Reconstruction of Lake Level and Paleoenvironmental Changes from a Core from Balkhash Lake, Kazakhstan

Kunihiko Endo[1)]* , Takashi Chiba[2)], Toshihiko Sugai[2)], Tsuyoshi Haraguchi[3)], Hideo Yamazaki[4)],Yasunori Nakayama[1)], Yuichi Yoshinaga[3)], Koshiro Miyata[3)], Shino Ogino[5)], Katsuhiro Arakawa[1)], Yuriko Nakao[1)], Jiro Komori[1)], Reisuke Kondo[1)], Haruka Matsuoka[6)], Bolat Z. Aubekerov[7)], Renato Sala[7)], Jean-Marc Deom[7)], Hidehiro Sohma [8)] and Jumpei Kubota [9)]

1) Department of Geosystem Sciences, Nihon University, Japan 2) Graduate School of Frontier Sciences, The University of Tokyo, Japan 3) Graduate School of Science, Osaka City University, Japan, 4) KinkiUniversity, Japan, 5) Mitsubishi Space Software Co., Japan, 6) Tsukuba Gakuin University, Japan, 7) Department of Geoarchaeology, Kazakh Scientific Research Institute on Problems of the Cultural Heritage of Nomads, Kazakhstan, 8) Nara Women's University, Japan 9) Research Institute for Humanity and Nature, Japan.

CONTENTS

1. Introduction

Using results from previous seismic and topographical surveys, we analyzed core samples taken in 2007 to investigate lake level and sedimentary environmental changes in and around Balkhash Lake, Kazakhstan, during the last 2000 years. In Sections 2 and 3, we summarize the results and

1) Department of Geosystem Sciences, Nihon University, Setagaya-ku, Tokyo 156-8550, Japan
2) Graduate School of Frontier Sciences, The University of Tokyo, Kashiwa, Chiba Prefecture 277-8563, Japan
3) Graduate School of Science, Osaka City University, Sumiyoshi-ku, Osaka 558-8585, Japan
4) Kinki University, Higashi-Osaka, Osaka, Japan
5) Mitsubishi Space Software CO., Kamakura City, Kanagawa 247-0065, Japan
6) Tsukuba Gakuin University, Tsukuba, Ibaraki Prefecture 305-0031, Japan
7) Kazakhstan Scientific Research Institute on Problems of the Cultural Heritage on Nomads, Almaty, Kazakhstan
8) Nara Women's University, Nara, 630-8506, Japan
9) Research Institute for Humanity and Nature (RIHN), Kita-ku, Kyoto 603-8047, Japan
* Corresponding author, email address: endo@chs.nihon-u.ac.jp

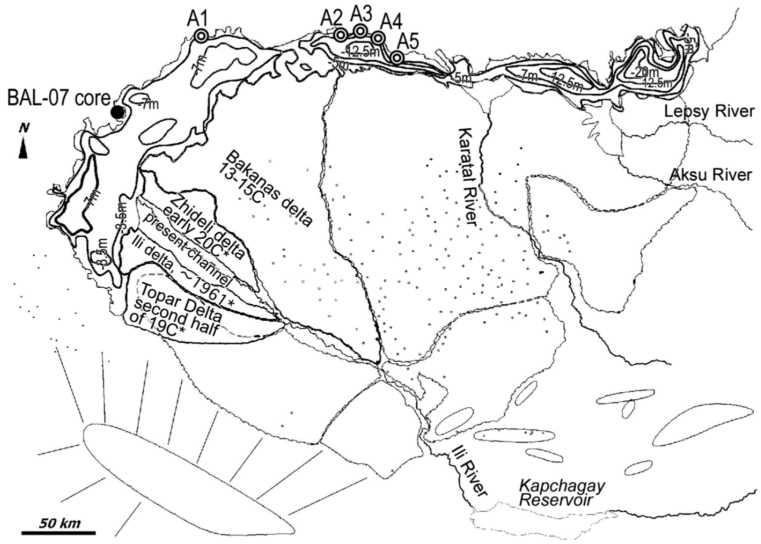

Fig.1 Map of the Balkhash Lake area.
The delta distribution is from Abdrasilov and Tulebaeva (1994).

conclusions of several previous studies of Balkhash Lake. Then, in Section 4, we present results of core analyses of magnetic susceptibility, soil color, grain size, chemical properties, accelerater mass spectrometry (AMS) ^{14}C and ^{137}Cs ages, and diatom and ostracod fossils. In Section 5, we compare our results with corresponding results from the Aral Sea and discuss environmental changes in this area over the past 2000 years.

2. Sedimentary condition in Balkhash Lake based on acoustic survey

To clarify the sedimentary structure of lake sediments in Balkhash Lake (Fig.1), and also to de-

