CHANGES OF ECO-SYSTEMS IN THE LAST 500 YEARS CAUSED BY HUMAN IMPACTS IN LAKE SUIGETSU, CENTRAL JAPAN

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Abstract Annually laminated (varved) lacustrine sediments have been found in many Japanese lakes including Lake Suigetsu. Several studies for the reconstruction of past environmental and climatic changes have been carried out with varved sediments. However we have not yet clarified the relationships among abrupt changes of environment, biologic changes in lake eco-systems, and organic and inorganic changes in bottom sediments. Two problems can be summarized as follows: 1) on authigenesis of minerals as main components of sediments and 2) on ecological response of living microplanktons to changes of lake water condition.

By reason of confirming how the chemical composition of authigenic minerals and the species composition of diatom assemblages in varved sediments are linked with chemical composition of lake water, we carried out new coring and took 8 cores of well-preserved varved sediments by Meckereth piston sampler at Lake Suigetsu in 2000. Based on varve chronological, sedimentologic and micropaleontologic investigations, we clarified the following facts: 1) most of authigenic mineral particles have precipitated directly from bottom water mass through sulfate reduction, but not from interstitial water in sediments: 2) abrupt environmental changes in water eco-system were caused by human impacts in and around Lake Suigetsu during the last 500 years: 3) after the lake eco-system gradationally evolved by low rate external impacts, it never returned to the initial condition without other impacts: 4) short term changes of lake eco-system and phytoplankton communities have been caused by external human impacts with high rate.

Key words: varve, lake eco-system, human impact, rate of environmental change

1. Introduction

Annually laminated (varved) lacustrine sediments have been found in many brackish water lakes of Japan, including Lake Suigetsu (Fukusawa 1995: 1999). Also, several studies have been carried out on the reconstruction of the paleoenvironment and the paleoclimate using varved sediments since 1991. However, we have not clarified relationships among abrupt environmental changes such as human impacts *etc.*, biological changes in lake eco-

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system and inorganic and organic sequential changes in the bottom sediment column. In other words, it is possible that abrupt mineralogical and paleontologic changes in sediment sequence do not always reflect directly lake eco-system changes in water mass above the sediment.

Now, we have identified two problems on reconstruction of environmental changes while analyzing lake sediments i.e., 1) authigenesis of biochemical minerals under pre-, syn- or post-depositional processes and 2) ecological responses of living microplanktons. In particular, we have to address four questions while dealing with the first problem. Where has it occurred in the sediment column? Has authigenesis of minerals been truly promoted in well-stratified water condition preserving laminated sediments? Do sequential changes of mineral and chemical composition in lake sediments indicate time-series of environmental changes in and/or around lake, if the authigenic minerals precipitated from interstitial water under post-depositional and early diagenetic stages?

In 2000, we obtained 8 cores for analysis measuring 4m in length, from Lake Suigetsu, central Japan. Figure 1 shows the coring sites. Except for two cores, laminated structures were recognized from bottom to top by naked eye and soft X-ray pictures on all cores. These cores are now being analyzed for diatom assemblages by the second author, for paleomagnetism by Prof. Akira Hayashida of Doshisha University, Kyoto and for sedimentary structure and texture by the first author.

Our purpose in this preliminary report is to answer the aforesaid questions and to show that biochemical particles in varved sediments of the lake could be a powerful proxy for high-resolution reconstruction of past environmental changes.

2. Authigenesis of minerals in bottom sediment column

Several studies have been undertaken as regarding the early diagenesis in the bottom sediments of Lake Suigetsu. Masuzawa and Kitano (1982) discussed sulfate reduction caused by seawater invasion in 70 cm long cores and concluded that authigenesis of pyrite (FeS_2) minerals promoted directly from interstitial water above 20 cm depth of sediment core. They also carried out diatom analysis in the same core and indicated that seawater invasion started at 35 cm core depth, though pyrite precipitation appears for the first time at a depth of 50cm. This investigation has indicated that core depth of mineral changes, caused by seawater invasion, was not equal to the diatom assemblage changes in the same sequence. If that is true then it follows that authigenic mineralogical changes of sediments have not always been useful for decadal to the century scaled reconstruction of paleo-environments. However we question the work of Masuzawa and Kitano (1982), because they never showed sedimentological and stratigraphic evidence at the sampling points for geochemical analysis. By reason of confirming how the chemical composition of authigenic minerals and the species composition of diatom assemblages in varved sediments were linked with chemical composition of lake water, we analyzed columnar sequence of Lake Suigetsu using the new cores which were taken in 2000. In relation with the depositional age of cored sediment, we could find one tephra and one turbiditic layer. The tephra layer was recognized at 50 cm core depth and seemed to correlate to Sakurajima tephra ejected in 1779 AD. The turbidite

