Lake Level Change and Environmental Evolution during the Last 8000 Years Mainly based on Balkhash Lake Cores in Kazakhstan, Central Eurasia

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Keywords: lake level change, Holocene, paleoenvironment, ostracoda, diatom, pollen, geochemistry, Balkhash lake, Kazakhstan

1. Introduction

Environmental evolution in Ili Delta and Balkhash Lake areas, Kazakhstan, has been investigated through geological, geomorphological and paleoenvironmental researches in the Ili project, RIHN, since 2007. In the first stage, the lake level change during the last 2000 years in the Balkhash Lake was investigated mainly based on diatom and ostracoda analyses using the 2007 core in the western part of the lake (Endo *et al,* 2009, 2010). In the second stage, several cores were taken in 2009 in the easternmost part of the lake, where is the deepest part of the lake (Fig.l). These 2009 cores cover almost Holocene, and have been analyzed using pollen, diatom, and ostracoda analyses, and also geochemical and magnetic property analyses. Geochemical analysis using high-resolution (100pm) X-ray fluorescence (XRF) instrument done for cores 0901 and 0902. These provide us continuous environmental records during the last 8000 years. The lake level change data are combined with geological and geomorphological evidences in the land survey along Lepsi and Ili rivers to discuss the environmental evolution especially during the mid-Holocene in central Eurasia.

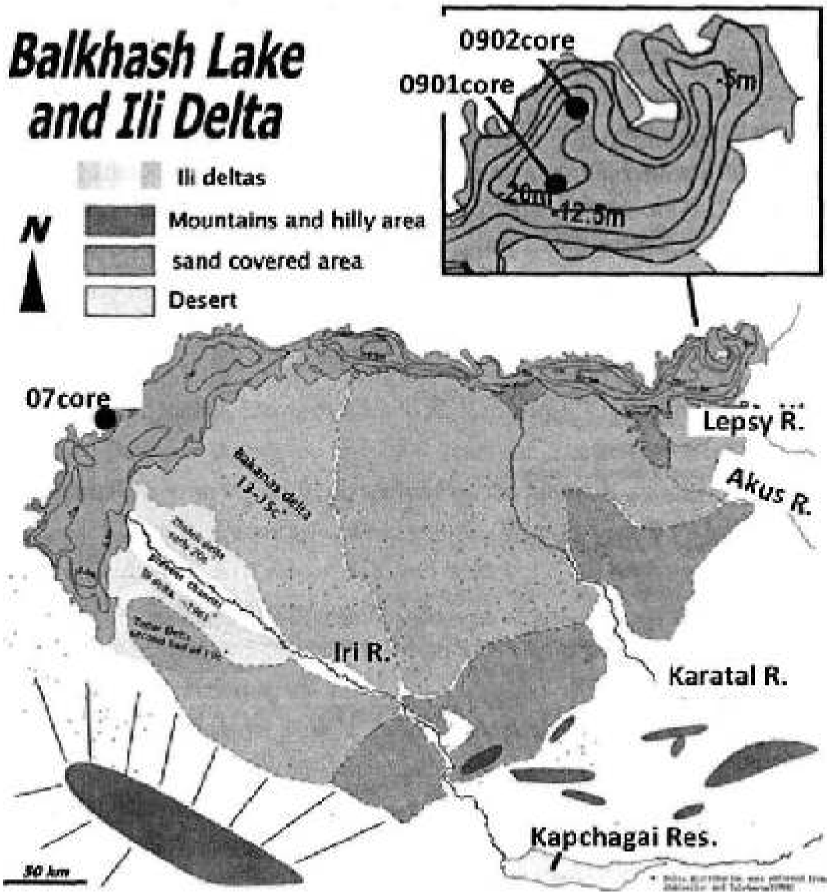

Fig.l Balkhash Lake and Ili Delta areas, showing the locations of lake cores

2. Lake level change of Balkhash Lake in the last 2000 years

Balkhash Lake is a huge but shallow, and closed lake. The bottom sediment is composed chiefly of clay and abundant in microfossils. Among them diatom assemblages are good indicators for reconstruction of lake level change in closed lakes, because dominance in saline benthic species shows low lake level, and dominance in freshwater planktonic species shows high lake level.

In order to reconstruct the lake level changes in Balkhash Lake, the 2007 core was taken in the western part of the lake and such analyses were carried out as fossil diatom and ostracoda, geochemistry and grain size. The core is characterized by homogeneous, light gray, and clayey sediment. Age control of the core is based on Cs-137 for the uppermost part and radiocarbon ages using fossil ostracoda from the core. Those provide an age-depth model during the last 2000 years. Diatom analysis shows mainly two different types of assemblages. One is characterized by dominance of freshwater planktonic species (e. g. *Aulacoseira granulata),* and another is dominated by saline planktonic (e. g. *Thalassiosira lacustris),* saline benthic species (e. g. *Rhopalodia gibba)* and freshwater benthic species (e. g. *Amphora ovalis).* The first one suggests higher lake level, and the second one suggests lower lake level, as same interpretation as Stoermer and Smol (1999). Moreover, the changes in assemblages are consistent with the observatory records of lake level during the last 120 years (Kubota, 2006).

According to the occurrence of these assemblages, the core shows six High lake level stages being dominant in freshwater planktonic species, and seven low level stages dominant in saline planktonic species, saline benthic species and freshwater benthic species in the last 2000 years (Fig.2). Moreover, high proportion of fossil ostra

