A preliminary study on the evolution of the tail-lakes related to the migration of the lower-reaches channels, Heihe, Inner Mongolia, China

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Abstract: There are many Tail-lakes of Heihe River at the front margin of the delta. Juyan-ze, Kashun-nur, Soug-nur have been the main ones. But most of them have been dried up one after another. Previous studies revealed that Heihe drainage basin was not closed. There was an outlet drainage system connecting a number of fresh water lakes underneath of the desert to the eastward. It is unknown if there was any tail-lakes underneath of Badanjilin Desert. But Juyan-ze should not be the oldest tail-lake at the Grea Ejina Fan margin after the basin was closed with the tectonic rising at the eastern region. Juyan-ze had a highest lake level marked by gravel bar at about 5000 aBP., and kept alive until at least Yuan Dynasty. But during its later time the lake was dried up temporarily many times, which is shown at sedimentary structures and yardan landforms. Kashun-nur was formed while Heihe channel migrated away from Juyan-ze to the westward. There is no evidence showing that Kashun-nur and Suog-nur were connected together. But Soug-nur looks much younger than Kashun-nur. Tectonic movement is responsible to the closing up of the basin and channel migration at the early stage. The migration related to channel filling occurred during last 1000 years. Human has obviously influenced the channels and the lake since 1940s although large area of agricultural farmland was built 2000 years ago.

Key words: Tail-lakes, Channel migration, Heihe

1.Introduction

Heihe (Black River) originates from Qilian Mountain on the south, and runs northward through fore-mount basins, then onto Alashan Plateau (Fig. 1). Actually the lower part on the plateau is called Ruoshui with 2 main branches. One is named as East River running into Suog-nur, and another is called West River running into Kashun-nur (Fig. 2). The mountains rise up to more than 4000 m above sea level (absl), and develop glaciers. Runoff is mainly produced in the alpine region that is only a very small area. Large area of the drainage basin belongs to arid land with desert landscape. The lower reaches cut into a great paleo-alluvial fan, and had formed a number of channels. Tail-lakes are formed at the end of the channels. Juyan-ze, Kashun-nur, Soug-nur have been the main ones. Other small ones can also be found at the margin of the great fan complex. But most of them have been dried up one after another.

The lower reaches have attracted scientists from various fields since 100 year ago. In the early period field survey was mainly carried out by archaeologists with geographers. Natural science studies and observation, including meteorology and hydrology, were started in 1950s. However, the historical records are more than 2000 years. Because there is a tremendous change

of the environment, the eco-system and the landscape of the lower reaches during the last 50 years, intensive studies, surface monitoring and observation were carried out in the last 15 years.

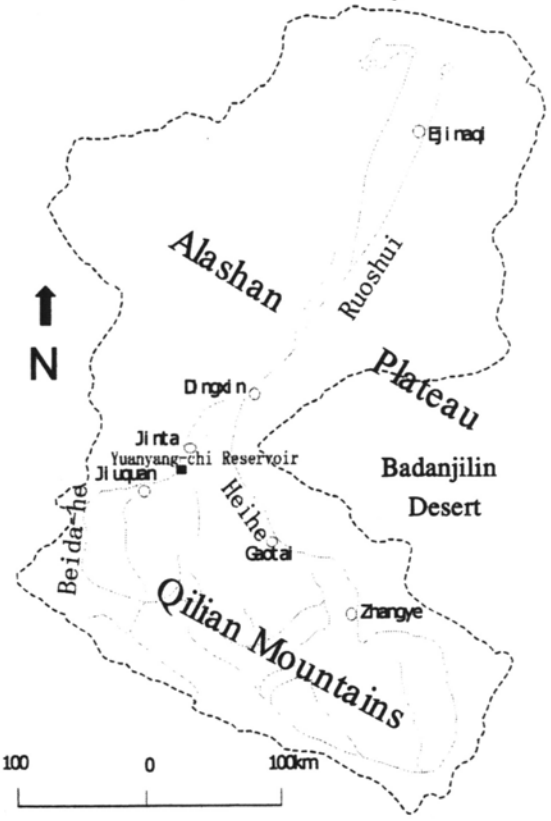

Fig. 1 Heihe drainage basin. The runoff is produced in Qilian Mountains, passes through fore mountain basins, Alashan Plateau, forms oases on the way northward, and gets into the tail-lakes. Water accumulating area is much smaller than water wasting area in extreme arid land.