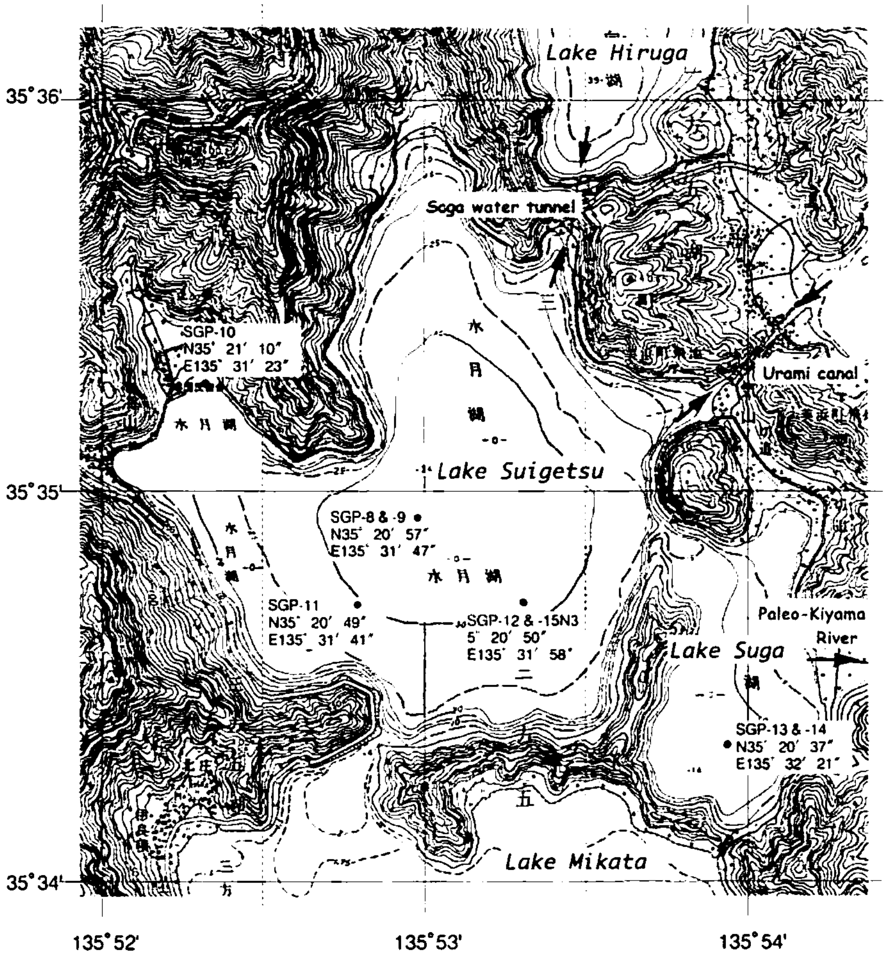

Fig. 1 Locations of coring sites of Lake Suigetsu in 2000.

horizon caused by an earthquake in 1662 AD (Fukusawa *et al.* 1994) was represented at the depth of 110 cm. Figure 2 shows pictures of the muddy turbidite layer under a microscope. In this figure, we could observe upward fining sequence in grain size and inclusion of woody fragments and both planktonic and benthic diatom frustules.

Fossils of diatoms which lived in the sea and brackish water occurred above 100 cm depth in these cores (Kato *et al.* 2001). This occurrence indicates the seawater invasion into the lake. According to the historical documents around Lake Suigetsu (Fukusawa *et al.* 1994), seawater invaded from Lake Kukushi, through an artificial canal of Urami River in 1664 AD from the north.

