistically analyzed the results of the chemical analysis of the sediment samples. Concentration correlation matrix method carried out for discovering generic relationships among the sediments. The method is a technique of matching, in which the ratios of the elemental concentration of the sample are compared with the equivalent ratios of other samples. Hierarchical cluster analysis was also done for the quantitative assessment of the correlation among the components of the sediments. Calculations are executed with the ESUMI multivariate analysis software version 4.0. The data were reduced to the six major elements of the sediments, and used for the average concentration in the top-15cm samples of the core.

Results and Discussion

Distributions of Major Elements in the Lake Biwa Sediments

The concentrations of 21 elements in the sediment cores from Lake Biwa were determined by an XRF analysis. The vertical
northern area of the North Basin, from the boundary area of the
High correlations were found among the sediments from the
neighboring sampling sites except C10-N16, W5-E5 and E4-C3.
numbers of more than 0.80 were obtained for each of
the sediments collected from Lake Biwa, high correlation
Lake Biwa were shown under the diagonal of Table 1. Among
correlation between samples and that is a value between zero
number calculated by the method means the intensity of the
matching the ratios of the elemental concentration of the sample
suggested that the redistribution of Fe occur between lake water
precipitate by the mechanics of the Gyre. 11-13 It seemed to form
mainly flow from the Ado River, and it will selectively
area of the Gyre (counter clockwise), which exists in the north of
is close to the deepest part in Lake Biwa, and it is in the fringe
concentration correlation matrix method. C10 (water depth 85m)
other sampling sites, as it is also shown by the results of the
Cluster I (C10) and Cluster V (E4, E5) clearly separated from
other sites are large. Similarly, the correlations between E4 and E5 and
other sites are small, because the dissimilarities between these
were shown over the diagonal of Table 1. It is shown that the
dissimilarities between adjoining sites are small and that the
correlations are high for it. The correlation between C10 and the
sites were very low.
The Lake Biwa sediment has been composed of five clusters. Cluster I (C10) and Cluster V (E4, E5) clearly separated from
other sampling sites, as it is also shown by the results of the
concentration correlation matrix method. C10 (water depth 85m)
is close to the deepest part in Lake Biwa, and it is in the fringe
area of the Gyre (counter clockwise), which exists in the north of
the North Basin. On the other hand, low correlations among the
sediments in the North Basin and the sediments in the South
basin. Especially, the correlations of C10, E4 and E5 and other
sites were very low.
The dissimilarity between samples must be estimated from
variables to make a dendrogram in cluster analysis. It can
calculate by various methods using analytical data, but the
standardized squared Euclidean distance between samples was
used as dissimilarity in this study. The correlation between
samples is higher, if the value of the dissimilarity is smaller. The
standardized squared Euclidean distance between sampling sites
were shown over the diagonal of Table 1. It is shown that the
dissimilarities between adjoining sites are small and that the
correlations are high for it. The correlation between C10 and the
other sites are small, because the dissimilarities between these
sites are large. Similarly, the correlations between E4 and E5 and
the other sites are also small. The matrix of the dissimilarities
between the sites in Lake Biwa by the standardized squared
Euclidean distance agreed well with the matrix of the correlation
numbers by concentration correlation matrix method.

### Table 1: Correlations among the sampling sites in Lake Biwa

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<th>C6</th>
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<th>W5</th>
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The values under the diagonal line are correlation numbers for matching criterion M=1.3. The values over the diagonal line
are standardized squared Euclidean distance. This table gives the correlations with the composition of major six elements (Si, Al,
Fe, Ti, K, Mg) in the sediments of a top-15cm layer.

distributions of many elements such as Na, Ca, S, P, Cl, Mn, Cu,
Zn, As, Sr, Ba and Pb showed that these elements were affected
by human activities or post-depositional diagenesis, whereas the
distributions of Si, Al, Fe, Ti, K, Mg, Cr, Ni and Rb showed that
the behaviors of these elements were not affected by that. The
analytical values of the major elements in the sediment were
used for a statistical analysis, because it seemed to reflect the
natural conditions of the sediments. The distributions of major
six elements in the Lake Biwa sediments are shown in Fig.2.
The concentrations were shown in the mean value of a top-15cm
samples. The length line means the range of minimum and
maximum concentrations.

