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Climate and environment reconstruction during the Medieval Warm Period in Lop Nur of Xinjiang, China

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We made multi-proxy analysis of ^{14}C, grain size, microfossils, plant seeds, and geochemical elements on samples from a profile in the central West Lake of Lop Nur. The grain size suggests relatively stable sedimentary environment around the Medieval Warm Period (MWP) with weak storm effect, which is followed by frequent strong storm events. Abundant microfossils and plant seeds in this stage indicate a warm and humid fresh to brackish lake environment. C, N, and stable elements are high in content in the sediments while Rb/Sr, Ba/Sr, and Ti/Sr are in a steady low level. In addition, plenty of red willows lived here prior to about 700 a B.P., indicating a favorable environmental condition. The results indicate that the environment in Lop Nur and its west bank turned to be favorable at about 2200 a B.P., where the Loulan Culture began to thrive. Then the climate and environment came to be in the good condition in the Tang and Song Dynasties, when the storm effect became weaker, rainfall increased and the salty lake water turned to be brackish to fresh lake water. Hence, limnic biomass increased with higher species diversity.

Lop Nur of Xinjiang, Medieval Warm Period, climate change, grain size, microfossils, geochemistry, ancient culture, paleo-vegetation

The Medieval Warm Period (MWP) is one of the most significant climate episodes in the world[1−5] and many researches have been done with aim to reconstruct climate variations with help of various proxy indicators. So far, the materials which can respond to environmental changes in high resolution are mainly from ice cores[6−9], tree-rings[10,11], historical literature[12−16], lake sediments[17−20] and so on. Due to the importance of MWP in Holocene study, many researches are available on the climate changes of MWP. However, there are still considerable discrepancies concerning the duration, amplitude of temperature changes, internal and external driving factors for the climate variations of MWP[21], which may be due to the different materials, methods and dating techniques the authors used in their study. In China, researchers have not reached an agreement on the issue about whether there does exist a MWP or not[22]. Besides, because of the regional difference, the historical literature was used in the East[23] to reconstruct the climate while the ice cores, lake sediments and tree-rings were used mainly in the West. Most results showed that there was obvious distinction on the warm-cold transition between West and East China. Thereinto, during 900—1300 AD, there was a distinct warm stage in the East, but unapparent in the West[24]. However, some researches showed that there was a remarkable MWP in West China. Thus, it is necessary to search for much evidence for trying to resolve the above-mentioned discrepancies[25].

Arid regions of the world are often poor regions with potential global treasure resources. The drought areas in China are underdeveloped with abundant resources, but the fragile ecosystems could be the vital problems

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we must face and resolve in the Develop-the-West Strategy. Lop Nur is a tail-end-lake of the Tarim River, the largest inland river of China. So its history of evolution and drying not only reflects the common rules of the lake evolution in the drought regions, but also records the environmental evolution of the drought areas. Since the 1970s, Lop Nur has become a hot area of scientific exploration. And in recent years, a lot of significant achievements have been available about the Quaternary natural environment and ancient human civilization evolution in the Lop Nur area, which showed that the environment experienced great changes for many times[26−29], and plants coverage increased when the climate was humid. But because the Lop Nur area and its surrounding region exceeded 2000 km^2 and the lake area ever reached several thousands to nearly ten thousands square kilometers, therefore, the water chemical property and sedimentary characteristics are different at different places. The environmental records by sediments from different parts of the lake usually reflect different climate changes, leading to biased conclusions. So, more work needs to be done to fully understand the environmental evolution of this area during the last 10000 years. Based on the analysis of multi-profiles from the West Lake, the authors considered the profile from the lake center and discussed the characteristics of climate and environmental changes during and around the MWP.

1 General information of the study area

1.1 Modern natural environment

Lop Nur, the central catchment of the Tarim Basin, is located in the eastern part of the basin, with an elevation of 780 m. The Altun Mountains lie to its south and the Tianshan Mountains to its north. To the east is the North Mountain and to the west is the Taklimakan Desert. The climate is extremely dry in this region. According to the meteorological records of 15 years in the Weather Station of Ruoqiang County, the average annual temperature is 12℃, the annual precipitation is 31.2 mm (11.0 mm more than the average data between 1961 and 1990), and the annual evaporation is 2901 mm. Averagely, there are 102.5 days with strong winds and dust storm in a year, among which there are 18.6 days with strong winds bigger than 8 levels. The climate in the lake area of Lop Nur is even severe with annual precipitation of less than 20 mm and annual evaporation of more than 3000 mm. There is no water on the ground but the hard salt crust, except few salty spring and temporary seeper after rainstorm near the piedmont areas. It was once called “the world’s most desolate area except the two polar regions” by Chen[30].