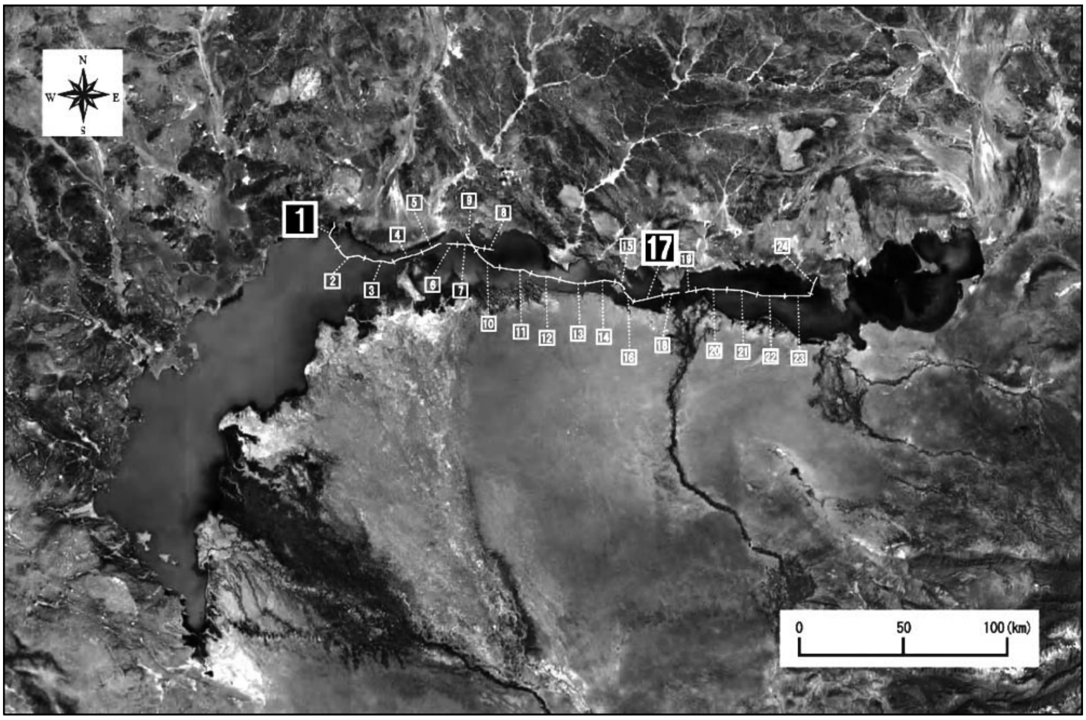

Fig.2 Seismic survey lines and locations of the profiles (Haraguchi *et al.*, 2009; base map from Google map satellite image).

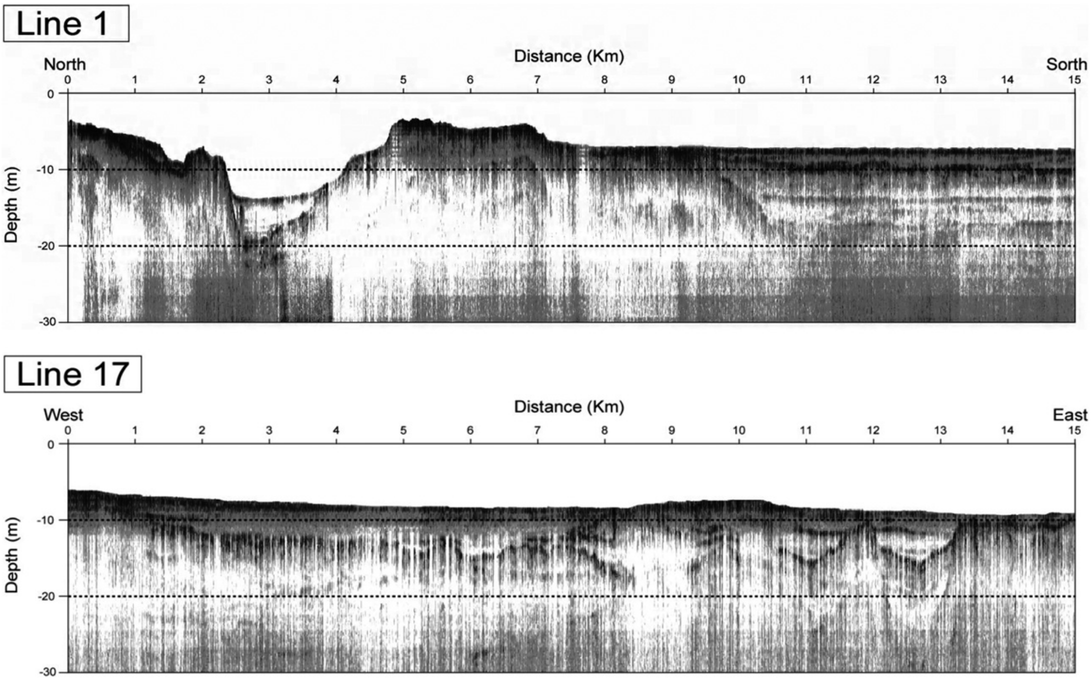

Fig.3 Seismic profiles along survey lines 1 and 17 (Haraguchi *et al*., 2009). Locations of the survey lines are shown in Fig.2.

termine suitable coring sites, a substratum seismic survey was conducted along a survey line about 290 km long in the eastern part of the lake with a StrataBox (3.5KHz; SyQwest Inc., Rhode Island, USA) seismic profiler (Fig.2). Positions of the boat were measured by GPS every second, and the boat was navigated using a map generated by Kashimir 3D software, Landsat images, and DEM (Digital Elevation Model) data derived from the SRTM(Shuttle Radar Topography Mission).

The topography of the Balkhash Lake basin shows that the elongated lake is located along the northern margin of the basin as a result of the progradation of deltas. The clastic materials of the delta area were supplied mainly by the Ili River but also by the Karatal, Aksu and Lepsi rivers.

Haraguchi *et al*. (2009) conducted a survey in which they determined that most of the lake is less than 10 m deep, and that the soft sediment has a maximum thickness of about 10 m. They also identified several buried valleys. The elevations of the buried valleys and erosional terraces suggest probable paleo-lake levels of 325 m, 330 m, and 335 m, or about 5 to 15 m lower than the present level of 340 m asl (Fig. 3).

