

## Paleoenvironment and Migration of rivers, delta and lakes in the lowest reaches of Heihe River

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### Abstract

Migration of rivers and lakes in the lowest reaches of Heihe River during the last 8000 years, was investigated mainly by field observation, micro-fossil and chemical analyses of sediments, AMS datings and satellite images, in relation to the shift of delta and sand dunes. The results are summarized as follows.

From 7500 to 1700 years BP, giant Old Juyan Lake was existed just faced on the Juyan Delta. The extension of Old Juyan Lake in the past was reconstructed by the former shorelines (gravel bars) and those ages were determined by AMS method using molluscan fossils from the bar deposits. The main part of the Juyan Delta is covered with sand dunes, but traces of braided channels still preserved. Around the Green City and western half of Juyan Delta, human occupation including irrigation channels and agricultural land was dominated at least in Han Dynasty.

After AD 250, the Old Juyan Lake was dried up or became very small lakes, because no former shorelines were found. At this moment a river began to enter into Sogo Nur. Sand dune formation was activated and disturbed the river course.

Around AD 1200, Heihe channels migrated to northward, commenced to form Ejina Delta. Frequent flooding deposits are distributed and the river water reached to Gashun Nur. In Xixia and Yuan Dynasties, they used still irrigation channels for agriculture around Black City and in the western part of Juyan Delta.

During the Little Ice Age, pollen and diatom analyses indicate that Gashun Nur environment alternated between water coverage and desiccation. AD 1450 – 1550, irrigation channels were covered with Tamarix cones, suggesting abandonment of the human occupation under such arid environments in the lower reaches of Heihe.

## 1. Introduction

In order to understand “historical evolution of the adaptability in an oasis region to water resource changes”, our group on topography and sediments in Oasis Project of RIHN has investigated the paleoenvironment during the last 8000 years mainly in the lowest reaches of Heihe River, in special relation to migration of rivers and lakes. Especially, we