1.2 Recent evolution of Lop Nur

There were quite a lot of researches and reports about the recent changes of Lop Nur, especially on the cause and age of the ear-like salt crust in the East Lake[31−36]. We think that Lop Nur could be divided into two parts since the middle Holocene: the East Lake and the West Lake (Figure 1), and that each lake has its own evolution process. The East Lake began to dry since 3.0 ka B.P.[26]. Chen[30] walked through the dry East Lake from the North Mountain at the end of 1930 and pointed out that the bottom of the lake was pure salt crust and it was getting harder and harder to the west. The West Lake was brackish and the area of the lake enlarged to 1900 km^2[30] in 1931 and has begun to shrink since the 1940s. The latest area change of the East Lake and the West Lake happened in August 1958, when it rained heavily in the Tianshan Mountains region of Kuqa and vast amounts of flood went into Lop Nur from the Konqi River. Then, plenty of water refilled the drying East Lake through the Tieban River. The above process can be verified clearly from the aerial photos taken at the end of 1958, which showed devious estuaries in the north lake and a lot of islands. Also we could conclude that the water depth was low because the previous three lake lines were out of water. The East Lake was dried again in 1961, thus there was no water on the monochrome CORONA satellite image taken in December 1961. At that time, there was only a small quantity of water in the south of the West Lake, which probably dried out next year. For the reason of different evaporation in different years and seasons, especially for extremely little evaporation in winters, there were obvious different lake lines in different seasons from 1958 to 1961. This is why there were 4 year-lines and many seasonal lines with different widths and different colors on the satellite images, which look like a large ear[35,37] (measuring line of A-A′ in Figure 1) by the effect of the lake shape.

2 Profile from the central West Lake

The West Lake was a kind of lake of water, characteristic mainly of detrital sediments containing sulphide. The profile (Figure 2) of 3.3 m depth lies in the center of the West Lake of Lop Nur (40°27′129″N, 90°20′083″E, as place II shown in Figure 1) with an elevation of 780 m. The lithology characteristics are described in Table 1.