In some narrow parts, flow velocity is so high that the bottom is eroded, and only coarse materials are deposited by the segregation of finer materials.

Coring sites for reconstruction of environmental changes must be stable and have continuous sedimentation. The survey of the eastern part of the lake, where it is deepest (about 20 to 25 m), showed that some inlets along the northern coast have thick deposits of soft sediment, and sites there are also suitable because wave action is weak and the inflow of terrestrial materials is low.

The same type of survey must be conducted for the western part of the lake as well to obtain a better idea of the sedimentary conditions in the entire Lake.

3. Lakeshore topography relating to past lake-level changes

On the basis of satellite data analyses in the past 30 years and high-spatial -resolution satellite data, topographies relating to the lake level have been distinguished and mapped on the images chiefly along the northern coast of Balkhash Lake (Fig.4; Nakayama *et al*., 2009).

In a 2008 survey of the northern coast, some shorelines indicated by coastal bars mapped on the high-spatial-resolution satellite images were recognized within a height of 3 to 4 m above the 2008 lake level (Fig.5). Behind the shorelines, additional bars and some lake terrace-like topographies are distributed about 6 to 12 m higher than the present lake level.

A record of lake-level changes from 1880 to 1988 was published by Kip-shakbaer and Abdrasilov (1994). Using their observations and data on lake area change based on satellite data during the last 30 years (Nakayama *et al*., 2007), Nakayama *et al.* (2009) created a lake level change curve of the last 128 years (1880－2007；Fig.6).

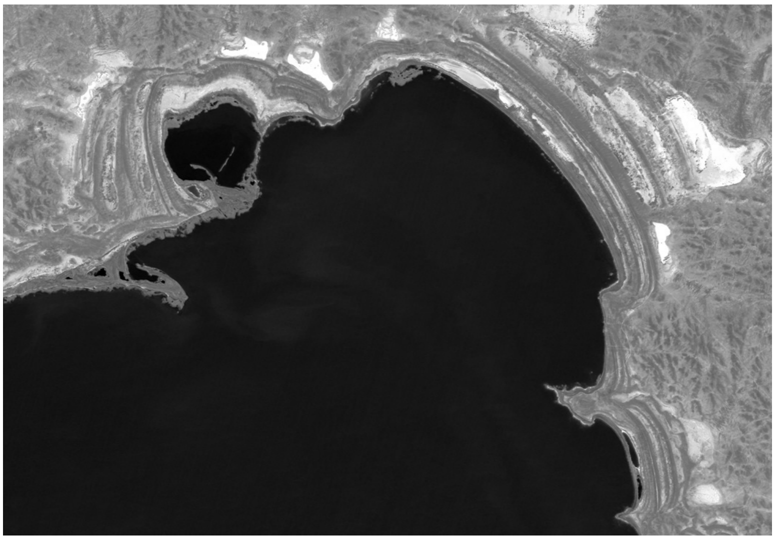

Fig.4 Satellite image of typical bar topography along the northeastern shore of Balkhash Lake (Nakayama *et al*., 2009)

The high lake level around 1908 (about 3 m higher than the 2008 level), and the high lake level

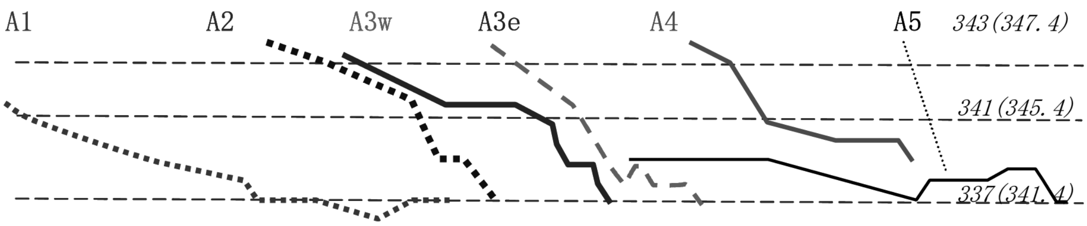

Fig.5 Topographical survey of older shorelines along the northern shore of Balkhash Lake (locations are shown in Fig.1)

from 1960 to 1972 (2－2.5 m higher than the 2008 level) probably correspond to the second and first shorelines (bars) from the present shore. Both are very well preserved and appear to be the youngest shorelines.

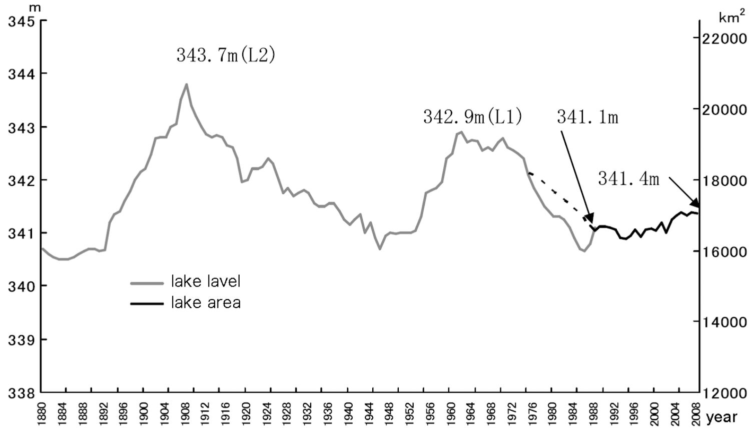

Fig.6 Balkhash Lake level and area from 1880 to 2007 (Nakayama *et al*., 2009)
1880-1988: Kipshakbaer and Abdrasilov, 1994
1988-2008 area change: Nakayama *et al.,* 2007

In a future investigation, we expect to use a highly precise Digital Elevation Model (DEM) derived from the ALOS/PRISM data with a 2.5-m spatial resolution to extract a detailed topography and a relative height survey.