Chemical composition of minerals also suggested the invasion of SO_4^{2-} ion-rich seawater. Microscopic observations, using thin sections, and powder X-ray diffraction mineralogy indicated that authigenic grains of pyrite precipitated in the sequence above 100 cm depth. On the other hand, Masuzawa and Kitano (1982) placed the horizon of seawater

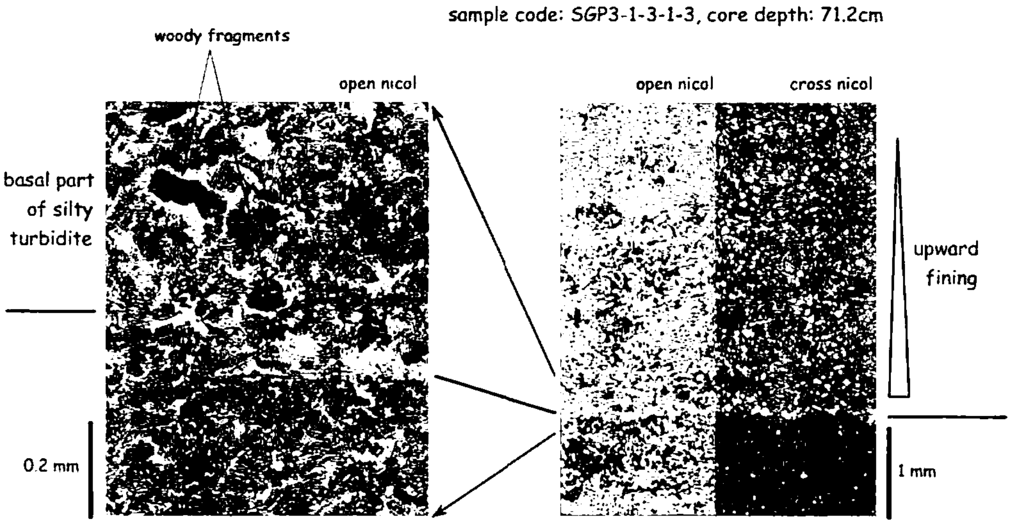

Fig. 2 Photograph showing sedimentary micro-structures of turbidite layer caused by 1662 AD earthquake.

invasion correlating to 1664 AD at 35 cm core depth. It is possible that chronological interpretation by Masuzawa and Kitano (1982) was not accurate.

In Lake Suigetsu, stable well-stratified water mass has been formed by seawater invasion under freshwater. In this stratified water column, vertical circulation of lake water has been interfered. Limnologic data worked out by Yagi (1981) shows that sulfate reduction has occurred in lower parts of water mass and that micro-grains of pyrite have precipitated above the surface of bottom sediments.

Based on such data, we propose the limnologic process under stratified conditions composed of seawater and freshwater (Fig. 3). Figure 3 shows two different chemical conditions of lake water. Lower figure shows the low-stand of sea-level before 1664 AD. In this condition, siderite ($FeCO_3$) grains precipitated only in disaerobic fresh water (Fukusawa 1999). The upper figure shows the high-stand of sea-level after 1664 AD. Under sulfate reduction conditions, pyrite (FeS_2) grains precipitated (Fukusawa 1999). In both cases, authigenic iron minerals were formed in oxygen-poor bottom water. Our interpretation supports that authigenic iron minerals precipitated at the sediment-water interface, but not in interstitial water of sediments.

3. Quick response of lake eco-system to human impacts

We also attempted to investigate correlation between abrupt sedimentologic changes and human activities such as artificial construction on the base of varve chronology and historical documents since 1500 AD. We here only discuss on 1) pyrite sulfur contents (wt.%), 2) total organic carbon contents (wt.%), 3) opal-A contents (counts per second (cps) by powder X-ray diffraction method) corresponding to diatom frustules, 4) primary production (gC/cm^2yr) calculated from other data such as bulk density, sediment accumulation rate