Space radar image study reveals a paleo-outlet drainage system in the subsurface of the sandy desert and the gobi (Guo Huadong, et al, 2000). The outlet drainage connected many fresh water lakes, and the drifting aeleon sand was just developed along the outlet valley. Fresh water lacustrine deposits were underneath the sandy desert in a very broad distribution. Accumulation of the lacustrine deposits was continued to the end of late Pleistocene (Zhang Hucai, et al, 1997), and probably to early Holocene. Environmental changes in terms of desertification gathered a great attention of geoscientists (GONG Jia-dong, et al 1998, WANG Gen-xu, et al, 1999) and bio-scientists (Zhang Yili, 1997). Anyhow, all the changes are somehow related to the evolution of the tail-lakes and the migration of the channels, which are going to be discussed.**2.Events and Evidences**

After the basin was closed with tectonic rising, there have been many events related to the channels and the tail-lakes. Formation of the tail-lakes, migration of the channels, dry-up of the tail-lakes and formation of the yardan landforms are the distinct ones. They are the indicators of local environmental evolution and the responds of regional and global changes. All these events have occurred on or at the margin of the great fan or delta-complex (Fig.2). In order to understand the event sequences and their origin we have presently gotten the following facts from field survey and remote sensing data.

2.1 Juyan-ze

Actually so far we do not know when Juyan-ze was formed. But the lacustrine deposits at Jjuyan-ze are not very thick. The thickness is less than 15 m observed in total, which is composed of clay-rich silt and sand layers in alternation. The bottom of the lacustrine deposits is settled on hard reddish thick massive clay sediments with gravel inter-beddings or lens (Tertiary Formation?), which are absolutely not lacustrine deposits. The contact is exposed in a machine-excavated pit at the the bottom of wind blown-outs nearby Tian-e-hu. At the middle of the lower part (about 3.5m from the bottom) a clay-rich silt layer is dated about 4580 cal.y.BP. by AMS method from mollusk valves. Upper part (about 13 m) of the deposits is shown at yardan outcrops. From about 2.5 m upward the outcrop is with many eolian sand layers. Underneath of the sand layer clay-rich layer developed patterned cracks at the top. The cracks are 1 to 5 cm wide, and run into more than 15cm deep, but do not disturb the overlying sand layer. The cracks were formed into the clay-rich layer before the sand layer. It means that the lake was temporarily dried up many times during its latest period.

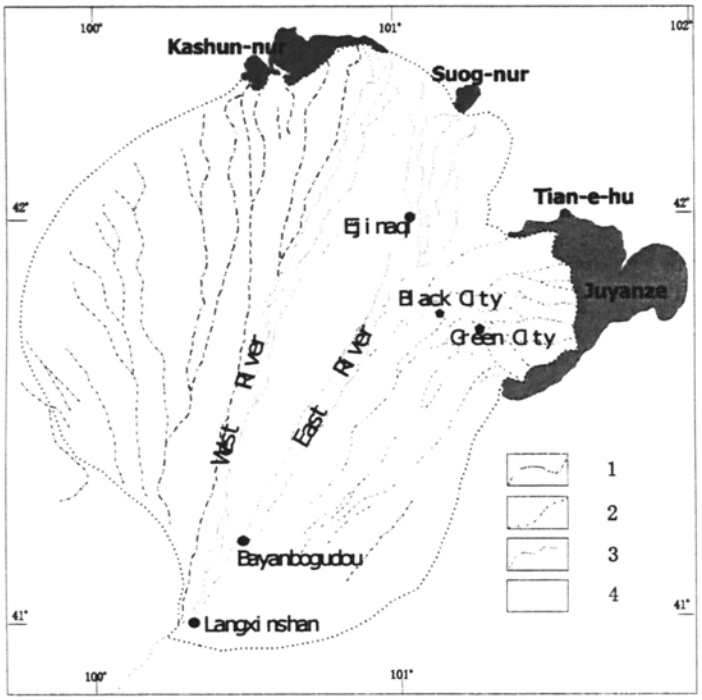

Fig. 2 Lakes and Channels on the Great Ejina Fan. 1 present channels, 2 channels mainly related to Kashun-nur stage, 3 channels related to Juyan-ze stage, 4 channels probably related temporary floods only.