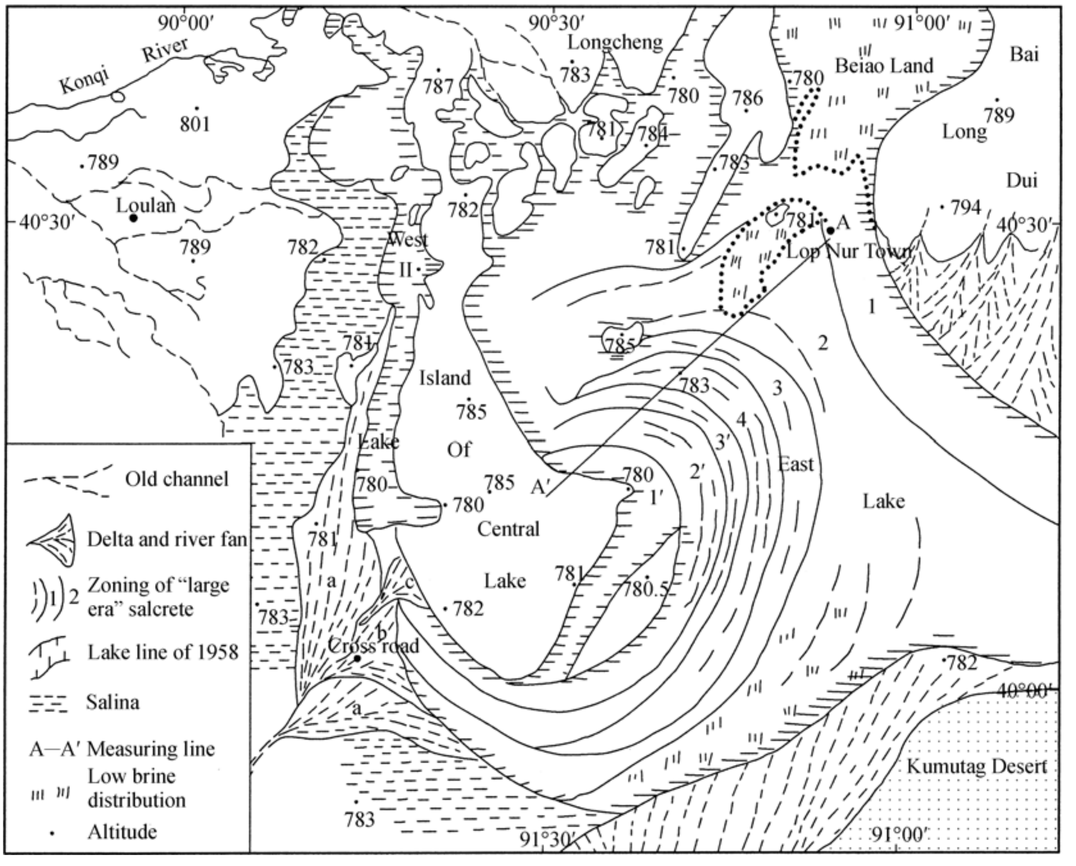

Figure 1 Sketch map of landscape and location of sampling site in Lop Nur.

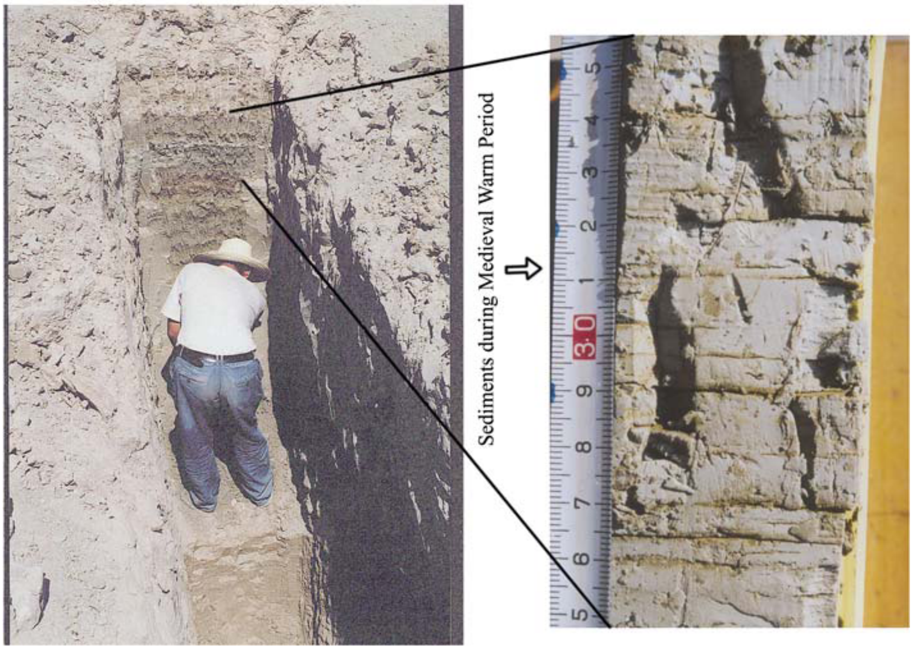

Figure 2 Photo of the profile from the center of Lop Nur.

Table 1 Lithology of the profile from the center of Lop Nur

Depth (cm)		Lithology	Subsection
0－39	0－11	lark farinaceous fine sand with rather hard texture	VI
	11－24	lark silty clay with interlayer of wafery white halite	
	24－39	grey sandy clay with interlayer of fine silt, with clear bedding and a little halite	
39－123	39－62	brown grey sandy clay with charcoals, bulrush roots and a little gypsum monocrystal	V
	62－80	dark grey silty clay with plant oddments and gypsum monocrystal, ^{14}C 871±45aB.P., AMS^{14}C 800±40aB.P.	
	80－123	dark grey silty clay with wafery bedding and plant remnant	
123－162	123－138	brown yellow farinaceous fine sand with level bedding and white halite patch	IV
	138－144	brown yellow medium-fine sand with a mass of white halite patches and inanition conformation	
	144－162	grey medium-fine sand with white halite patch, with transition to silty clay below	
162－209		brown yellow silty clay with wafery bedding, with a little halite patch and gypsum monocrystal	III
209－248	209－233	grey silty clay with interlayer of wafery yellow silt, with laminated structure	II
	233－248	dark grey clay with gypsum monocrystal, 9266±135 aB.P. (^{14}C) at 240 cm	
248－330	248－280	Kelly clayey silt with bedding, gypsum monocrystal can be seen	I
	280－330	yellow silty clay with an interlayer of wafery gypsum and the thickest gypsum monolayer (3.5 cm)	