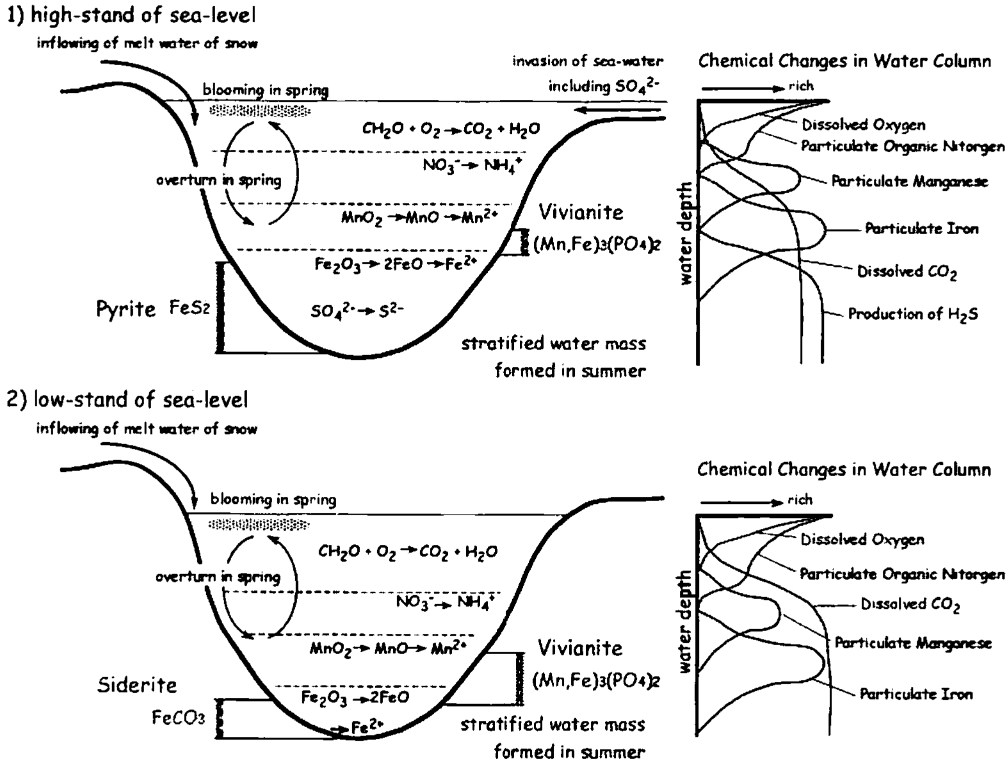

Fig. 3 Formation model of authigenic minerals in bottom water mass of Lake Suigetsu.

based on varve counting and organic carbon contents , 5) siderite contents (wt.%) accumulated only in freshwater conditions, 6) calcite contents (wt.%) accumulated only in sea and brackish water conditions (Fig.4: Fig.5).

Human activity has been very intensive around Lake Suigetsu as historical documents mention (Fukusawa *et al* 1994). In 1642 AD the Kiyama River, connecting Lake Suigetsu and Lake Kukushi, was dug deeper as the water level of Suigetsu was falling. This operation was done in order to irrigate and construct new rice fields. But in 1662 AD the river bed was uplifted by earthquake displacement (on 16th June. 1662 AD) and the lake level also rose abruptly. In 1664 AD the Urami canal connecting Lake Kukushi and Lake Suigetsu was constructed. Consequently, seawater began to flow into Lake Suigetsu through Lake Kukushi. In 1801 AD the Saga water tunnel connecting Lake Hiruga and Lake Suigetsu was constructed to prevent flooding around Lake Suigetsu. The tunnel was repaired and widened in 1848 AD and 1932 AD.

The freshwater fish community in Lake Mikata has been decreasing since 1932 AD. This faunal change indicates the invasion of seawater into Lake Mikata through the tunnnel. In 1934-1935 AD removal of slime in the Urami canal and the Saga water tunnel were carried out. These human impacts on the eco-system of Lake Suigetsu must have been recorded as the changes of mineralogical and micro-paleontologic composition in a sedimentary column.

Time-series changes of inorganic and organic composition since 1500 AD (Fig.4: Fig.5)