It is important to determine the ages of the higher lake levels, which are suggested by higher bars and terrace-like topographies, using the optically stimulated luminescence (OSL) dating method.

4. Analysis of the Balkhash 2007 core

4.1. Lithology, soil color, and magnetic susceptibility

A core (Balkhash 2007 core) was taken from the western part of Balkhash Lake (46°17’ 21.2″N ; 74°00’ 33.6″E) in summer 2007 by Kazakhstan members. The site is just west of Tasaral island (Fig.1), at the shadow of the main part of the lake. The core is approximately 6 m long and is composed of dark to pale greenish gray, homogeneous silty clay to clayey silt. The magnetic susceptibility and soil color were measured at each 2.4-cm intervals, and the results are shown in Fig.7.

4.2. Age model

To establish the age model of Balkhash 2007 core, AMS-method radiocarbon dating and ^{210}Pb and ^{137}Cs measurements were conducted. For the AMS datings, fossil ostracod valves were collected from six core horizons with peak ostracod abundance and dated in a laboratory at PLD (Paleo-Labo Co., Gifu Prefecture, Japan). Those six dates are plotted in Fig.8. Three preliminary bulk samples were dated in the same laboratory previously (Endo *et al*., 2009). The age of the ostracod sample from -550cm shows the similar age of one bulk sample from -585cm, which is near the bottom of the core and has the most ostracod fossils. The other two bulk samples were older than the trend shown by six ostracod samples.

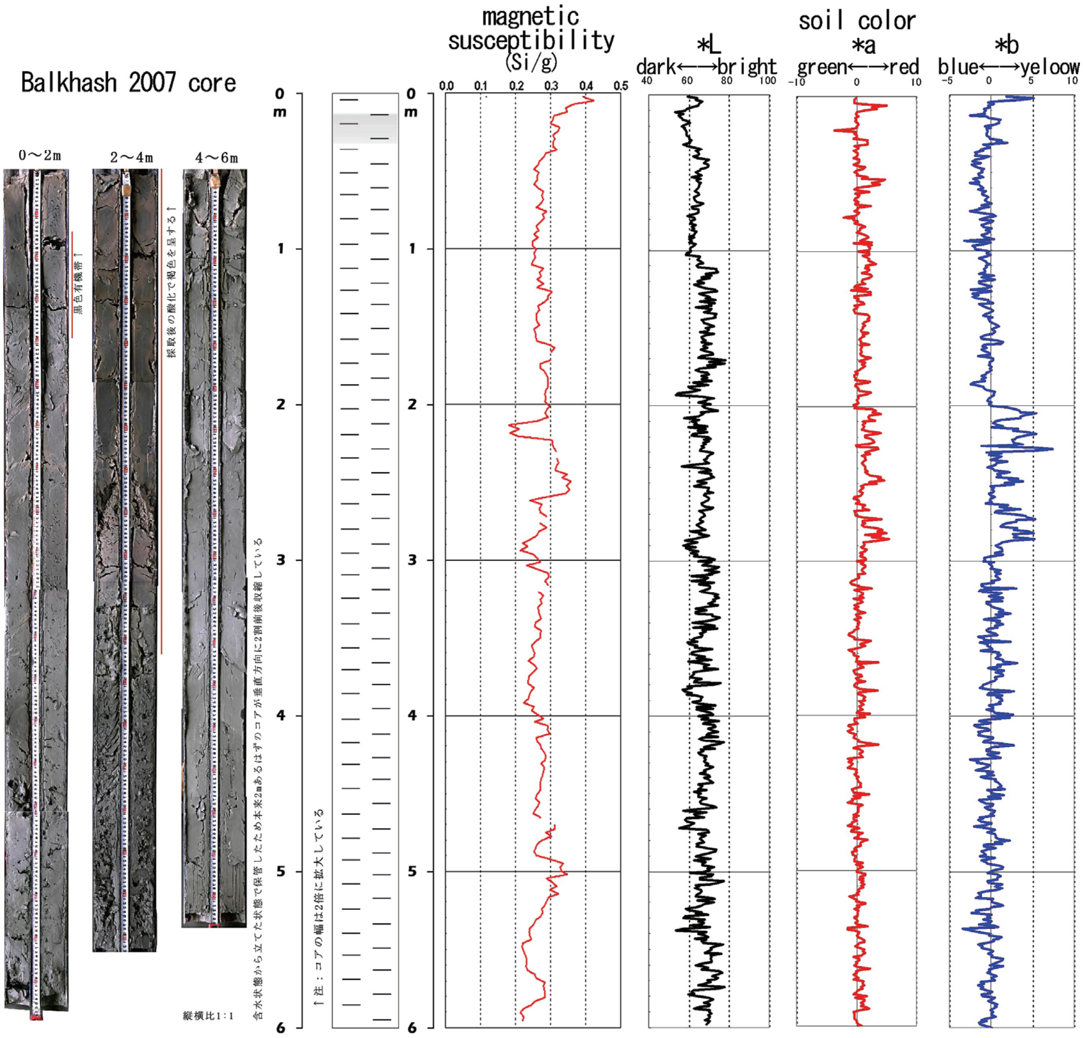

Fig.7 Columnar section, magnetic susceptibility, and soil color (*L, *a, *b) of the Balkhash 2007 core.

