Environmental Changes Printed in Lacustrine Sediments and Earth Surface Processes

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Environmental Changes Printed in Lacustrine Sediments and Earth Surface Processes

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Abstract – Lacustrine sediment information and earth surface processes are discussed for better understanding global environmental changes and earth surface response to them. Two cases (Lake Baikal records, long continental lacustrine information and short Japanese lacustrine information) are introduced for two time domains (10^5-10^6 years, and 10^0-10^2 years).

I. Introduction

Terrestrial sediments, especially, lacustrine sediments have some advantages that include high-resolution environmental records; biological-information-rich records as well as physical and chemical ones, compared with deep-sea sediment records and ice core records. Hence, we may obtain some clues of detailed biological evolution on the Earth in addition to physical and chemical process-based earth history with appropriate approach and method. This may provide more detailed and different stories from ones written through ocean sediment and/or ice information.

East Eurasia including Pan-Japan Sea area is highly sensitive region for climatic changes because of its location; Asian monsoon-related region. Located in the middle latitudinal zone, this region is not only affected by westerly circulation, but also controlled by East Asian monsoon. In winter, Siberian high dominates the climate of this region. Cold air mass from Siberia receives much evaporated water on the Japan Sea and causes to snow in the area facing to the Japan Sea. In summer, Asian summer monsoon due to the Himayalas and the Tibetan Plateau control the climate. Therefore climates and environments of East Eurasia (Pan-Japan Sea area) are closely related to each other.

Process-based study and comparative study based on lacustrine sediment information in this region will help to understand environmental changes in the past, present and future from East Eurasia to continental inland.

II. Long Baikal records

Lake Baikal, in eastern Siberia, is located in a crucial area for reconstructing insolation-related, long-term climate changes, because the area is known to be very sensitive to solar insolation [1]. Lake Baikal sediment samples recently obtained mainly from ridges are relatively undisturbed, preserve a continuous sedimentation record, and have been used to elucidate long-term environmental changes [2, 3, 4] .

Analyses of Lake Baikal sediments from Academician Ridge [5, 6, 7, 8] show that climato-limnological fluctuations in Lake Baikal sediments are closely related to global climate changes as seen in paleoceanographic records. These fluctuations reflect orbital cycles, including 400- and 100-kyr periods of eccentricity, the 40-kyr period of obliquity, and the 20-kyr period of precession.

It has been suggested that additional, longer periods may be related to orbital movement and to the initial influence of insolation on the Lake Baikal climate system [9]. Studying the initial influence of insolation is crucial for understanding the current long-term climate system, since it might reflect the beginning of major Northern Hemisphere glaciation. It is possible that the initial influence of insolation and Northern Hemisphere glaciation correlate closely with each other.

Major glaciations have been widely discussed with reference to understanding current climate systems [10, 11] and an abrupt environmental shift around 2.8 Ma has been a salient topic. This abrupt shift occurs both in Lake Baikal records [5] and in many oceanic records, and various models have been proposed to explain it [12, 13]. Most explanations assume that the main causes of this climate shift were closely related to tectonism, such as the opening and closing of isthmuses, and uplift of the Himalayan Tibetan plateau and southwestern North America [14].

Atmospheric CO_2 concentrations and insolation fluctuations have also been cited as triggers for the climate shift [15, 16]. However, recent long marine and loess records imply that major glaciation may have begun well before 2.8 Ma, within the 3.6 ~ 4.6-Ma interval [17, 18, 19]. It is essential to make this difference clear, so that we can better understand the current climate system with its major Northern Hemisphere glaciation and insolation cycles. This goal requires more information to refine models and clarify the main causes of the climate system. Orbit-related climate signals are imprinted in Lake Baikal records [5, 6, 7, 8]. Here, some relationships between solar insolation and long-term environmental change are introduced, mainly based on long BDP98 cores, to understand the beginning of the current climate regime (Fig. 1).

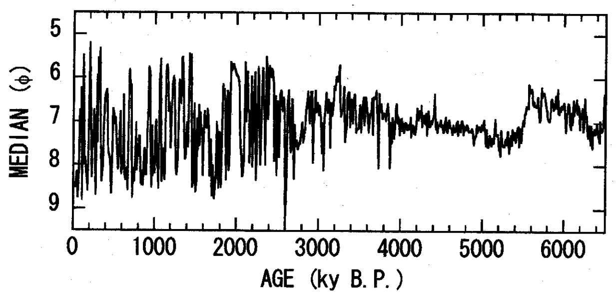

Fig. 1. Change in median grain size during the past 6.5 Ma.