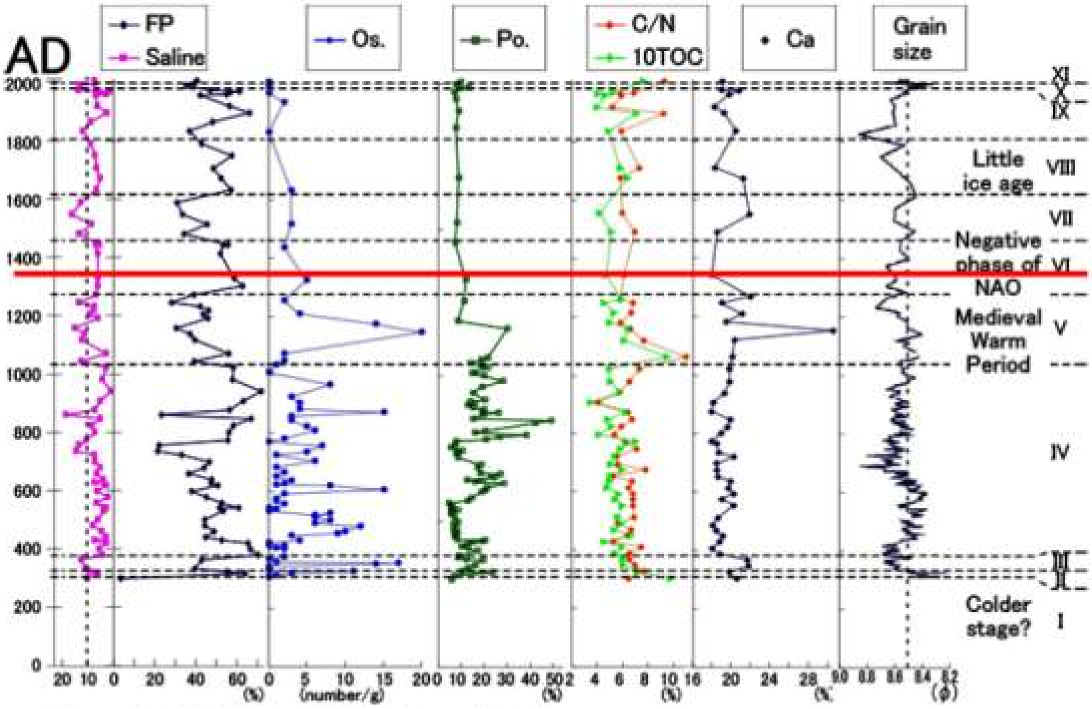

Fig.2 Lake level change of Balkhash Lake in the last 2000 years (Chiba et al., 2011)
From left, diatom, ostracoda, pollen, C/N, 10TOC, Ca, Grain size, zone. Characteristically the curve of percentages in freshwater diatom suggests lake level change.

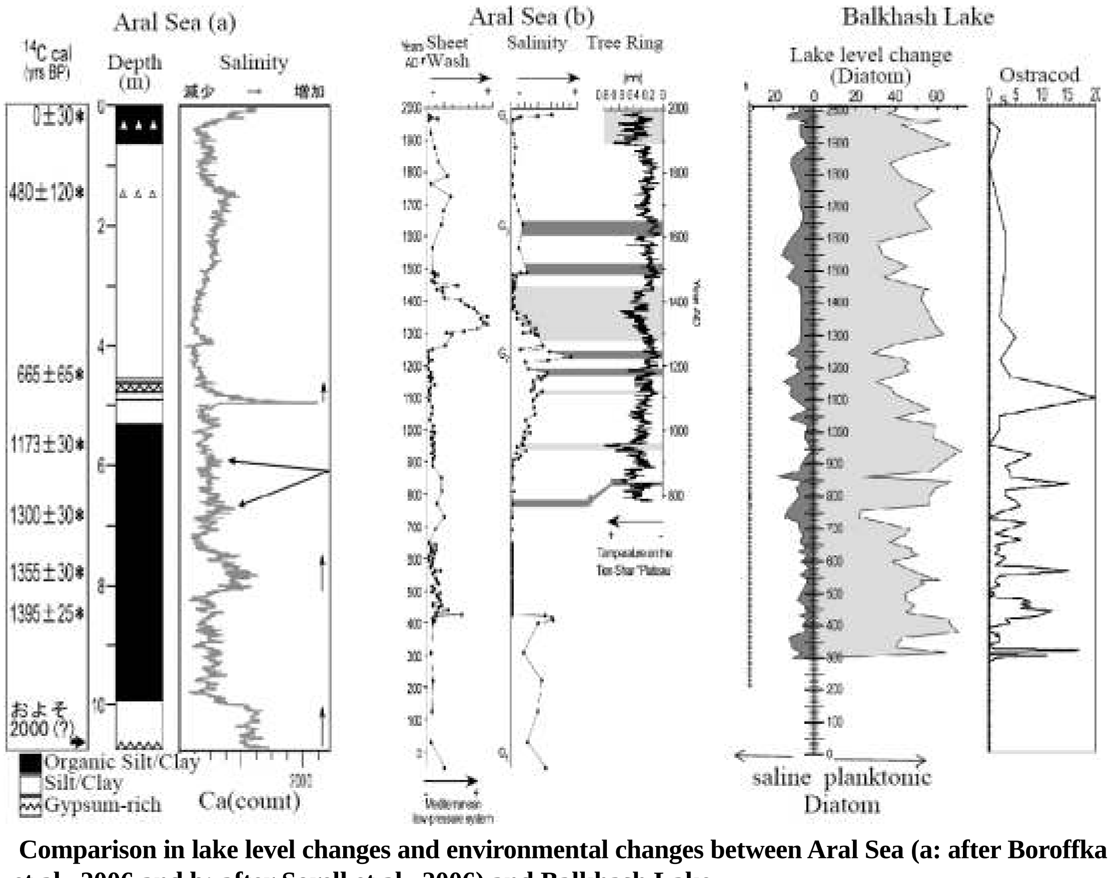

Fig.3 Comparison in lake level changes and environmental changes between Aral Sea (a: after Boroffka et al., 2006 and b: after Sorell et al., 2006) and Balkhash Lake

coda corresponds to each low level phase. Also, the correlation was recognized between fossil brackish ostracoda number (n/g) and relative abundance in saline planktonic and benthic diatoms.

Those low level stages are consistent with the lake level changes in Aral sea chiefly inferred from changes in fossil dinoflagellate assemblages (Sorrel *et a!.*, 2006) and geochemical analysis (Boroffka *et al.*,2006).
In the both Balkhash Lake and Aral Sea, low level stages of AD-400, 1000-1250, 1500-1600 were remarkable. During AD-400 and AD 1000-1250 corresponding to Medieval Warm Period, arid environments including sand dune formation prevailed.

After 1000-1250 and 1500-1600 AD, rapid lake level rising occurred. After 1600 AD, corresponding to "Little Ice Age", this rapid rising have formed submerged sand dunes and submerged delta distributed mainly along the southern coasts of Balkhash Lake.

3. Lake level and environmental changes during 8000 years

In order to examine lake level and environmental changes during the Holocene, coring was carried out in the deepest part of the lake and took several cores.

3.1. Locality of cores, lithological characteristics, and age-depth model

Location of two cores, 0901 and 0902, is in the easternmost part of Balkhash Lake, in the deepest part of the lake, about 20 m in depth. 0901 core with the length of 5.67 m, and 0902 core with the length of 5.80 m were used for analyses. Both cores are composed of whitish, massive clayey horizons, and blackish to brownish laminated silt/clay, partly sandy layers.