Photos of the top, middle and bottom of the core are shown from left to right respectively.

^{210}Pb and ^{137}Cs measurements were carried out on 14 samples from -3.6 cm to -44.4 cm, in a laboratory at Kinki University in Osaka. According to ^{137}Cs measurements, the lowest horizon in which ^{137}Cs was detected was deposited in 1950 and the peak horizon was deposited in 1963.

On the basis of these age data including AMS ages for 6 ostracod samples and the two by ^{137}Cs, 1950 and 1963, the age model shown in Fig.8 was estimated.

The average sedimentation rate was about 3.4 mm/year, but it decreased to about 1.1mm/year in the top 1 m. There are no sedimentation anomalies or boundaries, however, and the sediment looks continuous.

4.3 Diatom and ostracod analyses

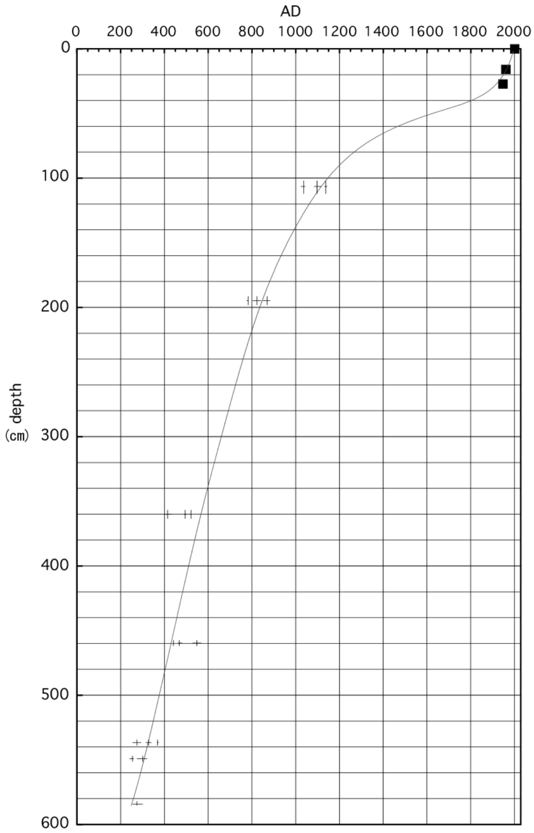

Fig.8 Age model of the 2007 core
+: ^{14}C age (calibrated) using ostracods
▪: ^{137}Cs

Diatoms living in various aquatic and partly terrestrial environments are good indicators of water quality, water depth, and other environmental factors. In this study, we used diatom flora to reconstruct lake-level changes in Balkhash Lake. Generally speaking, lake level and water depth changes are reflected in salinity changes in closed lakes. The diatom analysis of Balkhash 2007 core was carried out at 12-cm intervals, although the preliminary results presented in Endo *et al.* (2009) were for 24-cm intervals.

Fresh water planktonic diatoms of *Aulacoseira granulate* are dominant in almost all samples except in the horizons at -585 cm (the bottom of the core), -280 cm, -200 cm and -10 cm, where they decreased remarkably and abruptly and were replaced by saline benthic diatoms such as *Thalassiosira lacustris, Rhopalodia gibba*, *Scoliopleura peisonis*. In the horizons at -540 cm and -430 to -480 cm, freshwater planktonic diatoms also decreased but not as remarkably, and saline benthic diatoms increased.

These results suggest that a rapid decrease in lake level and an increase in salinity occurred, especially at the depths of -280 cm and -585 cm, because a very high percentage of brackish species occurs at these depths. Those are similar to benthic species in coastal sea water. However, just above these horizons, the abundance of freshwater and planktonic species increased abruptly. This change suggests a quick rise in the lake level at this time. Salinity change inferred from the diatom flora therefore appears to be a good indicator of frequent lake level changes in Balkhash Lake.

A fossil ostracod analysis was also conducted for the same core. As shown in Fig.10, the number of fossil ostracod was relatively high in only six horizons: -550 cm, -540 cm, -480 to -460 cm, -370 cm, -200 cm, and -100 cm. The horizon at -585 cm, at the bottom of the core, had the most fossil ostracod valves, but we could not include this horizon in our analysis because we had used the bottom sample for the AMS dating and an insufficient amount remained for analysis. Around -280 cm, where saline diatoms are abundant, ostracods show only small peaks. Almost all the major ostracod peaks, however, correspond to lowered lake level horizons as deduced from higher percentages of saline diatoms. They include abundant saline water species as *Cyprideis torosa* and *Cy-*