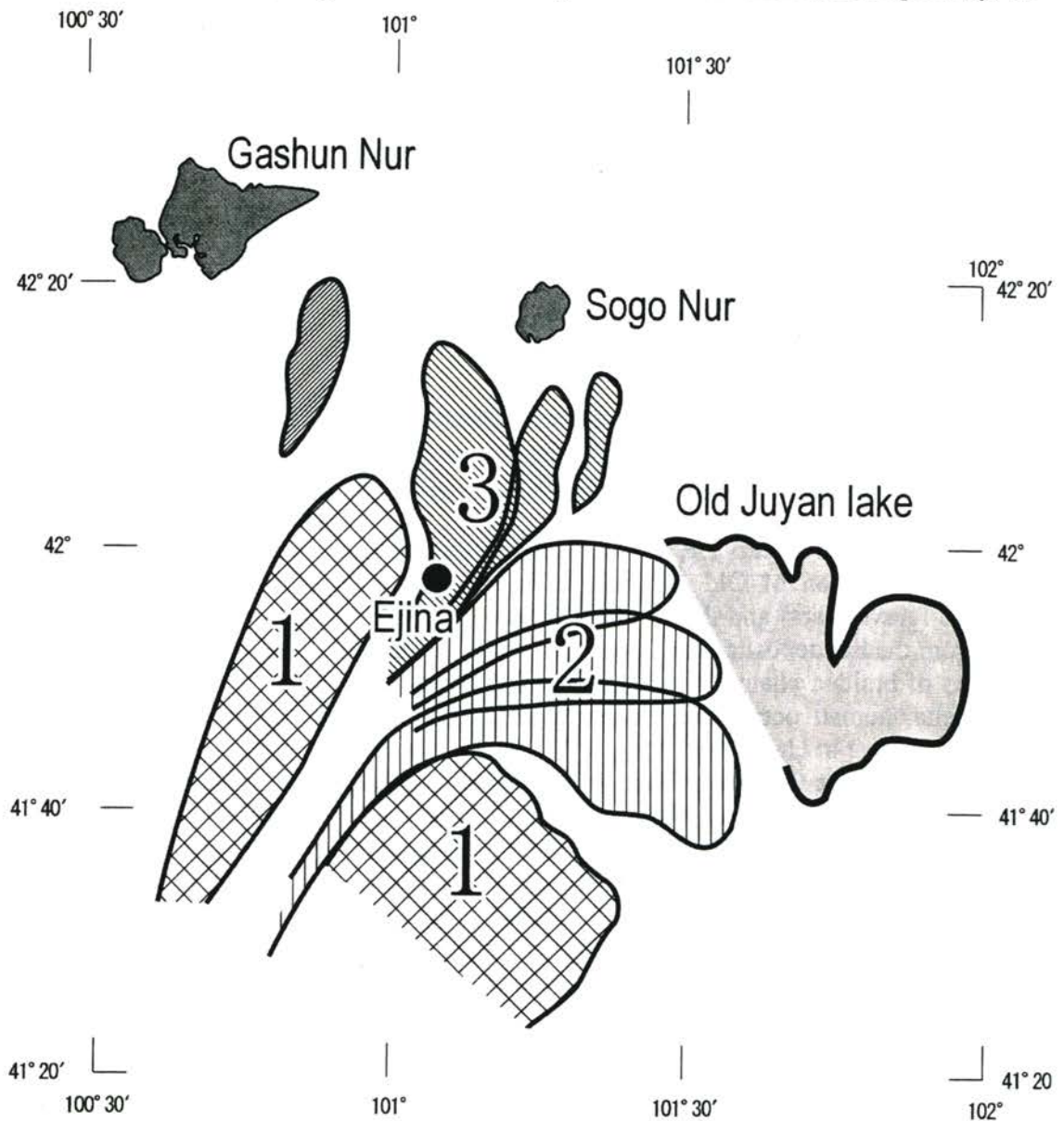


Fig.1 System of alluvial fan, delta and terminal lake in the lowest reaches of Heihe  
1 : alluvial fan, 2 : Juyan Delta, 3 : Ejina Delta



examined field evidences based on topographical and sedimentological observation, in addition to micro-fossil and chemical analyses of sediments, AMS dating and satellite images. On the micro-fossil analyses, diatom and pollen assemblages were checked. Age determination is based on AMS  $^{14}\text{C}$  dating, OSL dating, and historical evidences.

## **2. Delta systems in the lower reaches of Heihe**

Landsat images of the lower reaches of Heihe, Inner Mongolian, show clear topographic image of alluvial fan, delta, and terminal lake. Alluvial fan, delta, and lake make a series of topographic system, and these are connected with channel system. As a result of migration of channel system, another topographic system or new combination of fan / delta / lake appears.

Fig.1 shows delta system and its evolution, namely terminal lake / delta / alluvial fan combination and channel system in the lower reaches of Heihe. Here, older alluvial fan (1), Juyan Delta (2), and Ejina Delta (3) are illustrated. The older alluvial fan is probably the late to latest Pleistocene origin, but some part may be overlapped with younger alluvial fan deposits. As for the stages of Juyan and Ejina Deltas, alluvial fan deposits distribute only in the narrow zone between dissected topographies of the old alluvial fans.

Since 7500 years BP, two delta systems with braided channels were developed and migrated in the lower reaches of Heihe as follows.

### **Juyan Delta System**

Juyan Delta facing to Old Juyan lake, formed from 7500 to 1700 years BP, based on ages for gravel bars of the Old Juyan lake shorelines. Ages of the older Juyan lake suggest the delta date back to 7500 years BP, whose samples were obtained from the lake bottom sediment. Braided and/or sinuous (meandering) channels are dominated on the delta along with sand dunes. Such delta system, channel / delta / terminal lake, is subdivided into three sub-deltas based on difference in sinuous channel pattern (Gobi) on the Corona images. Gobi, recognized by black patterns on Corona images, is confirmed to be gravelly floor in the field. The deposits are composed of gravelly sand or sandy gravel. Surface of the deposits is gravels concentrated as "eolian lag gravel". Channels on the Juyan Delta are trending towards ENE to ESE.

Wide, whitish parts along black pattern of Gobi on the Corona images, were confirmed partly to be cultivated fields since the Han Dynasty. Their distribution pattern suggests that flood plains of both sides of the channels were exploited as cultivation fields. Black City, Green City and the surrounding areas are included in the Juyan Delta.