Juyan-ze has developed beautiful gravel bars in the north side. There are at least 32 bars counted from down upward at the elevation between about 936 and 965 m absl. All the bars are parallel with each other, and extend levelly in kilometers. By chance bar No. 19 was excavated with road construction, and a few mollusk shells were found in the exposure for C-14 dating. Its age is about 3290 cal.y.BP. According to the sedimentary structure and relationship among the bars it is clear that the higher bars are much older, and co-relatable with the lower part of the lacustrine deposits.

According to the dating data and local lacustrine deposition rate, Juyan-ze should be formed not more 6000 a BP. It was existed only while the lower reaches of Heihe turned to the east, and completely dried up while the river moved to the west in late Ming Dynasty. Since then, side wash and side-afluence have formed temporary lakes only at the center and some wind blown-out, such

as Tian-e-hu.

Present bottom of Juyan-ze is about 896 m absl. But the highest gravel bar that was the paleo-shoreline gets 965m absl. This elevation covers much larger area than Juyan-ze actually occupied before. Both Kashun-nur and Suog-nur are all below the bottom level of Juyan-ze. But there is no evidence showing that Juyan-ze once occupied the whole region.

2.2 Kashun-nur and Suog-nur

According to historical literature records Kashun-nur was formed during the later Yuan Dynasty (Ejinaqi Local Chronicle Editor Committee, 1998). Geomorphology of Kashun-nur and Suog-nur shows a young performance. On the airphotoes there is no high gravel bars around the lakes although the lower bars are in good presentation. There are about 6 bars around Kashun-nur and 1 or 2 bars around Suog-nur. But there is no one connected together with both lakes. Extension and continuity of the bars around Kashun-nur are even much better than that of Suog-nur. The outmost bar of Kashun-nur is even far away from Suog-nur. That means it is not true that two lakes once were connected together as one lake in the earlier time. At least there is so far no surface evidence to prove that.

A hand made pit about 65 cm deep reveals lacustrine deposits with an interbed of flooding advance (Fig. 3). A reddish massive clay layer is about 12 cm below the present surface. Underneath the flooding deposits thin-bedded grayish green silty clay is presented, but not penetrated with the pit. Above the reddish layer Kashun-nur deposits developed. The original surface composed of lacustrine sediments has been deflated down at least 40 cm by wind. Therefore, the upper lacustrine deposits is more than 52 cm, composed of grayish green clay with thin evaporates interbeds at the top.

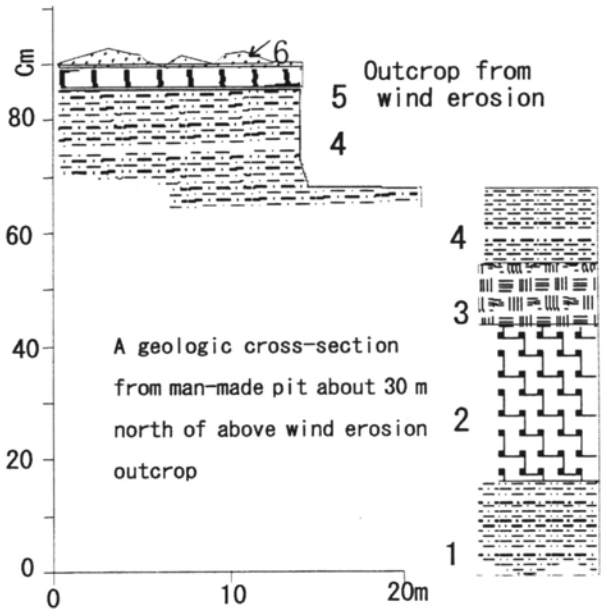

Fig. 3 A geologic cross-section at the bottom of Kashun-nur. 1 grayish green thin bedded silty clay; 2 brown massive clay, a few pebbles found; 3 grayish brown massive clay; 4 light gray thin bedded clay; 5 salt crust; 6 eolain black pebble-sand ripple.