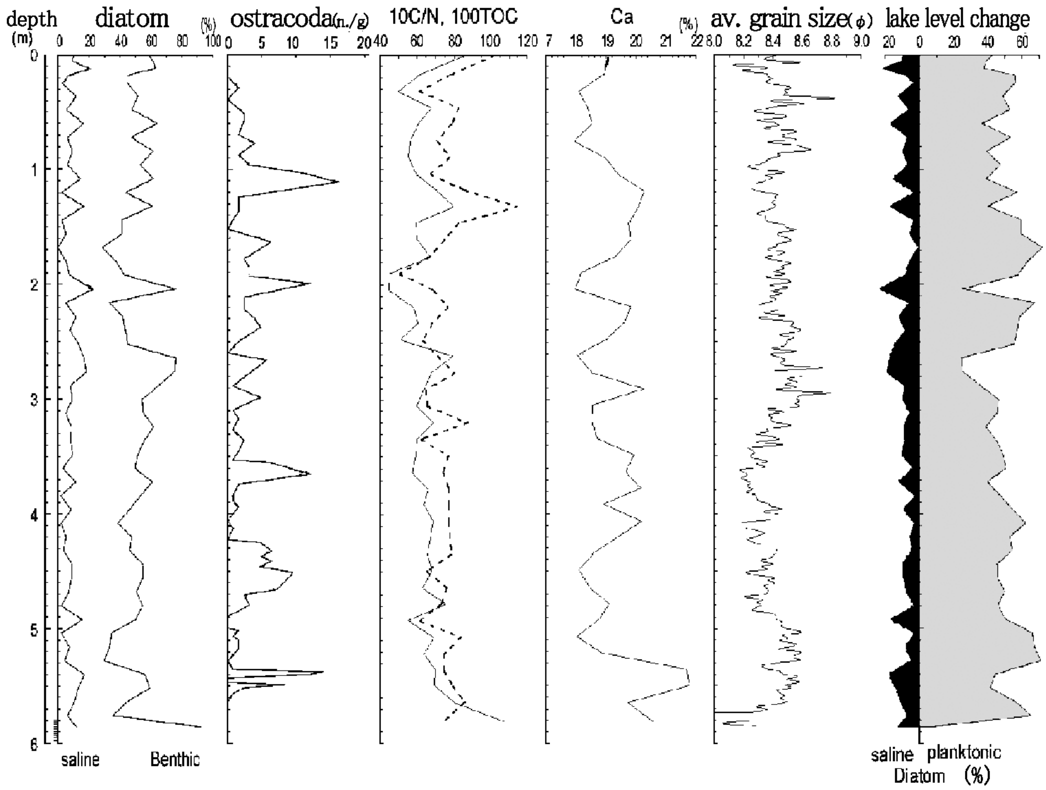

Fig.9 Results of diatom, ostracod, C/N, TOC, Ca, and grain-size analyses of the Balkhash 2007 core. Lake- level changes inferred from the diatom assemblages are also shown.

prideis spp. along with minor amount of freshwater species as *Darwinula* sp. and *Ilyocypris* spp. Especially, *Cyprideis torosa* is known to be tolerable in hyperhaline environment (e.g. Meisch, 2000). Only one peak (-370 cm) includes abundant amounts of saline and freshwater ostracods, indicating a rising lake level, although not a major peak (Fig.9). We attributed this peak to increased inflow of freshwater from the Ili River.

5. Discussion

According to our diatom and ostracod analysis result, decreasing lake levels are indicated at depths of -585 cm, -550 to -540 cm, -480 to -460 cm, -280 cm, -200 cm, and -100 cm, as mentioned previously. At -280 cm, ostracod data do not show a peak. However, the diatom data from all these horizons show an abrupt decrease in freshwater planktonic species and dominance of benthic and brackish species. Conversely, the high, wide ostracod peak of -100 cm suggests minor low lake level in diatom data.

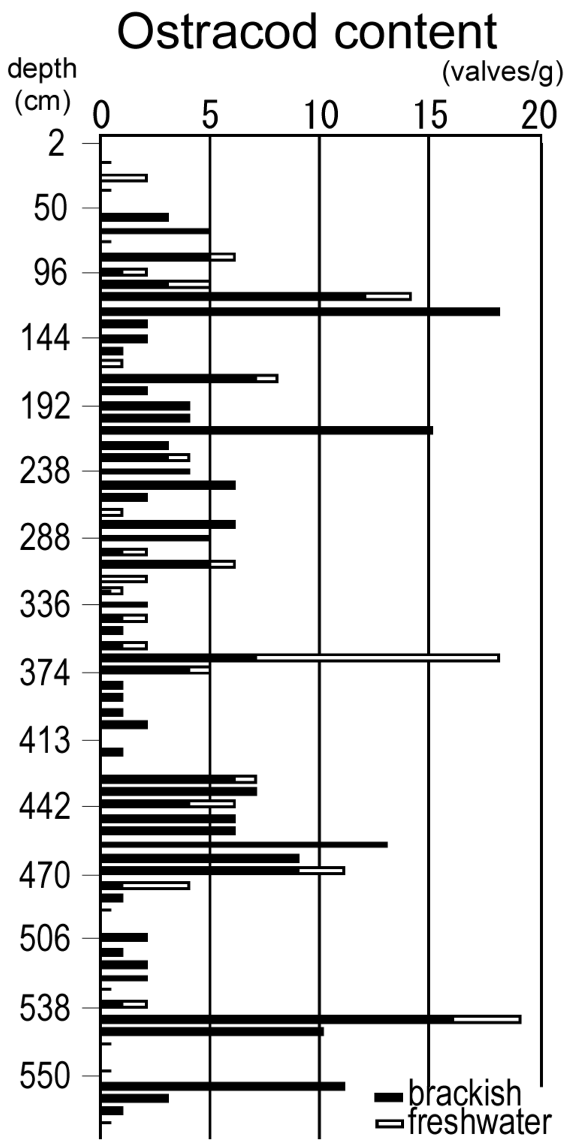

Fig.10 Proportion of brackish and freshwater ostracod species in the Balkhash 2007 core. (number / gram)

We compared the age model of the Balkhash Lake core with one from Aral Sea core (after Boroffka *et al.*, 2006; Fig.11). Environmental changes in the Aral Sea have been reconstructed primarily by analyses of dinoflagellate cyst, ostracods and pollen, but also archaeological and historical records (Boroffka *et al.*, 2006; Sorrel *et al.*, 2006, 2007; Boomer, 1993; Boomer et al., 2009). During the Medieval Warm Period (MWP) and AD 0 to 400, the level of the Aral Sea decreased and its surface area was greatly reduced. Soon after the MWP (around AD 1200 to AD 1400), the water changed from brackish to freshwater by increased precipitation. After AD 1400, the water became brackish again, corresponding to the beginning of the Little Ice Age.