Since about 2500 years BP, Sogonur had gotten water area (after Germany Team), but from the gravel bar data, the lake level of the Old Juyan lake was still maintained at higher level and dropped abruptly about 1700 years BP. Therefore, from 2500 to 1700 years BP, channels toward Old Juyan lake and toward Sogonur coexisted. The channels toward Old Juyan lake blocked with sand dunes about 1700 years BP.

### 3. Environmental changes and the evidence

Table 1 Environmental History of Lower Reaches of Heihe (1) - 7500 to 1700 BP-

Age	Events on Environmental Change	Evidence, Source, Notes
7500-4000 y. BP	Formation of Old Juyan Lake and Juyan Delta	Lake gravel bars, Lake sediments [Tian-e Hu], Braided channels in sand dune area
4000-3000 y. BP	Lowering of lake level, arid climate and/or sand dunes blocking river course	No gravel bars. Advancement of sand dunes
3000-	After the interruption, channel system moved to north (Tian-e hu channel)	Migration of braided channels
3000-	Development of Juyan Delta and braided channel system	Corona images
3000-1700 y. BP	Old Juyan Lake and braided channel system in the large sand dune zone(Juyan Delta)	Ages of gravel bars and channel deposits, Corona photo.
3000-2500 y. BP	Starting of blocking Tian-e hu channel with sand dunes	Sand dunes
	Repeating lowering and rising of water level.	Lake level changes, shown by gravel bars
2500y. BP	Water commenced to enter into Sogonur	Germany Group:beginning of lake sediment
	After 2500 y. BP, braided channels to Juyan Lake through sand dune zone still existed.	Higher gravel bars show existence of large Juyan Lake, which needs supply of water by channels
2000y. BP	Early Han Dynasty, agriculture lands and irrigation channels in large scale. After latest stage of Han, desertification dominant.	Ruins of te K710 and K688 West Han (BC206-AD8), East Han (AD25-220) Li (2004: Oasis Report, 4-2)
1700y. BP (AD250)	Channel network in Juyan Delta blocked with sand dunes	No bars suggesting rapid drop of water level of the Old Juyan Lake.
1700y. BP	Sogonur shallow water, littoral condition	Mischke, 2001
(AD25 年)	Water flowed down to Sogonur through Ejina East Channel, making Ejina East Delta.	Topography

#### 7500yBP to 1700 yBP

Table 1 shows the environmental events and their evidences, source and/or notes during the period from 7500 to 1700 years BP. Main data sources are gravel bars of Old Juyan Lake, located in the surrounding area of Tian-e Hu, and lake bottom sediments around Tian-e Hu. Other data obtained from older channel deposits and sand dunes covering them are also used. Archeological sites of Han Dynasty are good tools to determine the age of delta topography.

What is main processes to change the river course ? Actually, Juyan delta areas are covered with moving sand dune zones in various places. Distribution of these sand dune



Table 2 Environmental History of Lower Reaches of Heihe (2) -1700BP to AD 1200-

Age	Events on environmental change	Evidence, Source, Notes
1700y. BP- (AD250~)	Blocking of channels with sand dune (Sand dunes covered channel networks of Juyan Delta)	Lake level drop in Old Juyan Lake (no bar → rapid drop of the level) , Fixed sand dune.
1400~700y. BP  (AD250)	Sogonur high water level  Water went to Sogonur through Ejina east channel, making Ejina east delta.	Mischke, 2001  Topography
AD250- AD1200	Minor channels in Juyan Delta Sand Dune co-existed with Ejina East main channel. But minor channels not reach to Juyan Lake.	Water in Sogonur (Germany team) No archeological site
About AD1000	Sogonur distinct drop of lake level	Ostracoda (Mischke, 2001)
AD1038	Xixia founded. AD1038-1227	Sato (Oasis Rep., 5-1)
	Xixia controlled this area since early 11C, built Black City.	Inoue (Oasis Rep., 5-1)
	Cultivated fields and irrigation channels	Corona images
AD1160~	Wheat cultivation (Green City) Irrigation channel necessary.	Age of carbonized wheat
AD1185~	Occupation surface near irrigation channel (Dadon west)	Ages of charcoal
AD1200~	Sand dune activated. Main channel carried water to Gashun Nur, to be lake.	Diatom(lake), age of lake sediment

zones is controlled by wind actions. Thus, wind directions determined the distribution pattern. On the other hand, vegetation cones, mainly Tamarix cones, are distributed along the both sides of Gobi, which shows the older channels.