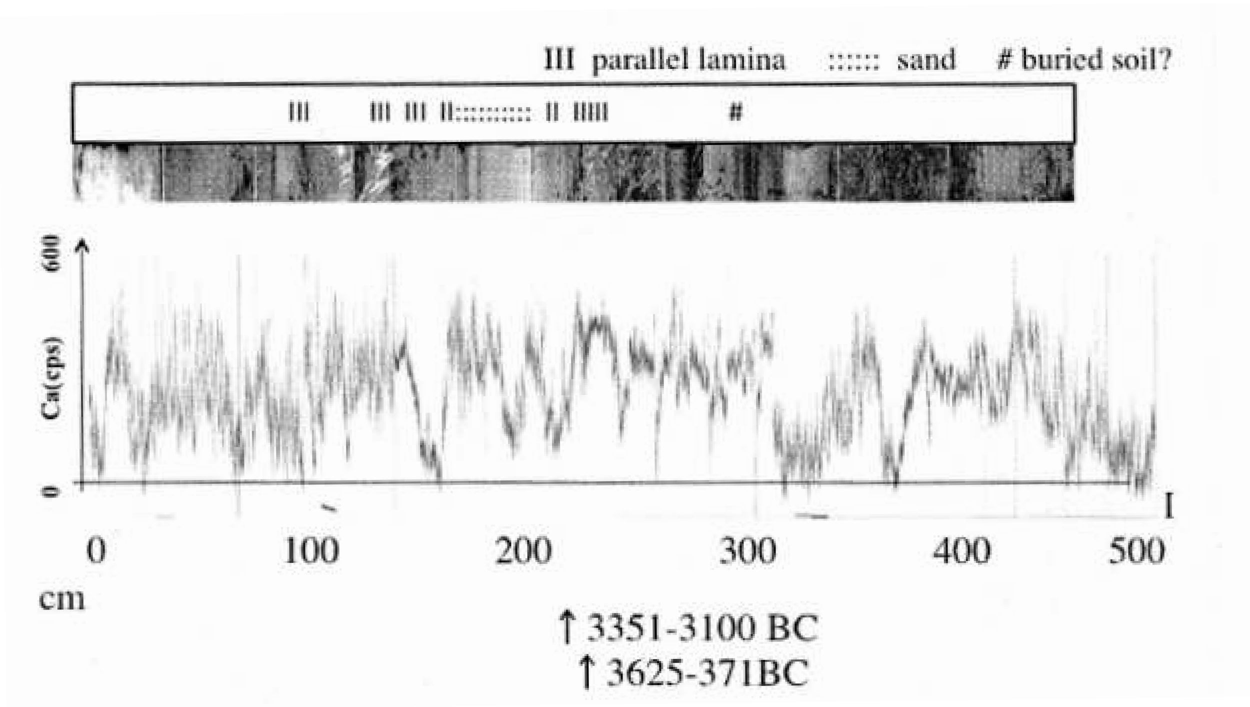

Fig.4 Balkhash 0901 core and high-resolution Ca content (X-ray fluorescence data)
(Sugaietal.,2010)

Both cores can be divided into three main sedimentary units of A (upper), B (middle) and C (lower). In the core 0901, the unit A(0-1.1 m) and unit C(4.0-5.6 m) consist of massive whitish clayey sediments, and the unit B(l. 1-4.0 m) is the alternations of finely- laminated sediments including sandy layer from 2.6-3.0 m. In the core of 0902, three units show the same character as 0901 core but the thickness is a little different, the unit A (0-2.1 m), the unit B (2.1-4.85 m), the unit C (4.85-5.8 m). As shown in Fig.4, both units A and C show High Ca, while unit B relatively low Ca (High Fe and Si). Especially in 0902 core, fine gypsum crystals are rich in the 3.55-3.68 horizon of the unit B, probably suggesting rapid desiccation of the lake floor. In this case, the lake level must be 20 meters lower than the present level.

An age-depth model of the cores, shown in Fig.5, is based on radiocarbon dates measured using fossil ostracods and partly plant remains from the core.

3.2. Diatom assemblages and lake level change of 0901 core

Diatom analyses were done for 0901 core as shown in Fig.6. 35 species were found, but main 15 species are shown in the diagram. Diatom zones are divided into 12, among them five High lake level stages and four low lake level stages are included.

As a whole, saline benthic species are dominant. Those species may be living in very high salinity similar to the sea water. Diatom Zones V, VII, IX, XI are in the low lake level and accompanying resting spores of *Chaetoceros* , suggesting probably the alternative environments between nearly dry-up condition and very shallow water.

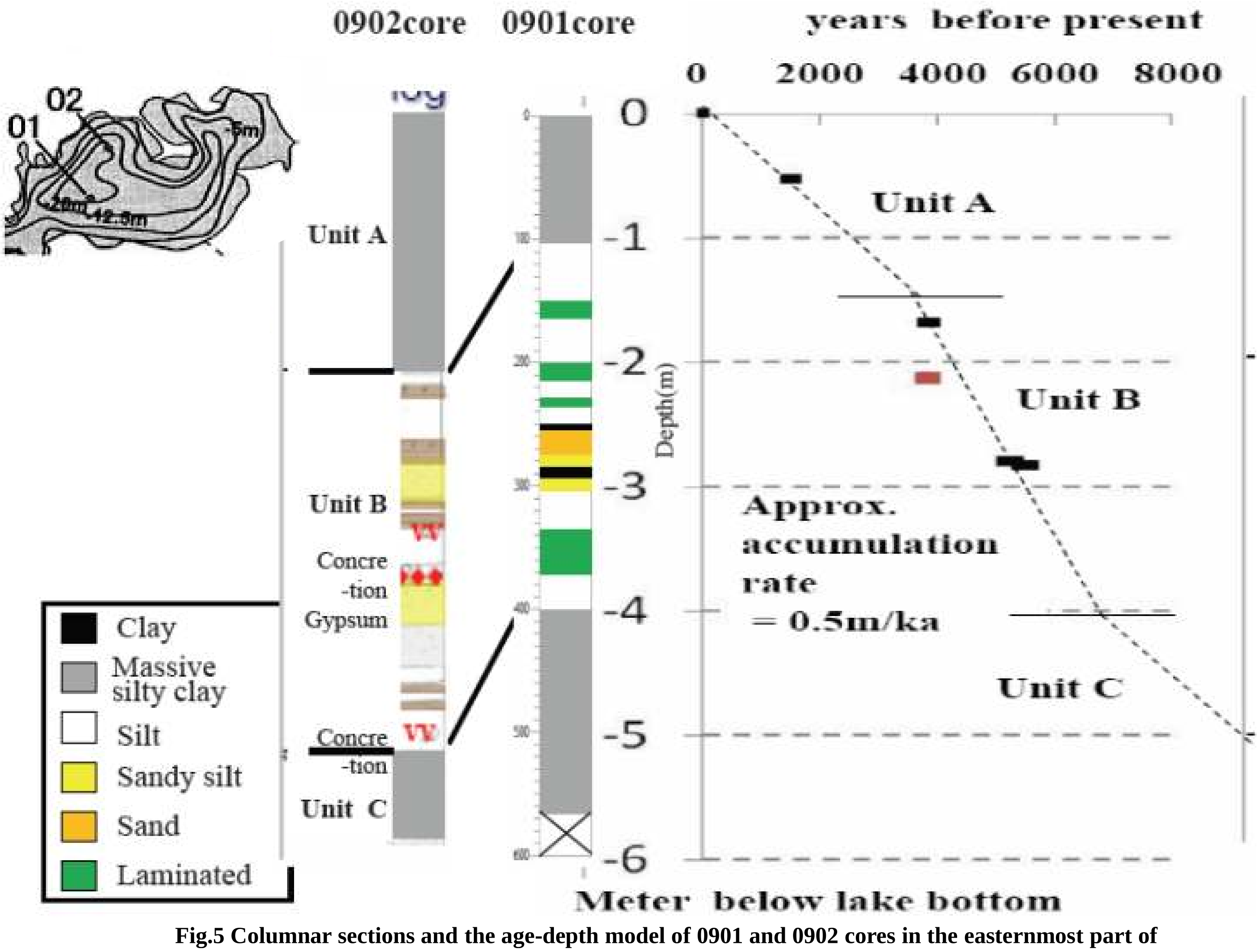

Fig.5 Columnar sections and the age-depth model of 0901 and 0902 cores in the easternmost part of Balkhash Lake