The results from the Balkhash 2007 core indicate that Balkhash Lake probably experienced similar environmental changes in Aral Sea (Boroffka *et al.*, 2006; Sorrel *et al.*, 2006, 2007; Boomer *et al.*, 2009). For example, the low stage at -100 cm in Balkhash Lake probably corresponds to that of AD 1200 in Aral Sea core, which was characterized by a rich occurrence of gypsum crystals. In the Balkhash core, the diatom flora around -100cm (corresponding to AD 1050-1200) do not clearly show a low lake level, but the high, wide ostracod peak is conspicuous and occupied with only brackish species. Above this horizon, ostracods are rare. Consequently, a larger environmental change probably occurred just after AD 1200, which may be related to the change from the MWP to the Little Ice Age.

Below -100 cm, lake level changed frequently but at shorter intervals (about 50－100 years). In future research, it will be important to clarify the cause of these short intervals.

The low stages at -585 cm and -540 cm may also correspond to the horizon of approximately 2000 years ago in Aral Sea (Boroffka *et al.*, 2006) .

During the MWP, the lake level must have decreased in both Aral sea and Balkhash Lake. Even if the supply of water increased, evaporation increased more than enough under the warm climate to lower the lake levels. Currently, Balkhash Lake freezes from November to April. The length of freeze season is related to the amount of evaporation. Even if the supply of water to the lake decreased during the Little Ice Age, the lake level might still have risen if evaporation also greatly decreased. To clarify this question at Balkhash Lake, we need more detailed data especially for the period encompassing the Little Ice Age, the cause of the shorter interval changes, the source of water, e.g. the relation to the Mediterranean Low transporting moisture and North Atlantic Oscillation (NAO) (Yamakawa, 2005; Sorrel *et al*., 2007), and their influence to the inland China (Endo *et al*., 2006, 2007).

Central Asia is an important region for the study of environmental changes, but more types of data and higher resolution data are needed to better understand of environmental changes in this area.

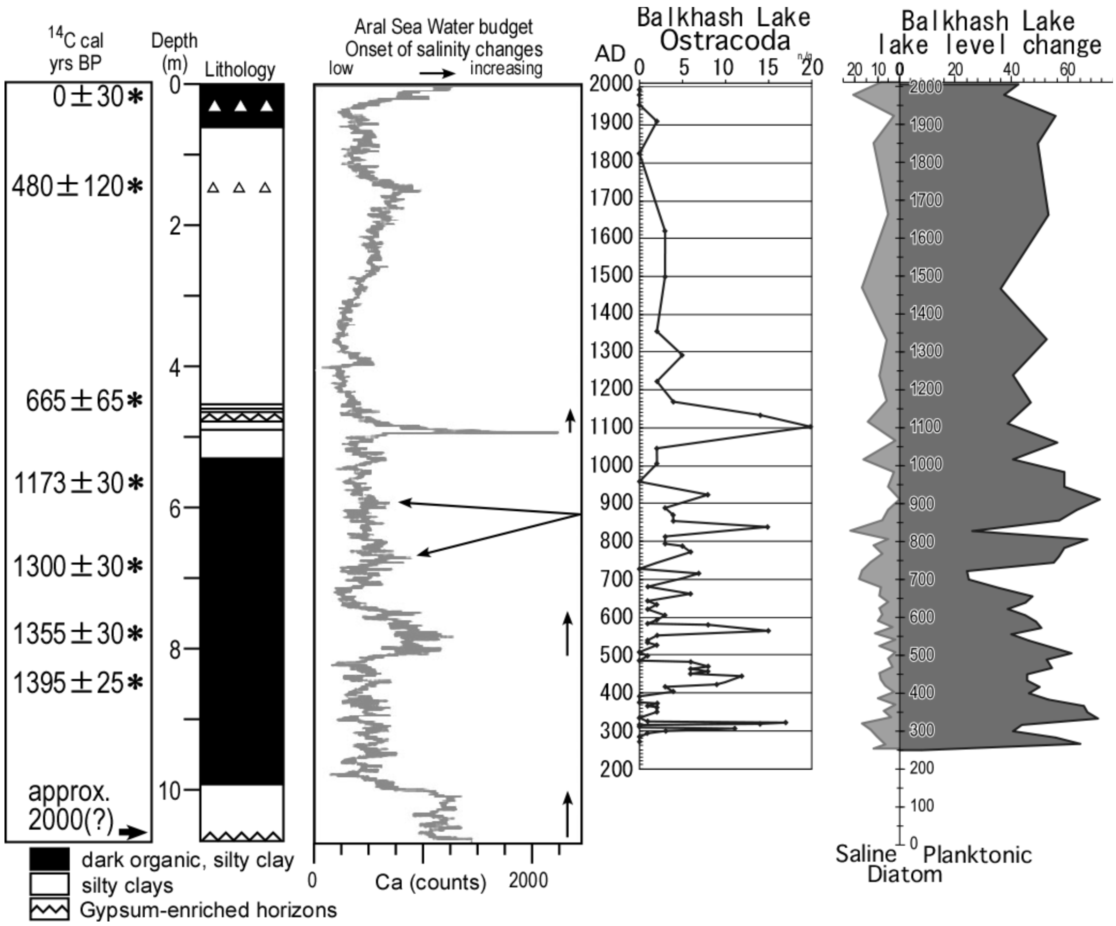

Fig.11 Comparison of salinity and lake-level changes between Balkhash Lake and the Aral Sea. Balkhash Lake data are from our diatom and ostracod study; Aral Sea data are from Boroffka *et al*. (2006).