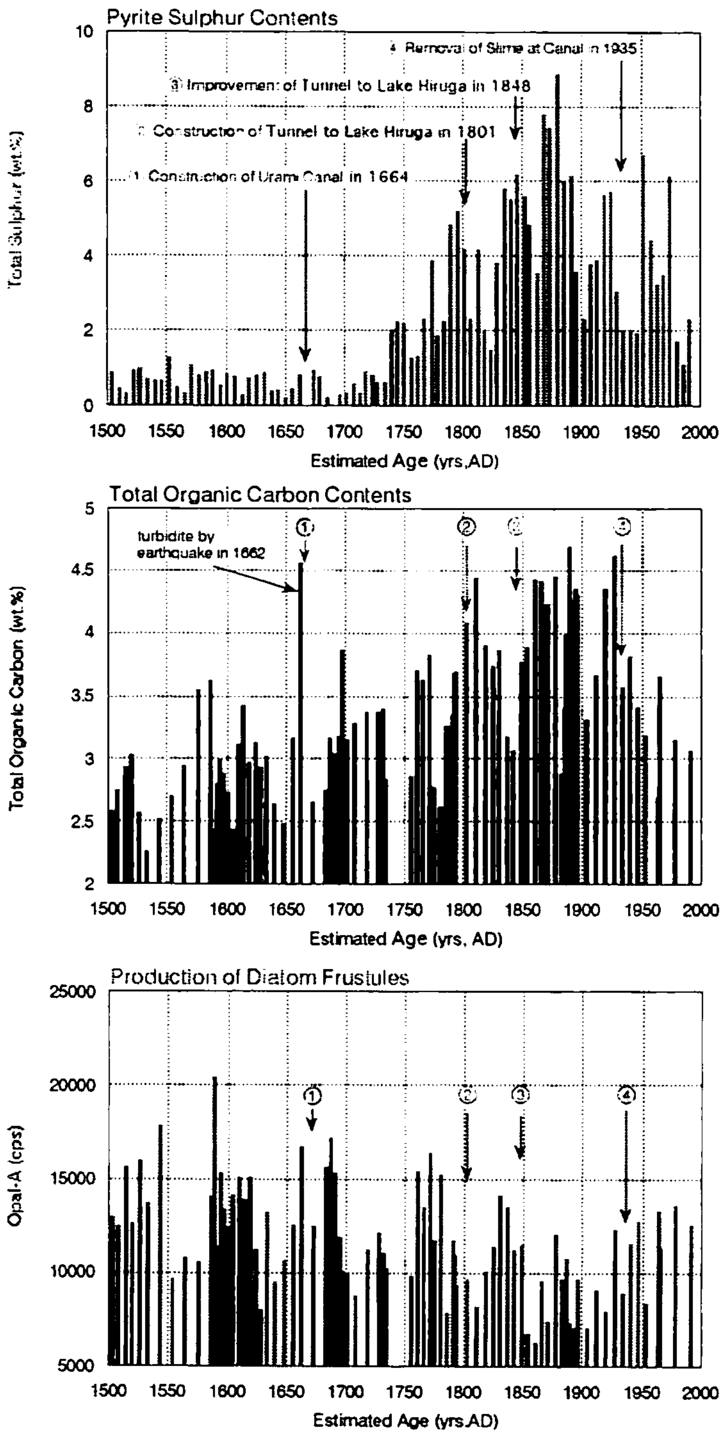

Fig. 4 Time-series changes of total sulfur (upper), total organic carbon (middle) and opal-A (diatom frustules) (lower) contents since 1500 AD recognized in cores obtained from Lake Suigetsu.