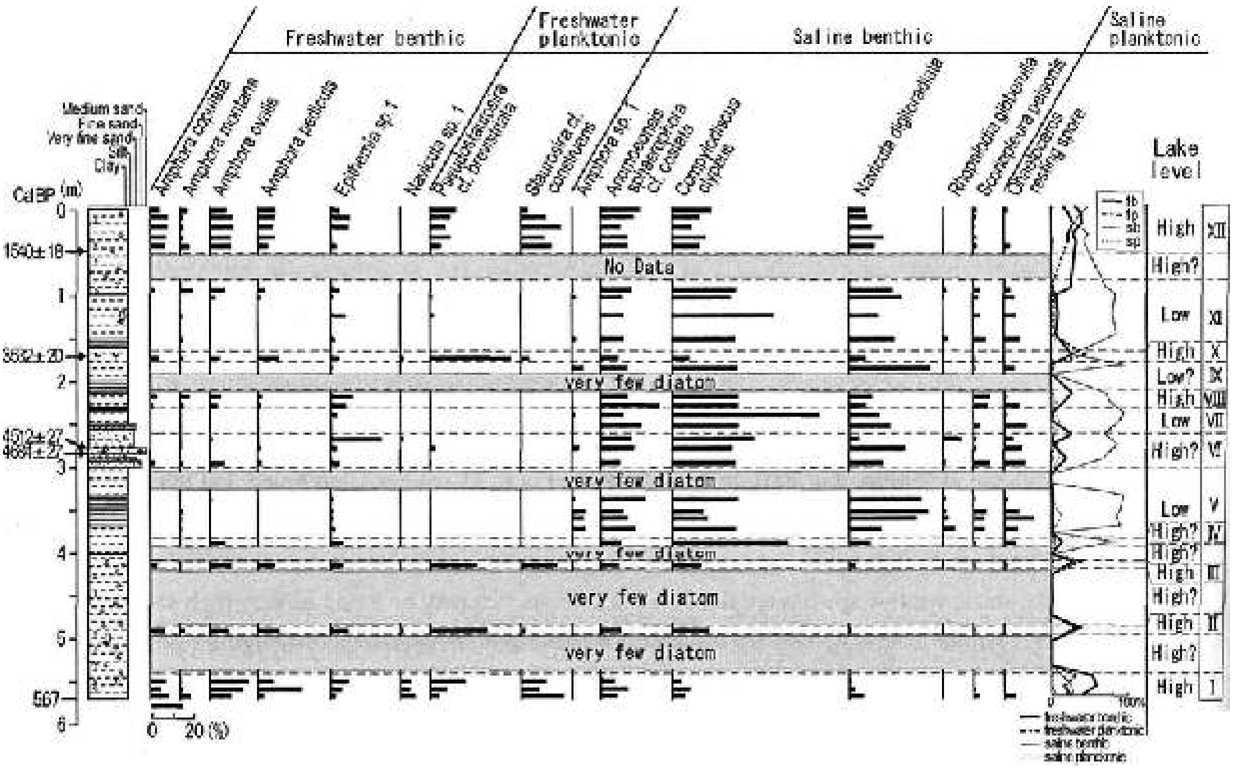

Fig.6 Lake level changes based on diatom assemblages during the last 8000 years, for the Balkhash 0901 core (CIliba et al., 2011)

At the lowered lake level, Balkhash Lake must have been divided into 4 to 6 small lakes. Easternmost part of Balkhash Lake, where the cores are located, must be a small lake. This means quick lake level changes were much easier. The desiccation event of Ostracods Zone III, is correspond to the peak of saline diatom-rich horizon (diatom Zone V).

Between main peaks of saline benthic species, short peaks of fresh water planktonic species are intervened, like Zones I ~IV, VI, VI, X, X Π, which indicate high lake level. In these stages, small lakes were connected and large amounts of fresh water were supplied from Ili river.

3.3. Ostracoda and lake level change of 0901 core

Ostracoda analyses for the core 0901 demonstrated that *Limnocythere inopinata, Candona* sp., *Cyprideis torosa* are dominant (Fig.7). Especially, in the top 0.5m (Zone IX) and the bottom 1.6m (Zone I), all these species are existed in favorable condition, the salinity of 2-6.7 %o (probably 6- %o) and deeper water.

From Zone II to VIII,*Limnocythere inopinata* or *Candona* sp.shows High proportions alternately and *Cyprideis torosa* is almost no occurrence. This trend suggests abrupt and big-scale change in environments. *Cyprideis torosa is* most tolerable against High salinity among three. *Limnocythere inopinata*, however, favors shallow water, may be 1 to 2 m in the most favorable condition based on Donggi Cana Lake(Mischke et al., 2010). When the water level drops to lowest condition (Zone II), two species, *Limnocythere inopinata* and *Candona* sp, survive to be dominant. *Limnocythere inopinata*, however, could not survive under the completely dry-up condition. On the other *hand,Candona* sp. could survive even in the completely dry-up condition because of their eggs which are tolerant to desiccation (ex. Mischke, 2001).