Acknowledgements

We are grateful to Prof. Ian Boomer of University of Newcastle, UK and Prof. Nikolaus Boroffka of Deutsches Archaologisches Institut in Berlin for their useful discussions. We are also thank Dr. Mitsuko Watanabe of Research Institute for Humanity and Nature in Kyoto, Mr. Sergey Perevosov of Institute of Geological Sciences in Almaty, Mrs. Almagul Hirono in Tokyo for their kind assistance with our field survey.

References

Abdrasilov, S.A. and Tulebaeva,K.A. (1994) Dynamics of the Ili delta with consideration of fluctuations the level of Lake Balkhash. Hydrological Construction, 28-8. 421-426 [translated from Gidrotekhnicheskoe Stroitel'stvo, No. 8, 1994].

Aubekerov, B. J., Sala, R. and Nigmatova, S. A. (2003) Late Holocene Paleoclimate and Paleogeography in the Tien Shan-Balkhash Region. PAGES News, 11, 2&3, 24-26.

Boomer, I. (1993) Late Holocene and contemporary Ostracoda of the Aral Sea. Palaeogeography, Palaeoclimatology, Palaeoecology, 103, 141–153.

Boomer, I., Wunnemann, B., Mackay, A. W., Austin, P., Sorrel, P. Reinhardt, C., Keyser, D., Guichard, F. and Fontugne, M. (2009) Advances in understanding the late Holocene history of the Aral Sea region. Quaternary International, doi : 10.1016 / j. quaint. 2008.03.007

Boroffka, N., Oberhansli, H., Sorrel, P., Demory, F., Reinhardt, C., Wunnemann, B., Alimov, K., Baratov, S., Rakhimov, K., Saparov, N., Shirinov, T., Krivonogov, S. K. and Rohl, U. (2006) Archaeology and climate : settlement and lake-level changes at the Aral Sea. Geoarchaeology, 21, 7, 721-734.

Endo, K., Komori, J., Sohma, H., Haraguchi, T., Chiba, T., Yoshinaga, Y., Miyata, K., Nakayama, Y., Ogino, S., Sugai, T., Kubota, J., Aubekerov, B., Sala, R. and Deon, J-M. (2009) Preliminary report on lake level change deduced from the Balkhash Lake core 2007. Project report on an oasis-region (Research Institute for Humanity and Nature: RIHN), 7(1), 1-9 (in Japanese with English Abstract).

Endo,K., Sohma,H., Mu,G., Qi,W., Hori,K., Murata,T. and Zheng,X. (2006) Paleoenvironment and Migration of rivers, delta and lakes in the lowest reaches of Heihe River. Proceedings of International Symposium on RIHN, Project report on an oasis-region (Research Institute for Humanity and Nature), 5(2), 161-171.

Endo,K., Qi,W., Mu,G., Zheng,X., Murata,T., Hori,K., Sohma,H., and Takada,M. (2007) Environmental evolution and human activities during the last 3000 years in the lowest reaches of Heihe River. Project report on an oasis-region (Research Institute for Humanity and Nature: RIHN), 6(2), 181-199. (in Japanese with English Abstract).

Haraguchi,T., Yoshinaga, Y. and Miyata, K. (2009) A report on subsurface seismic profiling in Lake Balkhash, Kazakstan. Project report on an oasis-region (Research Institute for Humanity and Nature: RIHN), 7(1), (in Japanese).

Kipshakbaer, N.K. and Abdrasilov, S.A.(1994) Effect of economic activity on the hydrologic regime and dynamics of the Ili delta. Hydrotechnical Construction, l28-8, 416-420.

Meisch, C. (2000) Freshwater Ostracoda of Western and Central Europe. In J. Schwoerbel and P. Zwick, editors: Suesswasserfauna von Mitteleuropa 8/3. Spektrum Akademischer Verlag, Heidelberg, Berlin.522p.

Nakayama,Y. and Ogino,S. (2007) Recent change in the water area of Aral Sea and Lake Balkhash by satellite data, Proceedings of the 2007 meeting, The Japanese Association for Arid Land Studies, 17-18 (in Japanese)

Nakayama,Y., Ogino,S., Endo,K. and Sohma,H. (2009) Investigation of topography along the coast of Balkhash Lake - A case study of investigation in 2008 -, Interim report of Ili project (Research Institute for Humanity and Nature: RIHN), 9p (in Japanese).

Sorrel, P., Popescu, S. M., Head, M. J., Suc, J. P., Klotz, S. and Oberhansli, H. (2006) Hydrographic development of the Aral Sea during the last 2000 years based on a quantitative analysis of dinoflagellate cysts. Palaeogeography, Palaeoclimatology, Palaeoecology, 234, 304–327.

Sorrel, P., Popescu,S.-M., Klotz,S., Suc,J.P. and Oberhansli,H. (2007) Climate variability in the Aral Sea basin (Central Asia) during the late Holocene based on vegetation changes. Quaternary Research, 67, 357–370.

Yamakawa,S. (2005) Climate variations from the viewpoint of seasonal to multi-decadal scale. Journal of Geography, 114, 460-484.