The Asian continental interior cooled that the climate gradually, although not steadily, that there were several major shifts in environment, and that there were long-term periods related to insolation. Such periods had durations of about 1000 kyr, 600 kyr and 400 kyr, in addition to 100-kyr, 40-kyr and 20-kyr periods [5, 6, 9]. Another long period is introduced here and climate shifts are discussed here.

Filtered variations in grain size for the 6.5 myr clearly indicate that there was a longer period of around 2.0 myr in addition to the 1.0-myr and 0.6-myr periods. The 1.0-myr and 0.6-myr periods may be related to orbital oscillations [9]. Spectral analysis also supports these long periods. Most long periods known until now are generally related to orbital cycles. Calculated results for insolation with the same filters above indicate that it is certain that there is a period of around 2.0 myr, in addition to other long periods.

Several climate shifts are recorded in the long Baikal records. A shift in about the 2.6-2.8-Ma interval has been widely discussed in relation to major Northern Hemisphere glaciation. Shifts at around 3.6-4.6 Ma have recently been proposed, and have been mostly attributed to tectonic movements, such as the formation of isthmuses, uplift of the Himalayan Tibetan plateau, or the presence of islands [18, 19, 20]. Lake Baikal records also indicate that most orbit-related oscillations began to fluctuate more clearly at ca. 4.0 Ma, especially an oscillation at about the 400-kyr period (Kashiwaya et al. 2003).

Until now, major shifts in climate oscillation have been attributed to tectonism, as have the shifts at around 3.6-4.6 Ma and 2.6-2.8 Ma, as noted above. Other causes have been proposed more recently, because these rapid climate shifts cannot be explained by tectonism alone. It has been suggested that the first shift at about 4.0 Ma may have been related to solar insolation; an increase in the amplitude of 400-kyr filtered (eccentricity component) insolation clearly began at about 4.0 Ma, and that the amplitude of 40-kyr filtered (obliquity component) insolation increased at about 4.0 Ma as well as at 3.0 Ma, although there was no large fluctuation in other filtered insolations, suggesting that the shift at about 4.0 Ma was closely related to changes in insolation, especially to obliquity and larger eccentricity components. This idea is supported by the numerical simulations of Li et al. (1998)[21], in which ice-sheet volume in the Northern Hemisphere began to increase with a pulse after 4.0 Ma, and more frequently after 2.8 Ma in the case of a gradual decrease in atmospheric CO_2 concentration. These studies lead to the conclusion that the beginning of the current climate regime (characterized by major Northern Hemisphere glaciation) was at around 4.0 Ma, and that it intensified at about 2.8 Ma, both dates being closely related to changes in insolation. The 400-kyr eccentricity and obliquity parameters are interrelated for the 4.0-Ma shift, but the obliquity parameter alone is related to most of the 2.8-Ma shift. A small shift at about 3.6 Ma may represent a minimum point of eccentricity-related insolation.

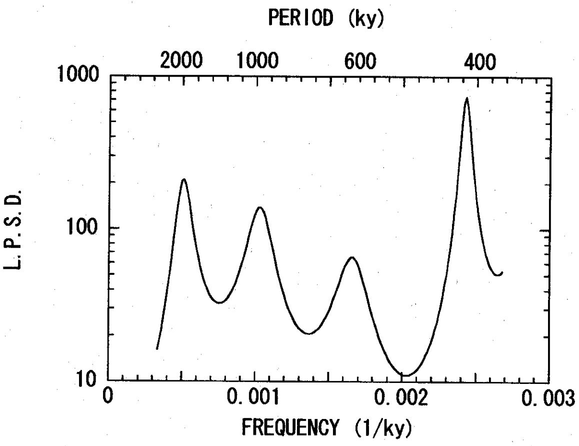

Fig. 2. Spectral analysis for the grain size fluctuation

Analytical results for comparatively short interval of the core obtained nearly the same point in the Academician Ridge are shown in Figs 3 and 4, indicating the fluctuation and periodicity are similar to those given by oceanic records although Baikal records are more sensitive to insolation..