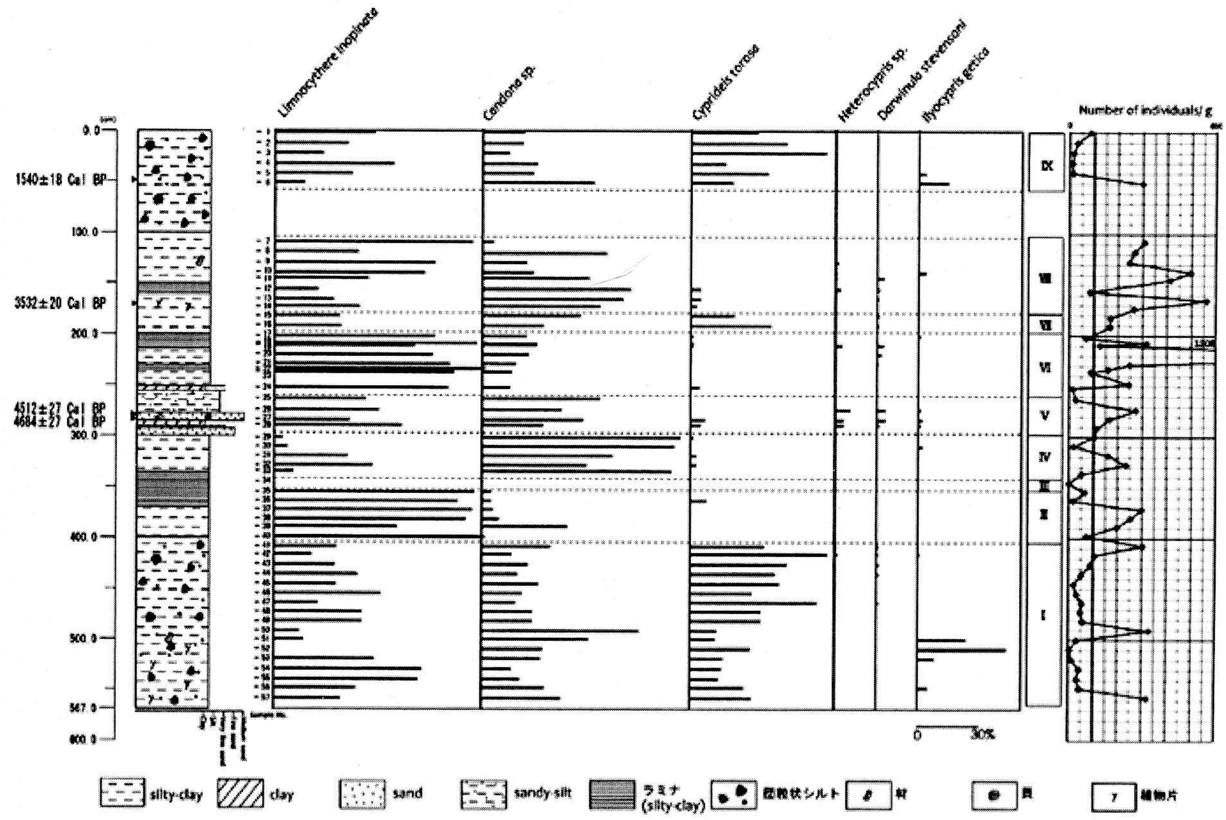

Fig.7 Diagram showing vertical changes in Ostracoda, number of Ostracoda per gram, columnar section with C-14 ages and fossil assemblage zones of Ostracoda (Nakamura et al., 2012).

Therefore, at the depth of 3.40m, following to the highest proportion of *Limnocythere inopinata*, no ostracods appear (Zone III), and then *Candona* sp. increased abruptly (Zone IV). Probably, *Limnocythere inopinata*, could not survive for this strong desiccation event, but only resting eggs of *Candona* sp. survived and immediately after the dry-up event *Candona* sp. increased enormously

In Zone V, supply of sand from the river increased and freshwater species accompanied, suggesting the lake level was rising slightly. Lake level was higher in Zone VII, but lower in Zones VI and VIII.

3.4. Pollen and Spores of 0902 core

Pollen and spores were analyzed for the sediment from 1.0 to 5.8 m of 0902 core. Diagram shows the dominance in grass pollen like *Artemisia*, Chenopodiaceae and so on. In tree pollen, *Pinus* subgenus diploxylon mainly occurs less than 5 %. Six pollen zones were divided. Especially, in the pollen zone 4 (4.0 – 2.65 m), *Pinus* subgenus diploxylon disappeared completely. Aquatic plant of *Pediastrum* also disappeared. In tree pollen, only *Betula* increased slightly. This zone corresponds to gypsum crystal horizon. Grass pollen increased mostly, Artemisia might extend the distribution in surrounding areas of highly reduced Balkhash Lake. Present distribution of *Pinus* subgenus diploxylon is limited to northern part of Balkhash Lake area including Siberian taiga. This suggests it is concerned to change in the wind system in this region. Weakening of the northeast wind, one of the prevailed wind direction, is a possible process.