Suog-nur is about 50 km on the east of Kashun-nur, and about 50 m higher than it. Gravel bars or paleo-shorelines are not clear around the lake. Main channels of Heihe at the lower reaches are now connecting with the lake. An about 60 cm deep pit dug at the shore in August, 2002,

shows that the off-shore wash occurred into lake bottom while the lake dries up or extremely shrinks. Latest off-shore wash occurred from 1992 to 1999, and accumulated about 50 cm thick reddish sandy clay, containing pebbles. Both Kashun-nur and Suog-nur are at a little bit lower position than Juyan-ze. Present elevations of Juyan-ze is about 896 to 920 m absl (dry bottom level), Kashun-nur is about 890 to 898 m absl (dry bottom level), and Suog-nur is about 900 m absl (water surface). The biggest difference between the bottom of Kashun-nur and the highest gravel bar of Juyan-ze is about 75 m. In-between landforms of the lakes look like very flat and even in present time. So far there is no clear evidence showing the relationships among the lakes, and no clear evidences showing any disturbance on the channels. Anyhow we do not know what it is in the subsurface at the lower part of the alluvial fan and the deltas, especially under the Kashun-nur Delta and the Suog-nur Delta.

2.3 The Channels

Channels are widely distributed on the great fan (Fig. 2). A large number of them have been abandoned with the migration of the river course. At the lower reaches related to Juyan-ze almost all channels are dried up. A channel beside the Black City is about 20 m deep from the surface on which the ruins settled (fig. 4). This channel was still fully filled with water in 13th century, but dried up at the end of Yuan Dynasty or at the beginning of Ming Dynasty (about later 14th century). Since then there was no more water coming down from the upper reaches at this point. The channels completely migrated away to the westward, and Juyan-ze was dried up. By following this event, many other abandoned channels in the west of the fan are also related to migration of the river course and combination with incising down into fan.

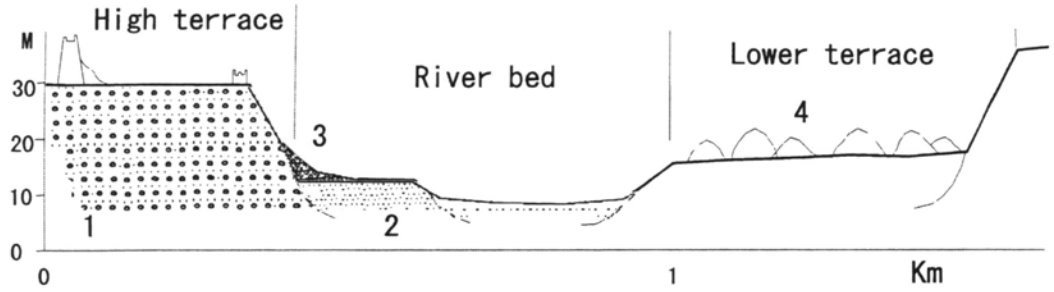

Fig. 4 An abandoned channel beside Black City. Tamarix cones are at low terrace surface. Black City is on the high surface with pebble pavement. The channel is about 20 m deep from the high surface. 1 middle-coarse sand; 2 alluvial sand; 3 sandy colluvium; 4 Tamarix cone on lower terrace.

Another channel at the lower reaches of the West River, related to Kashun-nur, is a latest dried up channel. It is mostly related to over-use of water at the upper streams. The channel is about 2 m deep in average, and about 3 m in maximum. The channel bed is sandy, but the terrace surface is covered with pebbles, and the terrace is composed of cross-bedded fine gravelly coarse sand. It suggests that the carrying capacity was reduced very much when the channel was formed.

The top of the great fan in the south at around Langxinshan is a key point for the channel migration. The two main branches, East River and West River (Fig. 2), have been existed at the same time at least since Ming Dynasty. East River has been existed at least when Juyan-ze was formed, and became the main influx channel of Juyan-ze until West River was fully filled with water to charge Kashun-nur. Of cause, the lower reaches was not to the north, but turned to the

eastward. When the river flow moved from West River to East River again, the lower reaches directly flowed to the north into Suog-nur, and one of main branches even turned to the west to charge Kashun-nur. The abandoned channels on the southeast of East River are older than (or at least as old as) the channels on Juyan-ze Delta. The abandoned channels on the Juyan-ze Delta were formed as the river courses migrated to the west and West River courses were formed. A bunch of abandoned channels on the west of West River were formed when the courses migrated again eastward. The latest abandoned channels were formed on Kashun-nur Delta, and led the lake dried up.