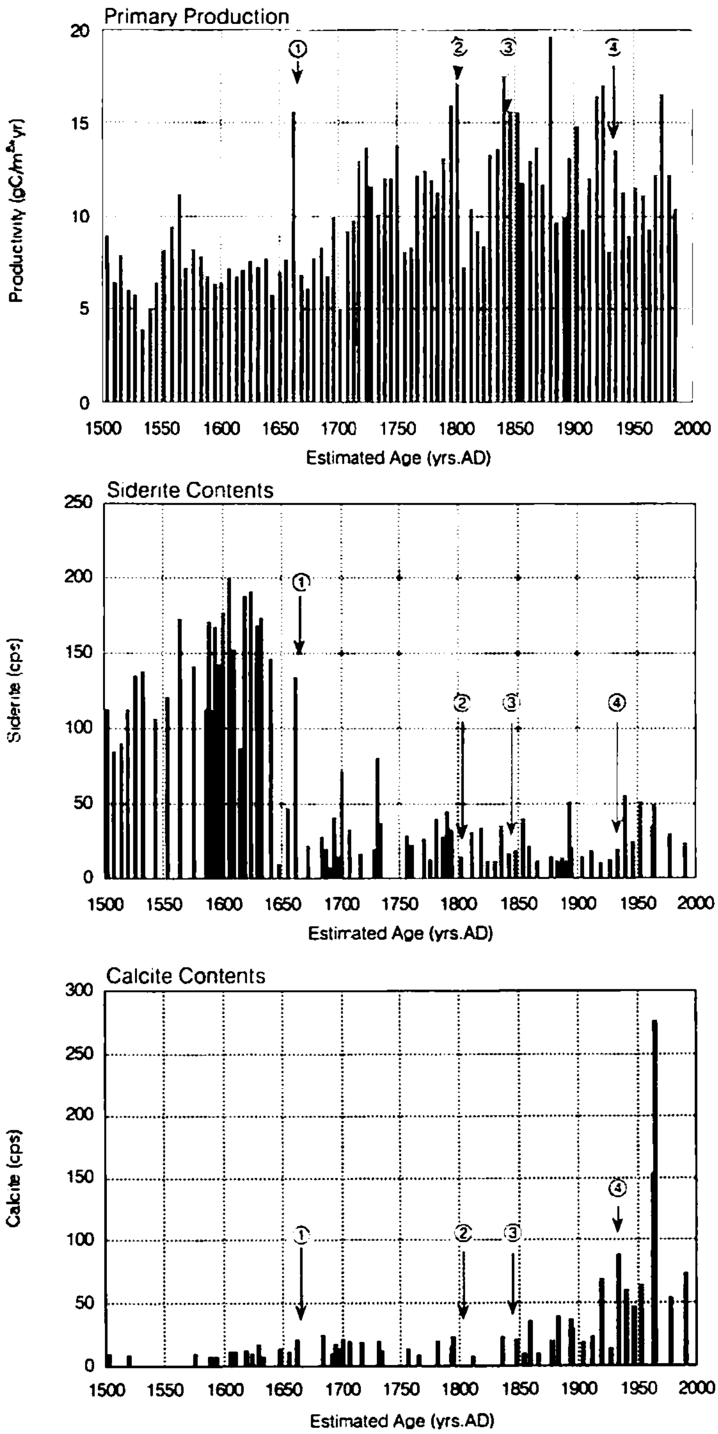

Fig. 5 Time-series changes of primary productivity (upper), siderite (middle) and calcite (lower) contents since 1500 AD recognized in cores obtained from Lake Suigetsu.

give us an understanding of human impacts. Results of sedimentologic analysis indicate that siderite contents decreased abruptly after 1664 AD, but pyrite contents increased from 1740 AD. This turn over of iron minerals indicates the replacement of fresh bottom water by SO_4^{2-} ion-rich seawater (Fukusawa 1999) . An increase of organic carbon contents shows that primary production has increased since 1720 AD. Organic carbon seems to be produced by phytoplankton except diatom, because diatom contents have not shown remarkable increase since 1710 AD. The other taxa of phytoplankton, except diatom, which bloomed after 1710 AD, did not have resistant tests. Hence we could not undertake many tests except for diatom, cyanobacteria and resting spores *etc.* (Kato *et al.* 2001).

Pyrite and organic carbon contents decreased abruptly after artificial constructions of 1801, 1848 and 1932-1935 AD (Fig. 4; Fig. 5). These constructions seem to cause active water circulation between Lake Suigetsu and its surrounding lakes as pyrite sulfur contents decreased abruptly after these reconstructions. However, organic carbon contents increased after the abovementioned constructions. Increase of organic carbon contents attributes to the large blooming of phytoplankton except diatom induced by inflow of nutrient- and oxygen- rich brackish water into Lake Suigetsu. These facts strongly suggest that the eco-system in Lake Suigetsu responded to human impact with quick changing rates and then recovered to diatom-dominated conditions 20-30 years later.

As an exception, in the case of 1664 AD canal construction, there was a time gap between the seawater invasion and change of water mass condition in Lake Suigetsu. Precipitation of pyrite grains and stratification of water column became clear 70-80 years after 1664 AD (Fig. 4). This stratified water condition was sometimes destroyed slightly by inflow of oxygen-rich water, when canal and tunnel were constructed. However, bottom water mass of the lake has maintained a disaercbic condition since 1740 AD.

These evidences support our interpretations i.e., 1) lake water eco-system is sensitive to human impacts such as inflow of seawater, 2) when the impacts occur in a short time, lake water eco-system quickly recovered to a diatom-dominated condition, and 3) once the lake water eco-system is evolved by external impact over a long time, it will never return to its initial condition.

4. Concluding remarks

To make accurate prediction of environments surrounding human cultures, it is valuable to decipher the past climatic and biologic records. Particularly, the rates of these changes are important for predicting the future environment. As an example, the response mode and speed of eco-system to the water condition changes were clarified using varved lacustrine sediments.

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