Records from Lake Biwa, central Japan, located in the middle latitude are also shown in Figs 5 and 6. They also show similar fluctuation and periodicity, more sensitive than Oceanic records and less sensitive than Baikal records, suggesting its geographical position.

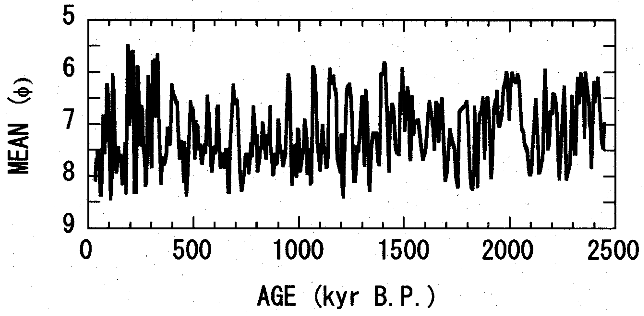

Fig. 3. Change in mean grain size of BDP96 during the past 2.5 Ma.

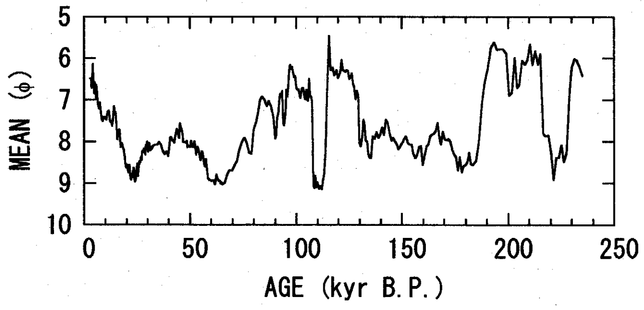

Fig. 4. Change in mean grain size of VER97 during the past 0.25 Ma.

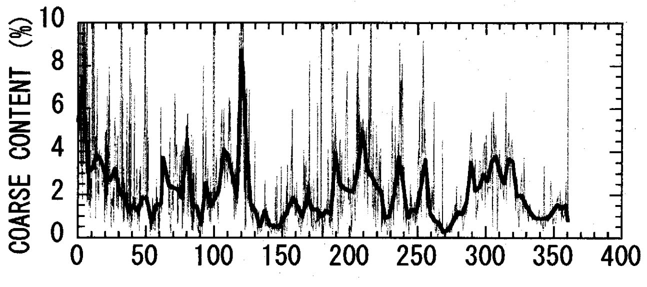

Fig. 5. Change in coarse content of grain size during the past 0.40 Ma for Lake Biwa.

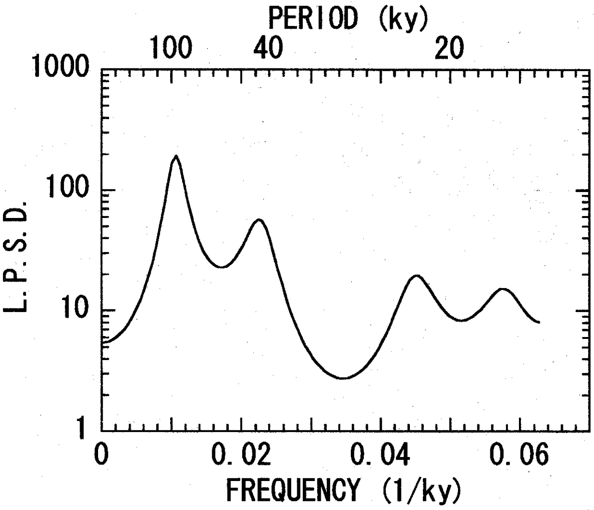

Fig. 6. Spectral analysis for the Lake Biwa fluctuation

III. Short lacustrine records

Changes in geomorphic systems are closely related to physical aspects of the Earth's surface, including topography, vegetation and hydrology, which are the result of tectonic and climatic forces in the present study area. The processes of erosion, transportation and sedimentation are observable in a typical catchment-lake system. For example, a large amount of sediment is produced by heavy rainfall, and it is transported, deposited and retransported within the catchment area before finally settling in a downstream lake. As a result, lacustrine sediments essentially are a record of environmental conditions in the catchment area, and have been used to reconstruct modern and ancient environments. Correlating observable catchment processes with modern lake sediments also provides useful insights into the relationships between past processes and sedimentation.