2.4 The Great Ejina Fan and Deltas

After Heihe got onto Alashan Plateau a great alluvial fan, the Great Ejina Fan, was formed with unloading its sediments. Actually the great fan is a fan complex. According to regional geological studies, earliest fan deposits have already been cemented as conglomerates and sandstones. They are now exposed at gullies dissecting into the fan in the south, and distributed at the upper part of the great fan. Its age can be co-related with lower Pleistocene Formation of this region, named as Jiuquan Conglomerates. Since the oldest fan was formed, the river channels have incised into the fan deposits and moved new fans or deltas far northern ward for several times, and the fans or deltas became much smaller (Fig. 5). New lakes were formed and migrated from the corners to corners while the deltas squeezed northward into the mountains. Probably some former lakes were wholly or partly buried underneath the delta when the great fan expanding northward. Actually Juyan-ze Delta settles in the west of Juyan-ze bottom. Delta probably buried a big former lake before Juyan-ze stage on the south of Kashun-nur.

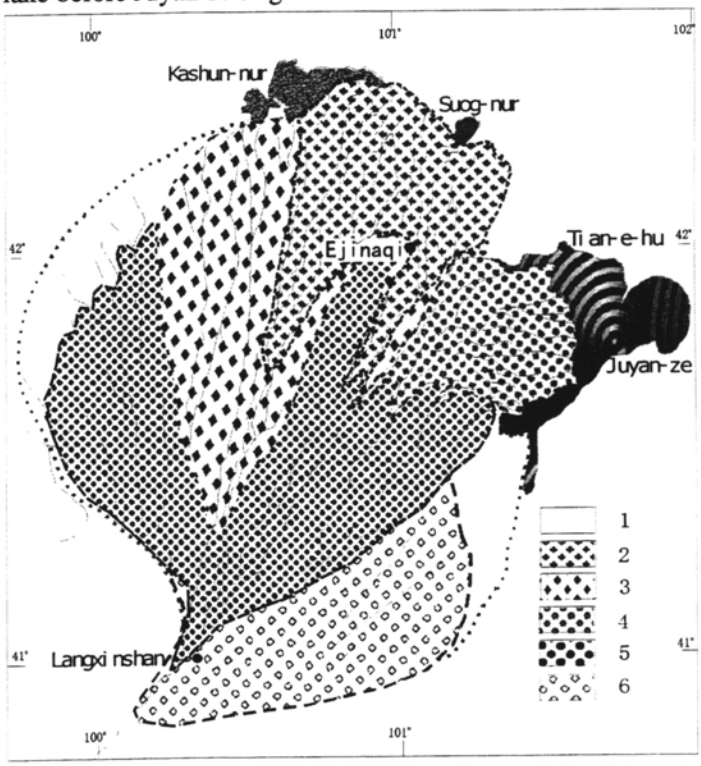

Fig. 5 Migration of the Great Ejina Fan and the deltas, based on remote-sensing data only. To refine this map ground truth and surface geology are needed to carry out. 1. alluvial plain reworked from the great fan; 2. Modern deltas formed in Kashun_nur and Suog-nur stage (early Ming to present), Soug-nur Delta; 3. Delta formed in the Kashun-nur stage (Yuan Dynasty), Kashun-nur Delta; 4. Delta of Juyan-ze stage (Han to early Yuan Dynasty), Juyan-ze Delta; 5.

Middle Pleistocene to middle Holocene great fan, Pre-Juyan-ze Fan; 6. Early Pleistocene great fan.

Very important fact should not be neglected is that all the formations of Pleistocene and Holocene are thin, but broad distribute within the great fan. Maximum thickness of Quaternary deposits is not more than 350 m, and average is leas than 100 m.

2.5 Literature Records and Previous Findings

Historical literature has been found as early as 2000 year ago in this area. But only a few words mention local natural condition. Of cause, the limited information is very important for us to reconstruct the paleo-environment. The literature records on human activities and ruin-sites can also help us to measure and image the physical geography. Juyan-ze was mentioned in ancient Chinese literature as early as 770 BC, and frequently appeared in the documents of Han Dynasty. But Kashun-nur appeared after Yuan Dynasty, and Suog-nur appeared even later in early Ming Dynasty (Ejina Local Chronicle Committee, 1998). According to the records on the locality of historical events, migration of ancient city, changes of population and agriculture, previous study has figured out some figures on Juyan-ze. The lake once was as large as 2600 km^2. It still kept for about 726 km^2 during Qin (Dynasty)-Han (Dynasty) period (Wang, S., et al, 1998, 2002). Agriculture, military installation and administration office were all on the Juyan-ze Delta until end of Yuan Dynasty. A defense wall of Han dynasty was built along the west bank of the East River. All these give information that the oases in Han Dynasty were distributed on the east of the East River only. In terms of defense there was no reason to divide the oases into parts or even cut into half with military installation.