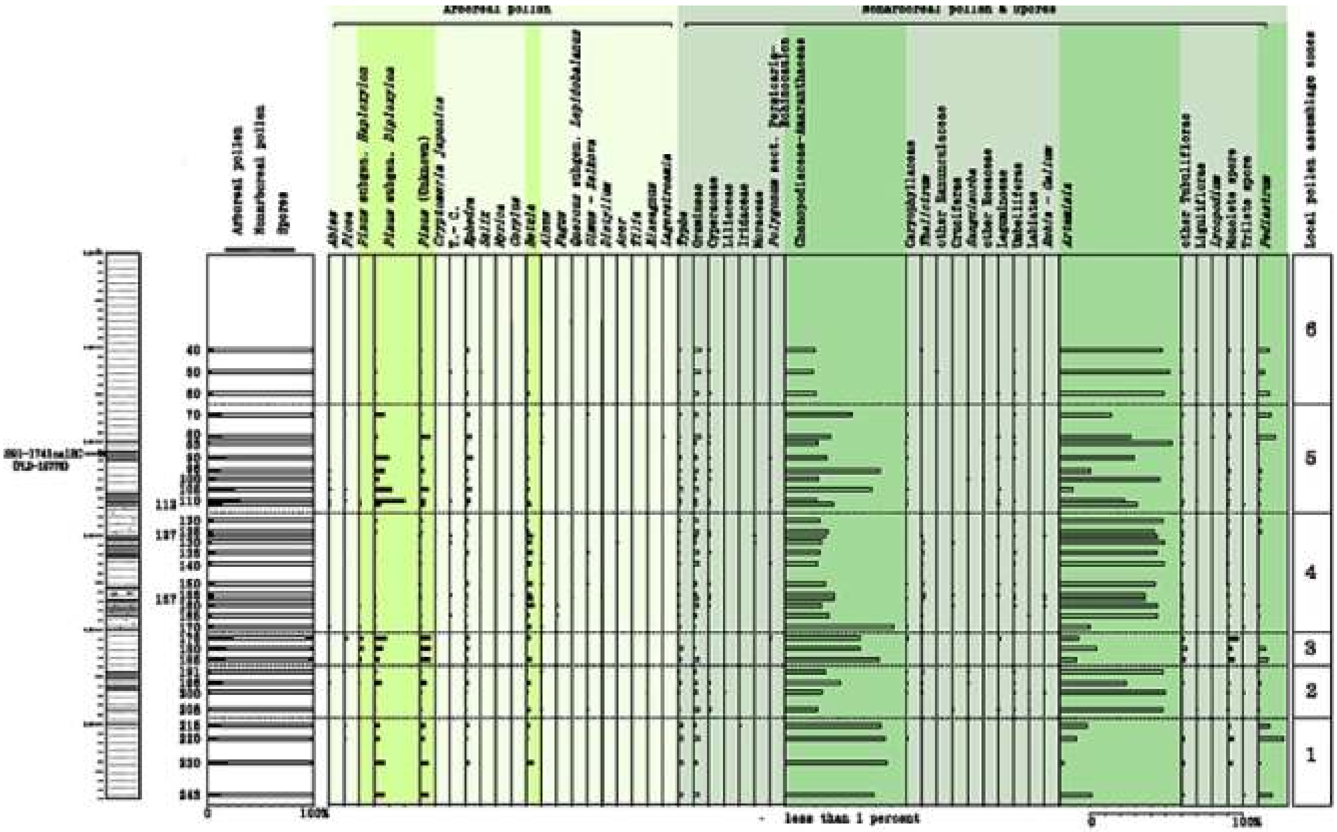

Fig.8 Pollen and spore diagram for the core 0902

4. Acoustic survey in Balkhash Lake

Acoustic surveys and coring were done in the central and eastern part of Balkhash Lake in 2008 and 2009(HaragucIli et al., 2009, 2010 and Montani et al., 2010). Acoustic profiles show lake sediments clearly with depth of 15 meters in maximum. As the strong reflection surfaces, flat erosional surfaces and buried valleys are recognized at 12, 17, and 20 meters below the present lake level. They are one of evidences suggesting lowered lake level to 20 meters or more below the present level.

Along the survey line 13, sand dune-like topography is observed on the lake bottom, probably suggesting lake level rising more than 10 meters after sand dune formation to form submerged sand dunes(Fig. 9).

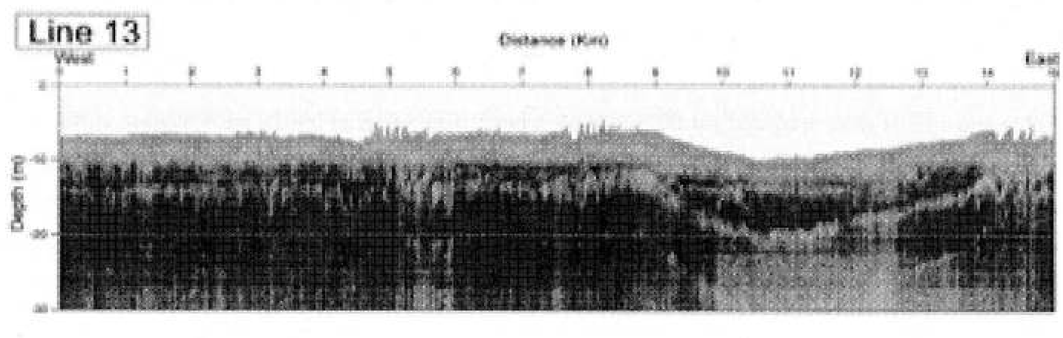

Fig.9 Acoustic profile of survey line 13, middle part of Balkhash Lake, showing buried valley topography, erosional surfaces, and sand dune-like topography on the lake bottom (Haraguchi et al., 2010 ;Montani et al., 2011)

5. Topographical development along the coast of Balkhash Lake and along the main rivers - gravel bars and alluvial terraces -

5.1. Gravel bars

Strong wave action carries gravels along the shore to form a lower ridge a little Higher than lake level. Along the coasts of Balkhash Lake, a few lines of ridges are aligned along the shoreline, which show the former lake levels. Therefore those ridges composed of gravel or sand and gravel (gravel bars) are one of good indicators of the former lake level changes. Eighteen analyzed sites are located in west to east of the northern coast of Balkhash Lake, and in easternmost part of southern coast of the lake. On the basis of High-resolution DEM in each site by ALOS PRISM data, 52 transverse topographic sections were drawn, and the distribution and formation process were analyzed.

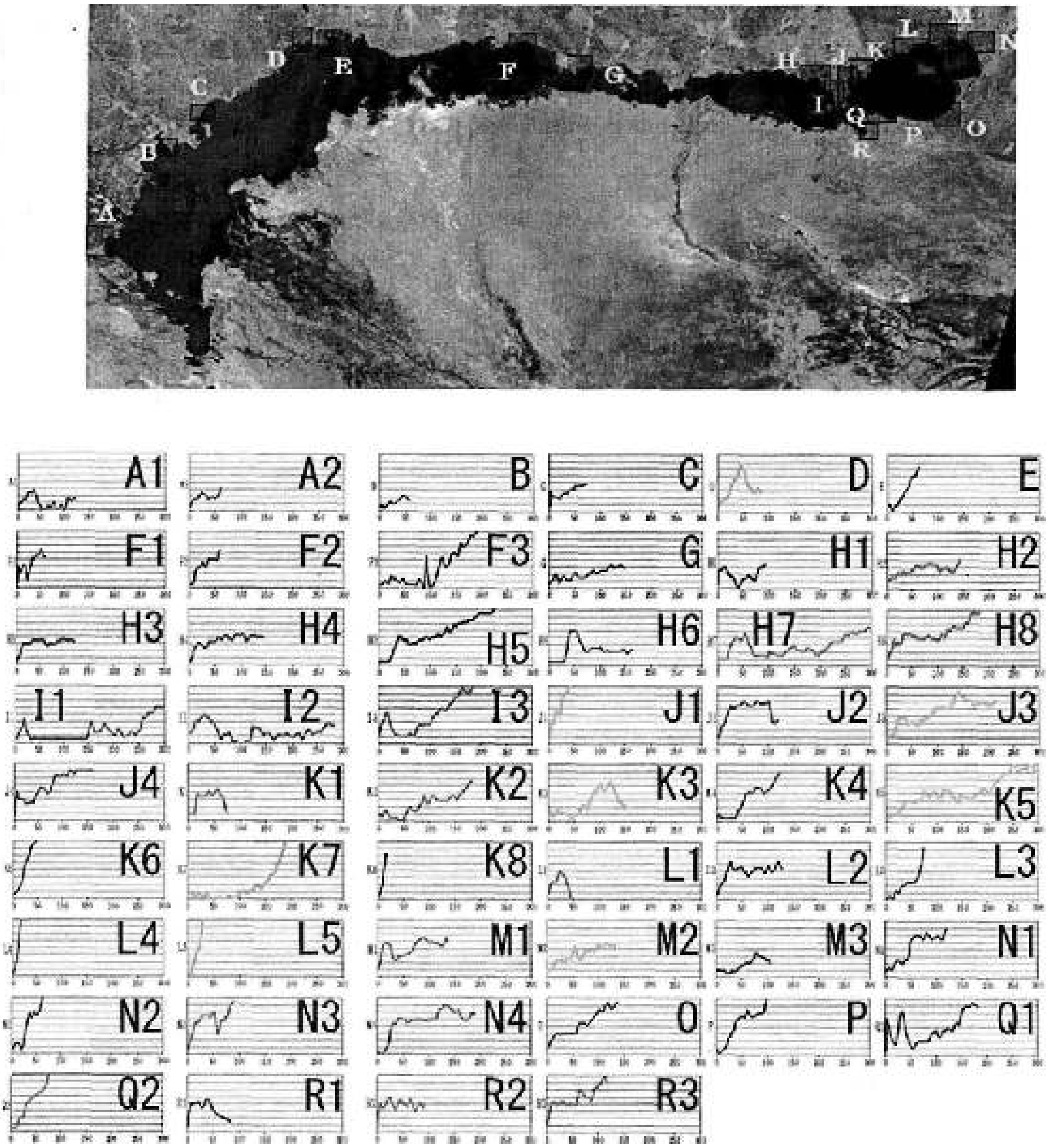

Fig.l0 Profiles of the gravel bars along the coast of Balkhash Lake, based on high- resolution analyses of satellite data (Hara et al.,2012; Nakayama et al., 2010). Top image showing the sites analyzed.