#### Beginning of Sogo Nur

Mainly based on the ostracoda analysis for Sogo Nur cores, Germany group proposed a lake level change curve of Sogo Nur. They obtained a radiocarbon age from the lower part of a core,  $1615 \pm 95$  years BP ( $1700 \pm 85$  conv. BP) and extrapolated the age of the beginning of Sogo Nur as about 2500 to 2100 years BP (Mischke, 2001).

This means the Heihe water flow already commenced reaching to Sogo Nur about 2500 to 2100 years BP. However, in this stage, the water level of Old Juyan Lake was maintained at higher level until 1700 years BP. It suggests that Heihe water was drained toward east to Old Juyan Lake and also toward north to Sogo Nur.

During this period, Heihe water reaching to Sogo Nur must use a channel of the eastern side, near Badaoqiao, making a small scale delta (Ejina East Delta) along the channel about 2500 to 1700 years BP.

1700 y.BP to AD1200

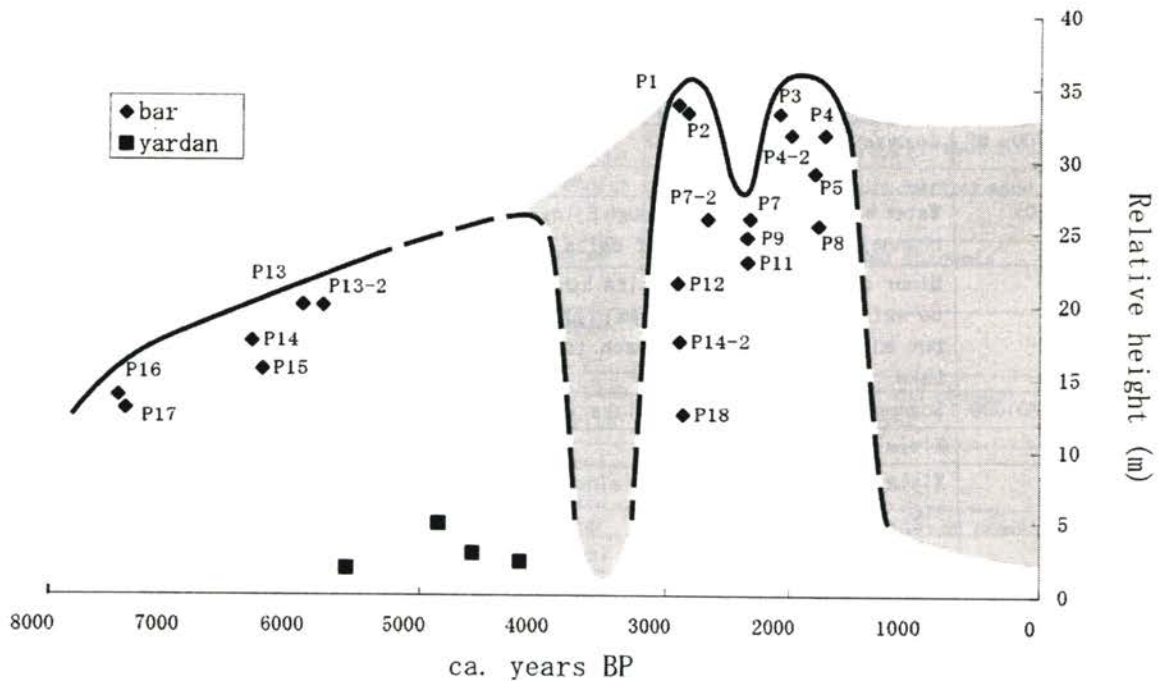


Fig.2 Lake level change deduced from gravel bars surrounding Tian-e Hu

Table 2 shows the environmental events and their evidence, source and/or other notes during the period from 1700 years BP to AD 1200.