The extraordinary destructive earthquake (M7.2) of January 17, 1995, killed more than 6000 people in and around Kobe, Japan. Several cracks appeared in the Earth's surface along fault lines, and landslides occurred in the vicinity of the fault lines. Many studies have been made on the geological, geophysical, technological and human aspects of this earthquake, and most geological research has focused on the earthquake itself, and on co-occurring earthquake-related phenomena [22, 23, 24]. It is well known that some earthquake-generated geological hazards occur only briefly during an earthquake, while others proceed more gradually. In the latter case, earthquakes can continue to influence an environment long after the actual shaking stops. What has been unclear until now is just how long such gradualistic, post-earthquake phenomena continue to impact the Earth's surface environment. With this question in mind, we set out two sediment traps in one pond of the Kobe district immediately after the earthquake, in order to learn the earthquake's influence on surface processes, to learn how long this influence lasted, and to determine the differences between hydrological and seismic phenomena because we had studied hydrologic and geomorphologic phenomena recorded in the same pond [25, 26, 27, 28].

The Kobe district has often experienced episodes of disastrously heavy rainfall prior to the 1995 earthquake [27, 28]. More than 400 people were killed by rapid mass movements during heavy rainfall in 1938, and about 100 people were killed in. Landslides and mudflows resulting from the heavy rainfalls were the main causes of these disasters. As a result, citizens in and around Kobe have paid a great deal of attention to hydrological phenomena that may lead to disasters, and local governments had prepared against hydrological disasters prior to the 1995 Kobe Earthquake. Research on landslides and rainfall in this context has also been done by Kashiwaya et al. (1988, 1995) [27, 28].

Kawauso-ike pond is located in the middle of the Rokko Mountains (575 m a.s.l.) in Kobe where there are some active fault lines related to the 1995 earthquake, and it has been used previously to study landslides and heavy rainfall. Its catchment area covers 28 hectares and has a relief of 70m. The average water area is about 0.38 hectare and its deepest point is about 2.8 m deep. The lithology around the pond and in the catchment area consists of deeply weathered granite that has often produced landslides due to heavy rains. Two sediment traps were placed on the bed of the pond on May 1995, after the earthquake, in order to investigate earthquake-related changes in erosion, transportation and sedimentation that may have been imprinted in the lake sediments. Cores made with a cylindrical sampler were taken near to the sediment traps to obtain comparatively long sediment records.

Meteorological data from the Kobe Marine Observatory were incorporated into this study. Fig. 7 shows an average of 50 mm of excess daily rainfall plotted for the past 100 years, which may be related to the movement of surface materials in this district. A filtered fluctuation (the solid curve in Fig. 7; five-year high-frequency cut filter) of the rainfall clearly indicates the years with rapid mass-movement events. This figure also shows that there has been no rainfall related to such mass movements for the past 20 years, including after the earthquake, even though large rainfalls over 50 mm/day have occurred.

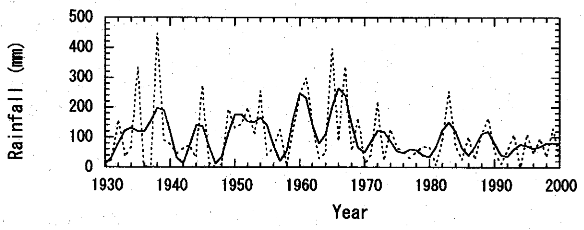

Fig. 7. 50mm excess rainfall (dotted line; original, solid line; filtered)

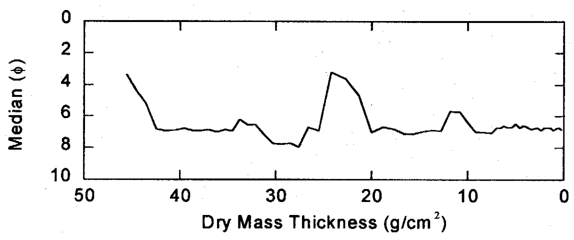

Fig. 8. Mean grain size fluctuation during the past 60 years

Fig. 8 shows temporal change in mean grain size for the cores over the past 60 years. Rapid coarsening events in the figure (arrows) may correspond to the rainfall-induced disasters mentioned above, which suggests that hydro-geomorphological processes are closely related to sedimentation (grain-size fluctuation). In other words, grain size in this case is a function of rainfall intensity. On the other hand, there is little change evident in the more-recent grain size in the cores, including for the earthquake period, which implies that the earthquake did not have a direct and strong influence on grain-size fluctuations (averaged over a few years). Age-scaling for these samples is based on Cs-137 concentrations.