Along with the satellite data analyses, geomorphological and geological survey was done in the several sites, where the topographic sections were measured and the sediment of gravel bars were checked at outcrops and survey pits for age determination.

From the satellite data analyses and land survey, heights of gravel bars are classified into three groups; lower one ranges 1 to 3 meters, middle one ranges 4 to 7 meters, and higher one ranges 8 to 10 meters. The lower group is located along the present shoreline, and the topography of bars is preserved very well. From the features, they are youngest ones, probably higher lake level stages of around 1910 and or 1970. On the basis of the heights of lower group, height difference between western and eastern parts is not clear, suggesting no or negligible tectonic effect.

Along the south coast of easternmost part, especially facing westward, gravel bars of the highest group are facing directly lake shore, without the younger and middle groups. It suggests that very strong wave actions by prevailing westerly attack the coast and erode the younger bars.

In Karashugan coast facing west, higher erosional cliff distributes. Higher gravel bar sediments from this outcrop and test pits of inner bars were dated by OSL dating method. The results show the ages of the Last Glacial, two of three are Last Glacial Maximum, and another is MIS3 (Fig.l 1; Kondo et al.,2011).

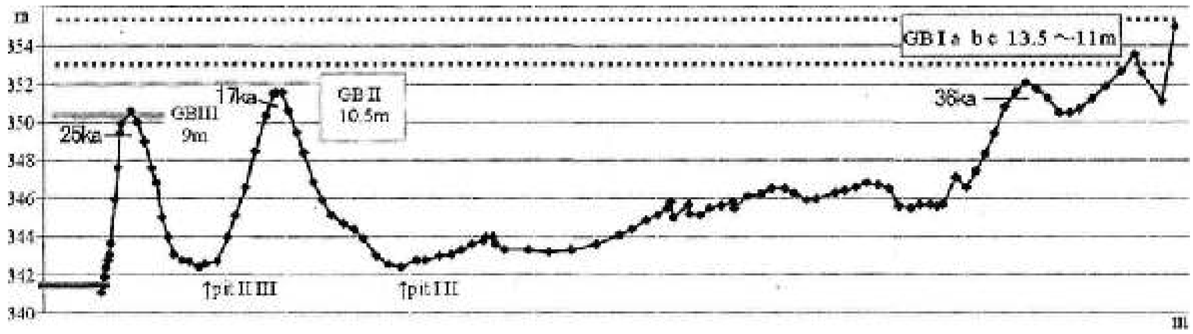

Fig.11 Topographic profile of gravel bars along Karashigan coast, easternmost part of Balkhash Lake. Ages of higher gravel bars are the last glacial maximum (Ages are after Kondo et al., 2011).

5.2. Fluvial terraces

The Lepsi River is the third largest river in the Balkhash lake catchment, having mountain glaciers at the uppermost reaches in Jungar Ala-Too range, going down through desert and sub-desert areas in the middle to lower reaches, and developing a delta system around river mouth in the easternmost part of Balkhash Lake. Along the lower reaches of Lepsi River, there distribute mid-Holocene and late Pleistocene terrace levels (LRT1,2,3).

In the Last Glaciation, higher terrace (LRT1) formed, probably corresponding to gravel bars of the higher group. After deepening, active sedimentation occurred to make middle terraces (LRT2) from early to middle Holocene, subdivided into LRT2a and LRT2b. Around 2000 years ago, the lowest one, LRT3, formed.

From 7000 to 2000 years BP, it is characterized by frequent riverbed change, probably by alternation of active sedimentation and vertical erosion.

0901 and 0902 cores located at 20km and 40km from Lepsi river mouth. Sugai et al. (2010, 2011) suggests that such riverbed change along the lower Lepsi River is relevant to the changes in environment (lake level) and geochemical properties of 0901 and 0902 cores.

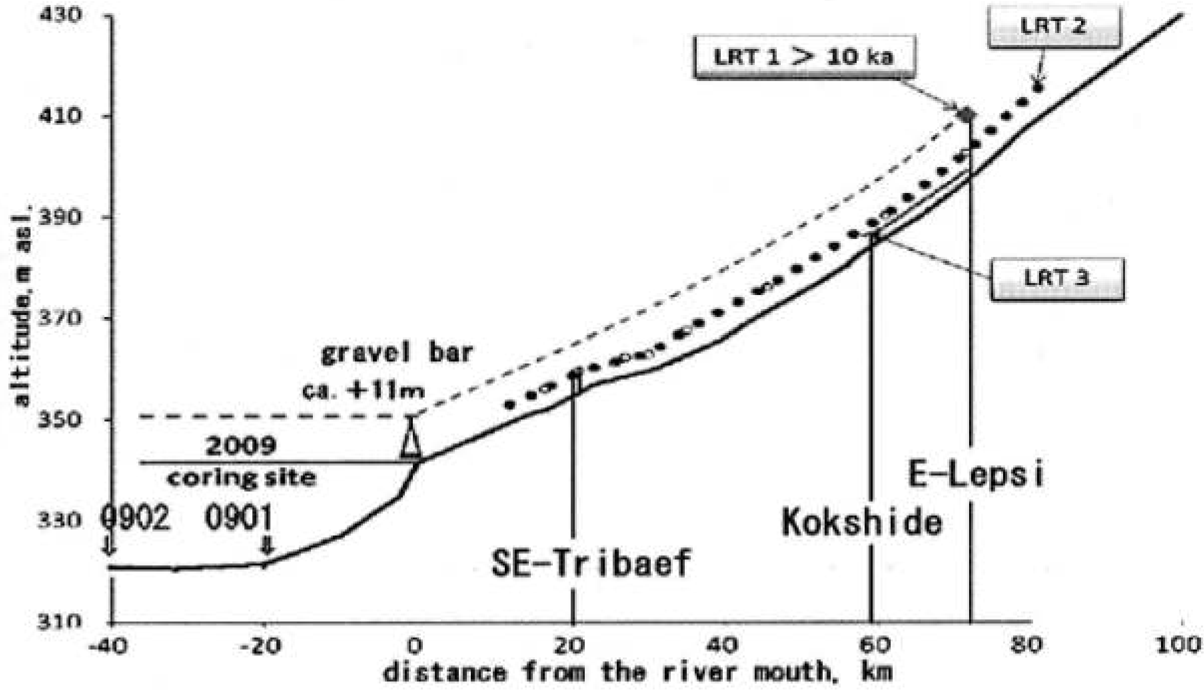

Fig.12 Alluvial terraces (LRT1,2 and 3) along Lepsi River and the positions of 0901 and 0902 cores in the easternmost part of Balkhash Lake. The present lake level and Highest lake level (Latest Pleistocene) are shown (Sugai et al., 2010,2011).