From 1700 years BP to AD 1200, the Delta was probably in drier condition. Paleoenvironmental data are few in this term.

Older shoreline topographies, gravel bars, are distributed around Tian-e-hu and extend to much eastern part. Those are the best evidence of Old Juyan Lake. Around Tian-e-hu, nineteen gravel bars are found. 24 dating samples were taken from the test pits of each bar and from outcrops of yardan topographies which composed of lake sediments. Fig.2 shows the trend of lake level change of Old Juyan Lake, based on the dating data for older shoreline topographies around Tien-e-hu. In this curve, the final gravel bar was dated as about 1800 cal.years BP. After this bar, no evidence of gravel bars are found. Lake sediments from yardan are also older. This suggests that after 1700 years BP (AD250), lake level dropped rapidly or desiccated. Since then a lake area must have been limited in the area of lake sediment (yardan), even if existed.

Mischke(2001) analyzed ostracoda from Sogo Nur cores, and reconstructed the lake level curve during 2500 to 500 years BP. It shows higher water level from 1400 to 700 years BP interrupted with a distinct lowering centered around AD1000.



Ejina Delta formation AD 1200 to AD 1500

Table 3 shows the environmental events and their evidence, source and/or other notes during the period from AD 1200 to AD 1500.

Table 3 Environmental History of Lower Reaches of Heihe (3) -AD1200 to AD1500-

Age	Events on environmental change	Evidence, source, Notes
AD1200~	Sand dune developed more. Main channel carried water to Gashun Nur	Diatom living lake water Age of lake sediment
	Irrigation channels are continuously	Artificial channel and archeological site
	Ejina main delta began to form (by Ejina main channel et al.)	Topography
AD1227	Xixia controlled by Yuan Dynasty	
AD1286	Mongolian forces Black City?	
AD1370?	Drought, bad crops. Dry stage started?	Oasis Meeting
AD1372	Ming Dynasty destroyed Black City.	Ming Dynasty 1358-1644
AD1413	Irrigation channels still used. (repaired?)	Age of channel wall.
AD1400~ (AD1350~?)	Frequent floodings, Ejina delta developed actively.	Age of flood deposits on Ejina delta in the lower reaches.
AD1475	Abandoned cultivation around Black and Green cities.	Ages of Tamarix cone and plant covering irrigation channel.
Little Ice Age or AD1400 (AD1350)~	Since AD1400 (or AD1350), Gashun Nur dried up repeatedly.	Diatom(resting spore) and pollen of Gashun Nur lake sediment.