Agriculture began as early as 88 BC at this area. But the early irrigation system was only on the Juyan-ze Delta, and did not made any change to the tail lake, lake Juyan-ze. A significant construction for water conservation was built in 1941 in the East River at the upper reaches, and the lower reaches of the East River was dried up for most of seasons. Then more constructions for water conservation were growing up later on, and man made oases were growing bigger and bigger in the upper valley (see Table 1).

3.Some Significant Points

3.1 Migration of the Channels

In geological history the great fan had migrated many times in a very broad range along with the migration of the river channels. The channels had not only migrated from the east to the west (or in reverse) but also extended from the south to the north. So far it is un-known what the landforms under the great fan were. There is a long geological history not clear before Juyan-ze stage (6000 years ago). Formation of the great fan must have filled and leveled up the small relief. During Juyan-ze stage (from about 6500 to 700 a BP.) the lower reaches of East River made a turn to the east into Juyan-ze at which is a little bit higher than the north part at which Kashun-nur is. There must be some thing underneath Kashun-nur Delta, which had blocked the way of the flow to the northward.

The channels migration westward in Yuan Dynasty occurred not only at the lower fan region but also at the top of the great fan. At Langxinshan the flow moved from East River to West River after using East River channels for thousands years. It implies that there was a geological event that had been occurred at the point in later Yuan Dynasty. Either something blocked the channel of East River or cleaned the channel of West River up. The lower reaches migrated to the west probably much earlier than that the flow moved from East River to West River.

The river flow partly returned back to East River channels in Ming Dynasty, but kept going northward into both Kashun-nur and Suog-nur. In 1941 East River was blocked artificially to lead the flow into West River, and later East River channels dried up. In 1947 Yuanyang-chi Reservoir (capacity: $0.12\times10^6m^3$) was constructed in Beida-he Valley, one of the main tributary of Heihe, and run off of the lower reaches of Heihe begun to be reduced by human activities.

3.2 Relationships of the Lakes

There were many big fresh water lakes underneath the Badanjilin Desert on the east of the great fan (Guo, H., et al, 2000). The lakes were alive with outlet in Pleistocene, and no salts were formed before dried up and covered with sand. It means that all the lakes were not for very long geological history in closed condition, and dried up rapidly. After the basin was closed, Tail-lakes were formed along with river channels. According to characteristics of the basin underneath the Ejina Great Fan and the relationship between the great fan and the surrounding landforms, Juyan-ze stood for one of the evolution stages of the great fan and the tail-lakes. Before Juyan-ze, there should be some other tail-lake or lakes in front of old great fan to collect water from the river and vicinity afluence. It is reasonable that fan deposits have buried former lakes while the great fan was migrating and growing northward.

Both Juyan-ze and Kashun-nur have gotten to the haloid stage at last, but there was no significant salts layer has been formed in the deposits of any one of them. Juyan-ze had lasted for about 6000 years according to the lacustrine deposit record. Kashun-nur was much younger, and lasted much shorter time. Suog-nur is the latest tail-lake. Shoreline elevation indicated by the gravel bars presents that the lakes had not been connected with each other, and characteristics of the gravel bars show that the lakes had not existed in the same stage, but one after other.

3.3 Sequences of the Events

There were many events occurred before Juyan-ze stage. But there is no dating data to cite the sequences. The great fan should be formed since early Pleistocene, but only occupied the southern part (see Fig. 5). There was an outlet of this basin, which existed until at least in late Pleistocene. The drainage system connected many fresh water lakes on the way out eastward. The basin was probably closed completely at the east in late Pleistocene or early Holocene. The fan grew northward, and filled up the basin step by step.

Both development of the Ejina Great Fan and evolution of the tail-lakes show stages. Juyan-ze was one of the tail-lakes of Heihe. Form the end of Pleistocene to middle Holocene there were mostly some older tail-lakes before Juyan-ze. So far there is not evidence to show where, when and how big the tail-lake (or tail-lakes) was (or were). They could be the former lakes before the basin was closed, or other lakes buried with eolain-sand or the fan-deposits later. Since its formation Juyan-ze only existed for about 6000 years. During Juyan-ze stage the flow turned eastward at the margin of the great fan. After Juyan-ze stage the channels migrated away from Juyan-ze, and run northward. Kashun-nur existed only for about 600 years and Suog-nur for about 450 years.