The concentrations of Si, K and Mg decreased for the
southern sites from the northern sites in Lake Biwa. The
concentrations of Al and Ti reversely increased. It is shown that
the constituents of the sediments gradually change between
sampling sites. On the other hand, the Fe distribution was
different from other major elements. The anomaly of Fe will be
suggested that the redistribution of Fe occur between lake water
and bottom sediment.

**Correlation of the Sediments in Lake Biwa**

The statistical methods were applied for the analytical data in
order quantitatively to assess the composition of the sediments
among the sites. The correlations among the sampling sites in
Lake Biwa were shown in Table 1.

The concentration correlation matrix method is a technique of
matching the ratios of the elemental concentration of the sample
with the equivalent ratios of other samples. The correlation
number calculated by the method means the intensity of the
correlation between samples and that is a value between zero
and one. The correlation numbers between the sampling sites in
Lake Biwa were shown under the diagonal of Table 1. Among
the sediments collected from Lake Biwa, high correlation
numbers of more than 0.80 were obtained for each of
neighboring sampling sites except C10-N16, W5-E5 and E4-C3.
High correlations were found among the sediments from the
northern area of the North Basin, from the boundary area of the
North Basin and the South Basin and from the southern area of
the South Basin. On the other hand, low correlations among the
sediments in the North Basin and the sediments in the South
Basin. Especially, the correlations of C10, E4 and E5 and other
sites were very low.

**Assessment of Chemical Characteristics of the Lake Biwa Sediments by Cluster Analysis**

A hierarchical cluster analysis was performed using a group
average method with standardized squared Euclidean distance. A
dendrogram for the sampling sites of the Lake Biwa sediments
was shown in Fig.3.

The Lake Biwa sediment has been composed of five clusters. Cluster I (C10) and Cluster V (E4, E5) clearly separated from
other sampling sites, as it is also shown by the results of the
concentration correlation matrix method. C10 (water depth 85m)
is close to the deepest part in Lake Biwa, and it is in the fringe
area of the Gyre (counter clockwise), which exists in the north of
the North Basin. In this water system, the sedimentary materials
mainly flow from the Ado River, and it will selectively
precipitate by the mechanics of the Gyre. 11-13 It seemed to form
the sediment of C10 by this mechanism. The area of E4 and E5
is called Akanoi Bay. There is very shallow (1-3m) and it has isolated from the offshore. Therefore, it is estimated that the chemical characteristics of the sediments here differ from other sites.

The sediments from the southern area of the North Basin belong to Cluster II. The sediments of Cluster III are from the boundary area of the North Basin and the South Basin, and the sediments of Cluster IV are from the southern area of the South Basin. The property of Cluster II is influenced in the Yasu River. N16 and J14 are located in the second Gyre,13 and the effects from the Ado River also received. In spite of 4 and C6 receiving large effects in the Yasu River, these sites have separated from Cluster II. The correlation of these sediments will be strong with the sediments in the northern sites of the South Basin. This fact suggested that the sediments of this area are affected of the high turbidity water, which flows from the South Basin in the winter.14 The sediments of Cluster IV will be terrigenous mud that flowed through the stream from the hinterland, because the positions of the sites are close to the shore.

The chemical characteristics of the Lake Biwa sediments could be thus quantitatively evaluated by using statistical analyses. The generic correlations among the sediments of Lake Biwa could be explained by the physical and chemical redistributions of sedimentary materials during the depositional processes in which the terrigenous materials such as soil and clay are transported through the water currents in Lake Biwa.

Acknowledgments

The authors wish to thank the crews of the R.V. Hattken–gou, Lake Biwa Research Institute, Shiga Prefecture, for their help in core sampling. This research was partially supported by a Grant-in-Aid for Scientific Research (C) (No. 12680535) from Japan Society for the Promotion of Science and by a Health Sciences Research Grants for Research on Environmental Health (H12-Seikatsu-019) from Ministry of Health and Welfare.

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