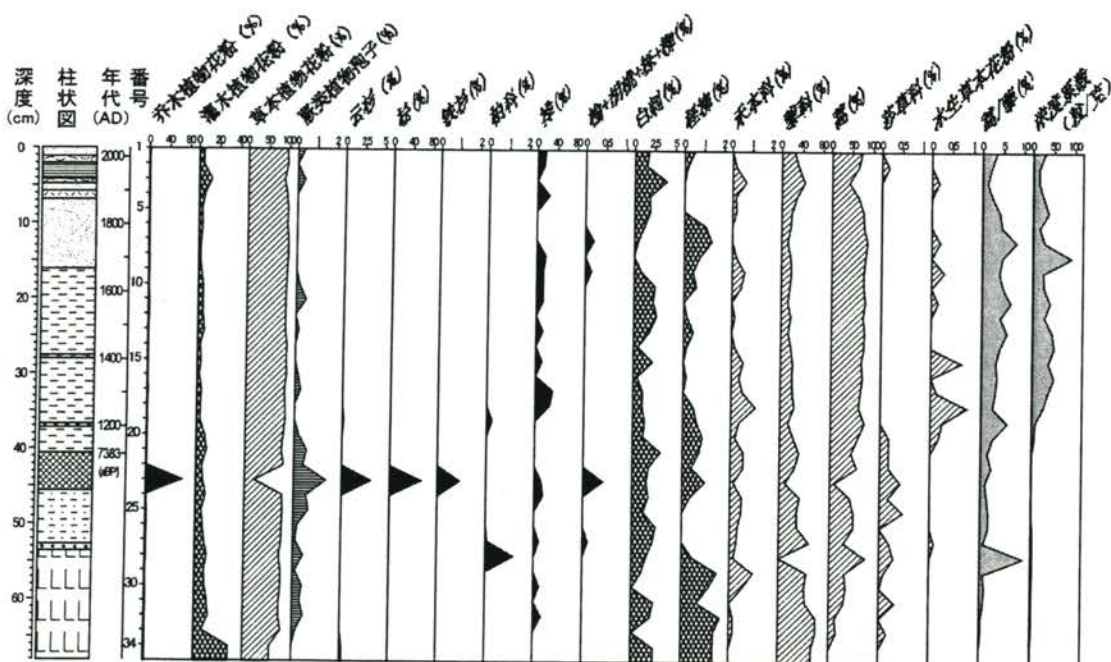


Fig.3 Pollen diagram for the deposits of Gashun Nur pit ( analyzed by Qi )

### Ejina Main Delta

Ejina main channel shifted the course to north, and flowed into Gashun Nur about 1200 AD. Along this river course, Ejina main delta developed with many flood deposits. Present Ejina town and cultivated fields are situated on the delta.

In Gashun Nur, a pit of 1.5 meters deep was dug. In the profile of the pit, top 40 cm is greenish gray lake sediments, and the lower part is reddish brown thick soil. The boundary between lake sediment and reddish soil is very clear. Nearly the lowest horizon of green-gray lake sediments includes a thin layer of caliche, which is dated by AMS <sup>14</sup>C method to be about AD 1200. The lowest part of the lake sediment includes fresh-water diatom and aquatic pollen / spore (Figs.3 and 4). The clear boundary and big difference in environment, suggest this changing process occurred abruptly about 800 years BP.

Around that time, in Xixia Dynasty, peoples were using irrigation channels for agriculture.

Flooding increased at least 1300's AD, and was active around AD1400.

At Yingluoxia, there is a stone monument on water hazard (Kato, Inoue, 2005).