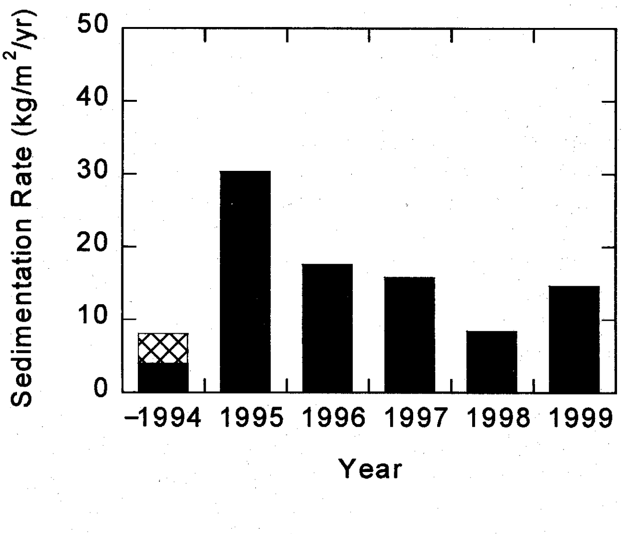

Fig. 9. Annual sedimentation rate

The annual sedimentation rate inferred from the sediment traps is shown in Fig. 9. The rate was high just after the earthquake and then gradually decreased. Seasonal changes in the sedimentation rate are generally controlled by rainfall, but there is no large fluctuation in annual (seasonal) rainfall despite a temporal decrease in the sedimentation rate.

These phenomena after the earthquake may be explained by a mathematical model (Kashiwaya et al., 2003), assuming that sedimentation rate in the lake is proportional to erosion rate in its catchment and erodible material (weathered one) is constant.

Theoretical sedimentation rate (dotted line) and observed one (solid line) are shown in Fig. 10, suggesting that the model introduced here is valid for the erosion-related sedimentation processes after the earthquake.

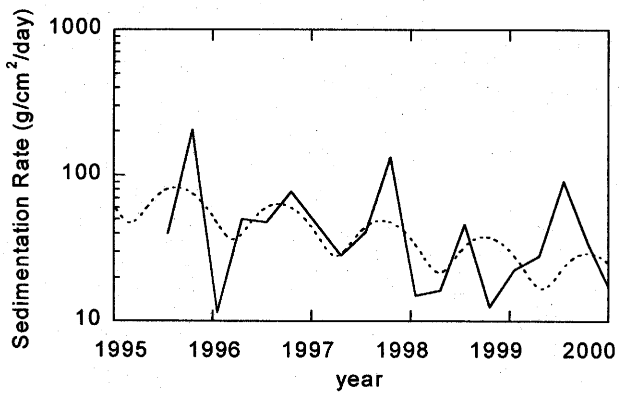

Fig. 10. Theoretical seasonal sedimentation rate (dotted line) and observed one (solid line)

Shaking during the 1995 Kobe Earthquake resulted in a greater rate of transport for surface material. The sedimentation rate in a pond near the active earthquake fault increased several fold just after the earthquake. However, this rate rapidly declined over several years, so that six years later there were no conspicuous surface movements related to the earthquake. The present sedimentation rate is only slightly higher than before the earthquake, so a new steady state for the structure of the surface evidently has been reached.

Most sediments were fine-grained after the earthquake, being nearly the same as before the earthquake, despite a high sedimentation rate just after the earthquake. The grain size remained mostly fine (slightly coarse, in a strict sense) even when comparatively heavy rainfall took place. The fine material generated during the earthquake would have remained in the surrounding catchment area after the earthquake, until a new steady state had been reached

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