Human made obvious impact on the tail-lakes and the river channels since 1941. Of cause growth of regional population, increase of agriculture and stocks, over-use of water resources have been resulted of tremendous regional environmental change and crisis of local ecology.

3.4 Origin

Tectonic movement closed the basin at the end of Pleistocene, or even beginning of Holocene in the east. Up-lift of Qilian Mountains brought vicinity higher and higher. Then the great fan

migrated northward into the mountains opposite. Anyhow, channel filling, tectonic movement and climatic change all might be responsible for channel migration and lake movement. But it is now difficult to tell what is the origin of migration of the channels and the tail-lakes after Juyan-ze stage. It should be channel filling by deposition and decrease of runoff on the deltas during the last 6000 years. Human disturbance occurred in much later time.

For the reasons of dry-up of the lakes, they are much easier to be understood. A great scale of shrinking of Juyan-ze was mostly related to decrease of the storage of glaciers in Qilian Mountains. Climatic change should be a significant rule for Juyan-ze evolution. But channel migration finally dried up Juyan-ze, and greatly influenced Kashun-nur. Human activities dried up the lakes and the channels.

4.Summary

An outlet existed until at least end of Pleistocene. Many fresh water lakes underneath the desert were connected with the outlet drainage system. After the basin was closed there must be some other tail-lakes older than Juyan-ze. They could be the former lakes before the basin was closed, or other lakes buried with eolain-sand or the fan-deposits later. Tail-lakes were formed and replaced one after another with the migration of the channels and deltas.

Juyan-ze was one of the tail-lakes of Heihe when the lower reaches kept to the east orientation. Kashun-nur and Suog-nur were formed one after another when the channels moved away from Juyan-ze and headed to the north. There is no evidence to show the lakes were once connected with each other.

Sufficient impact on the lakes by human behavior was started about 100 years ago. The latest human behavior is responsible to the dry-up of the present tail-lakes, Suog-nur although it will be naturally dry-up in geologic time.

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Table 1 Historical events of the channels and the tail-lakes, Heihe, China

Events / Place / Time	The river channels	The lakes
In late Pleistocene or even to early Holocene	The basin was not closed.	Fresh water lakes connected with outlet drainage (1)
During the early history (about 2000-220a BP.)		Water surface of Juyan-ze was about 726km^2 (2)
1270 DC	Full channel of water in the channel beside Black City (3)	
In Yuan Dynasty (1271-1368)	Water flow moved away from East R. to West R., Channel on Juyan-ze Delta dried up	Kashun-nur was formed (3)
At the end of Yuan Dynasty or beginning of Ming Dynasty	Paleo-channel of East River dried up (3)	
In Ming Dynasty ()	Runoff moved back into East R.	Suog-nur was formed (3)
About 400 to 600 a BP.		Juyan-ze was dried out, but it temporarily water refilled later on (3)
1930s	West channel of East R. run into Kashun-nur.	Depth of Kashun-nur was 2～9 m,and surface was about 190 km^2, Suog-nur was about 4.1 m deep (2)
1941	Channel of East River was blocked, and the lower reaches was short of water from 1941 to 1952 (3)	
1942-1952	East River was dried-up	Suog-nur dried up (2)
1947	Yuanyang-chi Reservoir was constructed in Beida-he Valley (capacity: 0.12×10^6m^3)(3)	
1952	A water-gate was built to divide water for both East River and West River (3)	
Early to middle of 1950s	Height of Yuanyang-chi Dam was increased several times. Capacity enlarged to 0.63×10^6 m^3 (3)	
Middle of 1950s	Jiefangcun Reservoir was built (Capacity: 0.39×10^6m^3)(3)	
1958		Kashun-nur was 267km^2, and Suog-nur was 35.5km^2 (2)
At the end of 1950s	No surface water from Beida-he supplies Heihe (3)	
1961 to present		Kashun-nur was dried out (2)
1973		Suog-nur temporarily dried out (3)
1980		Suog-nur temporarily dried out (3)
1986		Suog-nur temporarily dried out (3)
1992-1999		Suog-nur dried out (3)
2000-present		Water filled into Suog-nur (4) Water filled into Swan Lake

Note for references: (1) GUO Huadong, et al (2000); (2) WANG Su-ming, et al (1998); (3) Ejinaqi Local Chronicle Editor Committee (1998); (4) Authors' notes in field trip (2002).