According to Dunde Ice core data by Sakai, change in temperature became

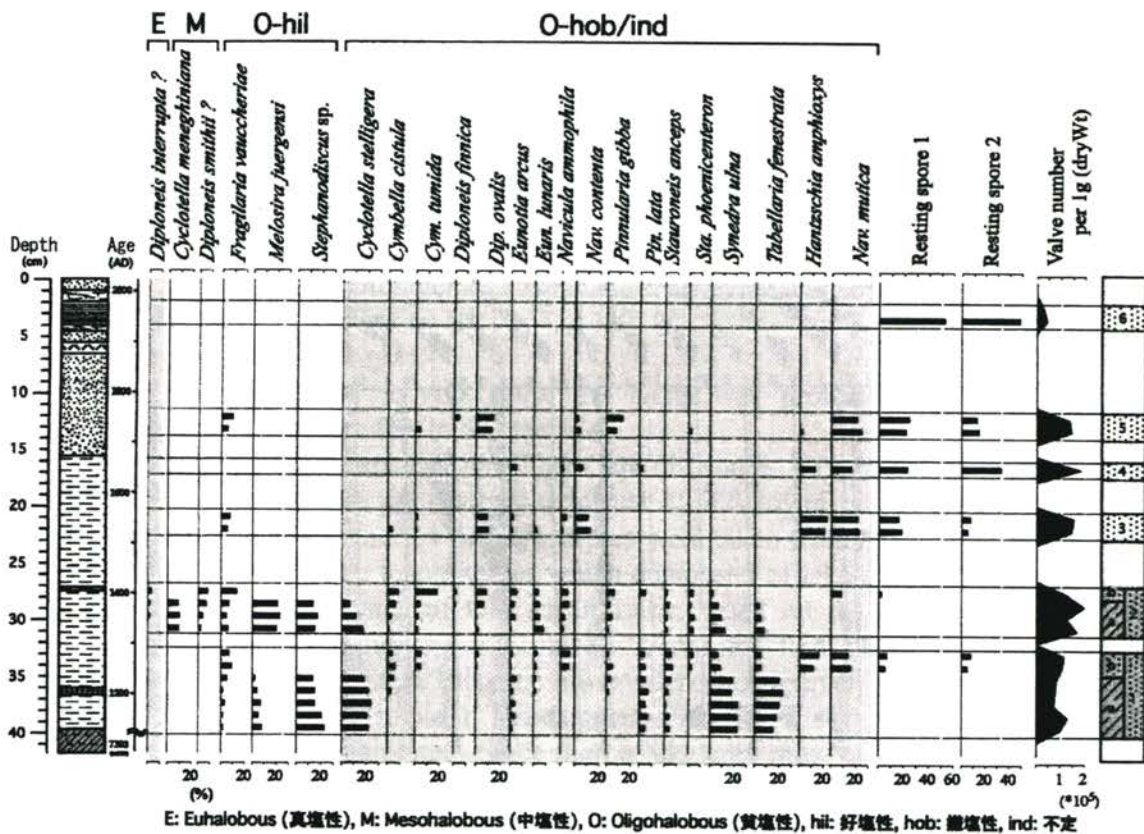


Fig.4 Diatom diagram for the deposit of Gashun Nur pit ( analyzed by Murata )



Table 4 Environmental History of Lower Reaches of Heihe (4) -AD1500 to present-

Age	Events on environmental change	Evidence, Source, Notes
Age not clear	Badaoqiao channel was blocked with sand dune to be a small lake	Topography, lamination of lake sediment
Early half of 20 <sup>th</sup> century	Gashun Nur was a perennial lake	Hedin, Stein(after Mischke, 2001)
1929	Sogonur maximum depth 4.12m	Hedin, 1943(after Mischke, 2001)
Early 1930	Big flooding from middle to lower	Grandfather of driver (查),
1958	Flooding (Ejina) Sogonur surface area 35.5km <sup>2</sup>	Driver (查) Gu, 1999(after Mischke, 2001)
1960, 1982, 1985	Sogonur salinity 0.6-3.4 ‰ 5-10 ‰	Liu, 1992
1961 Autumn	Gashun Nur dried up	Wan <i>et al.</i> , 2002
1973, 1980, 1986, 1994	Sogonur dried up	Do
1975	East of Badaoqiao, a terminal lake dried up in 1975	Driver
1989	Water was in Badaoqiao lake to 1989	Driver
2003 late Sept.	Water supplied in Badaoqiao lake from late September 2003, to early July 2004. 40-50cm deep. No water before long time.	Driver
2004 April	Badaoqiao lake had water of 50-60cm deep, but dried up in June, 2004.	Nomad near Badaoqiao
2005 Sept.	Badaoqiao lake dried up, no water	

As a reason of the shift of channel course, advancement of sand dune should be considered, adding to other reason such as increase of river discharge and/or precipitation.

After AD 1500

Table 4 shows the environmental events and their evidence, source and/or other notes during the period after AD 1500.

Gashun Nur had dried up in 1961 autumn (Wan et al. ed.,2002). Sogo Nur had dried up in 1973, 1980, 1986, and finally 1994 (Wan et al. ed.,2002).

#### 4. Discussion

Fig.5 is a model showing migration of channel/delta/terminal lake systems in the lowest reaches of Heihe during the last 3000 years .

From 3000 to 2000 years ago, Heihe flowed down to eastward in the lowest reaches, making braided channels, forming Juyan delta, and reaching to Old Juyan Lake (left one of Fig.5). During the Han Dynasty, cultivated land were distributed beside channels in the Juyan Delta area.