6. Discussion

Paleoenvironmental analyses such as diatom, ostracoda, pollen, magnetic susceptibility and geochemistry, were carried out for 0901 and 0902 cores taken from the easternmost part of Balkhash Lake. These provide us the results that rapid lake level and environmental changes were repeated especially in the mid-Holocene, while the first 1000 and the last 2000 years were characterized by higher lake level and comparatively stable environment during the last 10000 years, as shown in Fig. 13. In mid-Holocene, mainly two cycles of climatic changes, cold and wet to warm and dry, were recognized from 8000 to 4000 years ago. This is reflected in the lithology of the cores, Unit B of mid-Holocene shows frequent change in color and grain-size, but Units A and C are homogeneous. The unit B is also characterized by frequent changes in diatom and ostracoda assemblages, decrease and increase in pollen from coniferous forest, suggesting dominant stages in highly lowered lake level, and warm and dry climate. Especially in 0902 core, fine gypsum crystals are rich in the 3.55-3.68 horizon (about 5200 years ago) of the unit B, probably sugge sting rapid and almost complete desiccation of the lake floor. In this case, the lake level must be at least 20 meters lower than the present lake level. At this condition, Balkhash Lake must be divided into several small lakes.

This arid phase ranges from 6000-5500 to 3500 years ago, corresponds to the mid Holocene hyper arid stage, recently recognized in various regions.

In the lowest reaches of Heihe, the middle Inner Mongolian, about 20 paleo- shorelines (gravel bars) were dated. However, from 6000 to 3500 years ago, there are no gravel bars, suggesting highly lowered lake level. After 3500 years ago, fluvial processes were reactivated and lake level attained to the highest (Endo et al., 2005).

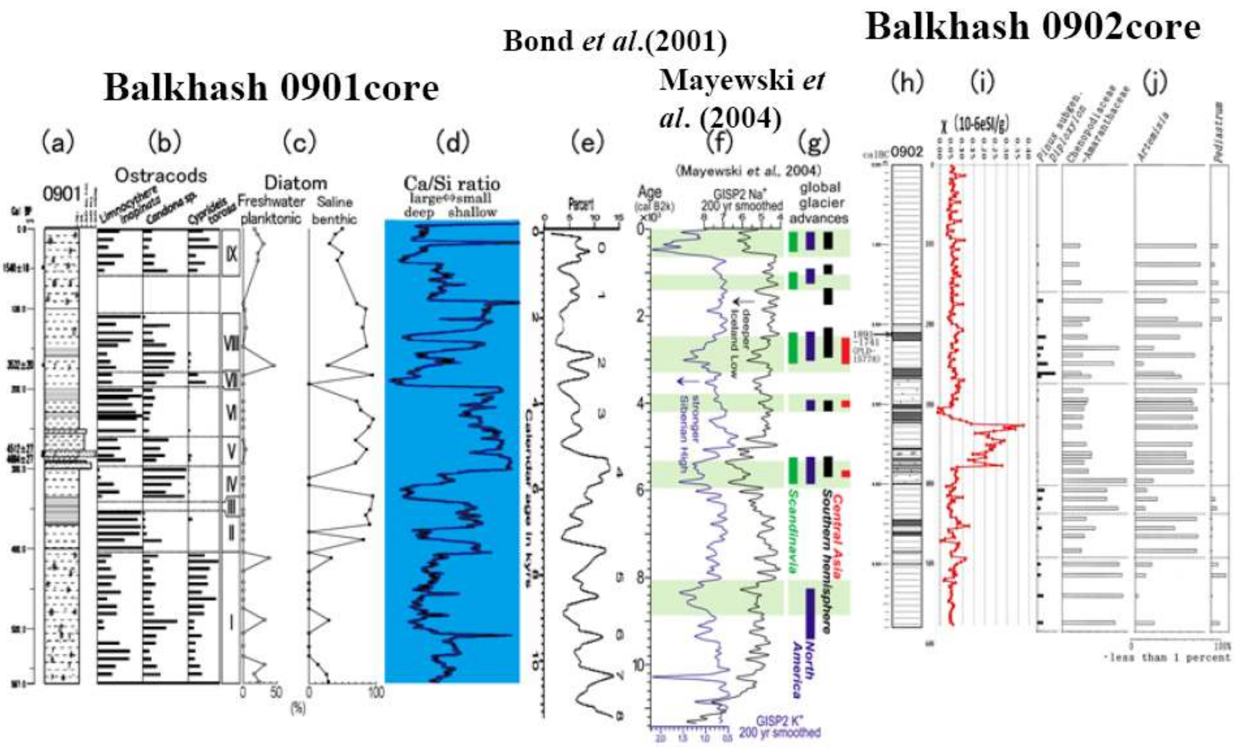

Fig. 13 Results of paleoenvironmental analyses of Balkhash cores (left: 0901 core, right: 0902 core) and comparison with Bond et al.(200l) and Mayewski *et al.*(2004)

a:0901 core - lithology, b:0901 core - Ostracods, c:0901 core - Diatom, d:0901 core - Ca/Si (Sugai et al.,2011), e: North Atlantic IRD (Bond Cycle) after Bond *et al.* (2001), f: Na+, K+ from Greenland ice core(GISP2) after Mayewski *et al.* (2004), g: Global glaciation after Mayewski *et al.* (2004), h:0902 core -lithology, i:0902 core - Magnetic susceptibility (by Matsuoka), j: 0902 core - main pollen

Nearly same situation as Balkhash lake cores is reported in Mongolian lake, Ugii Nuur, where 5800 to 3100 years ago, warm and dry conditions were dominant (Wang et al.,2011). They proposed the existence of mid Holocene drought probably in east and central Asia, and strong relation to Bond cycles (Bond et al., 2001).

The arid phases recognized in Balkhash cores seem to correspond to cycles 5 and 4 of the Bond cycles.

Lake level and environmental changes of Balkhash Lake in the last 2000 years were investigated using 07 core from the western part, mainly based on diatom and ostracoda analyses. This term is comparatively stable and in higher lake level, but clear lowering of the lake level is recognized. In Medieval Warm Period (MWP), there is a possibility that the lake level was 7 or 8 meters below the present level in maximum. Just after MWP, from 1200 to 1400 AD, the lake level was higher. From 1500 to 1600 AD, the lake level was lower again, but in Little Ice Age, after 1600 AD, it was higher.

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