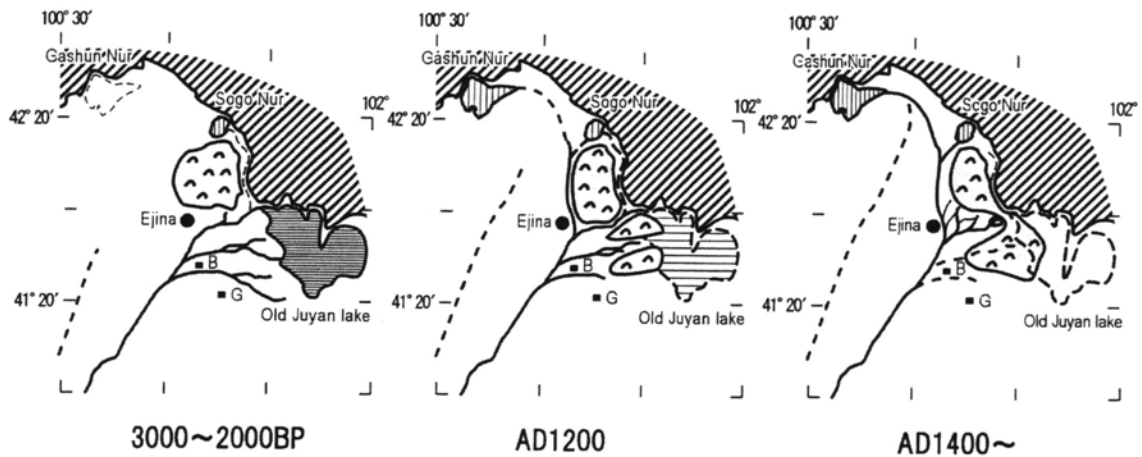


Fig.5 A model showing migration of channel/delta/terminal lake system in the lowest reaches of Heihe during the last 3000 years.  
 B : Black City, G : Green City

From 2500 to 2100 years BP, Heihe water commenced to reach to Sogo Nur using Ejina east channel, but the water was also supplied to Juyan delta and Old Juyan Lake. Water level of the Old Juyan Lake was very high from 3000 to 1800 almost continuously. Sand dune activity in the Juyan delta area probably started.

Around 1700 years BP, Old Juyan lake level dropped down abruptly. No gravel bar existed. Therefore, area of Old Juyan Lake was highly reduced or desiccated. As Heihe water might be mainly supplied to Sogo Nur, the water supplied to Juyan delta could not reach to Old Juyan Lake. Sand dune movement was very active and blocked channel courses.

Around AD1200, Heihe water reached to Gashun Nur using Ejina main channel to make a fresh water lake. In Gashun Nur, lake sediments overlying the reddish brown soil implies that dryer land spread before around AD 1200. Cultivation in Juyan delta area continued in the Xixia and Yuan Dynasties. They must have used many irrigation channels for agriculture in Juyan delta area.

In the eastern China, the warmest period in the last 1000 years was in the thirteenth century (Zhang, 1994). Moreover, abrupt climatic change signals on dry-wet are detected in 1217, 1266 and 1272 in most regions in the eastern China (Zhang, 1999). From the dry/wet grade curves of Zhang (1999), rapid change from drier condition to wetter condition can be detected in the thirteen century commonly in the eastern China. There is a possibility that wetter and warmer climatic condition contributed to the shift of channel course. For example, increasing of river water supply brought a large amount of clastics (sand and mud) in the lowest reaches, and drier condition under the warmer climate dominated in the desert and subdesert area strengthened transport of clastics, movement of sand dunes, generating dust and sand storms, and sometimes blocking channel courses.

After 1400 years BP, Ejina main delta has developed along Ejina main channels and its tributaries. Channel water reached to Sogo Nur and Gashun Nur to maintain freshwater lake



almost continuously. During this period, channels in the area of Juyan delta were dried up, and cultivated land and irrigation channels were declined or abandoned. From diatom and pollen analyses for Gashun Nur lake sediments, drier climate condition was probably dominated in the whole lower reaches. Sometimes, flooding water reached to Gashun Nur, but water level was maintained not long time. Increase of Tamarix pollen is also temporally.

To clarify the detailed process of migration of rivers, deltas and lakes, and relationship between such change in natural condition and human activities, it is necessary to understand the following problems.

Badaoqiao (Murneng Nur) dry lake deposit is laminated very well, having 637 layers. These laminated sediments probably indicate the condition in the Little Ice Age continuously in this area. Dating of those sediments is required.

Just before the abandonment, irrigation channels in the area of western Juyan Delta had been used (West of Dadon Site). Wide cultivated lands in the Xixia and/or Yuan Dynasties are situated near the main channel or upper part of the delta (move to easier part to obtain water). Much more data concerning to cultivation lands and irrigation channels are necessary.

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