3 Lop Nur during the MWP

3.1 ^{14}C dating of the sediments during the MWP

Because of the high degree of water mineralization in the West Lake since the Holocene, few aquatic species can exist in the salty or brackish lake. Synchronously, the extremely dry climate made it hard for plants to survive around the lake. So the content of organic matter was very low in the sediments and we could only get enough organic carbon for ^{14}C and AMS dating in a few layers. The OSL dating method was used in this study. But because of unconventionality of U content in the sands, the results were either too old or too young for emendation (The OSL dating results were 1250±120 aB.P. at 130 cm and 12300±200 aB.P. at 130 cm by the Geological Research Center of the Earthquake Office in Beijing). For some layers which cannot be dated by laboratory methods, we calculated the date by sedimentation rates. This method was used by Wang et al.[26] when they dated stratum in many different drill cores. For instance, the sedimentation rate was 0.13－0.23 mm/a at the depth of 0－5.5 m in Core K_1. Referring to their results and combining with our ^{14}C data, we calculated the sedimentation rates as 0.7 mm/a at the depth of 11－39 mm, 0.5 mm/a at the depth of 39－80 mm and 0.4 mm/a at the depth of 80－123 mm. Based on the sedimentation rates, we calculated the ages of different layers (Table 2). There is a segment of sediments containing a lot of plant fragments and charcoals at the depth of 39－123 cm of the profile from the lake center, especially at the depth of 65－74 cm. The dating results we got were respectively 871±40 (at 70 cm) and 800±40 aB.P. (at 75 cm) by conventional ^{14}C and AMS ^{14}C methods. The bottom of this layer is 123 cm and was 2200 aB.P. based on the sedimentation rates (Table 2).

Table 2 Dating results and sedimentation rate of the profile from the center of Lop Nur

Depth (cm)	Age (aB.P.)	Method	Sedimentation rate (mm/a)
39	400	deduced from sedimentation rate	0.70
62	670－690	deduced from sedimentation rate	0.50
70	871±45	conventional ^{14}C	
75	800±40	^{14}C(AMS)	
80	1100	deduced from sedimentation rate	0.50
85	1250	deduced from sedimentation rate	0.50
123	2200	deduced from sedimentation rate	0.40
162	3400	deduced from sedimentation rate	
200	5900	deduced from sedimentation rate	0.15
233	8150	deduced from sedimentation rate	0.15
240	9266±135	conventional ^{14}C	
248	9800	deduced from sedimentation rate	0.15
330	15300	deduced from sedimentation rate	0.15

3.2 Analysis of environmental proxy indexes

In this paper, samples at 3 cm intervals from the profile were used to analyze multi-proxy indexes, including grain size, organic matter content, C, N, and geochemical elements. In addition, plant macrofossils, plant seeds, ostracods, stonewort, and gastropod fossils were identified. Grain sizes were measured by Mastersizer 2000 in Nanjing Normal University. The contents of organic matter, C, N, were measured in the Key Sedimentary Laboratory of Nanjing Institute of Geography and Limnology, CAS. The geochemical elements were measured in the Analysis Center of Nanjing University. It is worth pointing out that the organic matter is quite few in the sediments, so it is difficult to determine the organic C and organic N. The element C we measured was mainly inorganic carbon with only a few organic carbon. The ostracods were identified by Dr. Peng Jinlan from Nanjing Institute of Geology and Paleontology, CAS and the plant seeds were identified by Prof. Liu Changjiang from Institute of Botany, CAS.

According to the lithology of the profile and all the environmental proxy indexes[38],1), we concluded that this area has experienced seven major climate changes since the Last Pleniglacial. It was dry with strong storm in the period from the Last Ice Age to 9.5 kaB.P.. The environment got better between 9.5—7.0 kaB.P.. It returned to be bad again from 7.0 to 4.5 kaB.P.. Around 4.0 kaB.P., the environment got better again. The Lop Nur experienced a drought event at about 3 kaB.P.; after that the environment turned good. The environment went to the best from 1250 to 400 aB.P.. And then the climate began to be dry, which finally led to the completely dry-out of the lake. We will focus our discussion on the climate and environmental evolution of Lop Nur around the MWP.

3.2.1 Grain size analysis. According to the lithology and sedimentary structure of the profile from the center of the West Lake, we conclude that Lop Nur had been a shallow lake for a long time. Because of the strong storm activities in this area, dust could fall directly into the lake, being one of the most sources of sediments. Due to a significant difference of grain sizes between aeolian deposit and lacustrine sediments, we could differentiate the wind storm effect from gain size distribution.

For a nearly 2000 km^2 lake the sediments should be clay in the lake center, but it was not the same for Lop Nur. Figure 3 shows that the sediments in the profile were poorly sorted, and then silt, clay and a certain amount of medium to coarse sands appeared in the same layer, which was quite different from other sediments in lake centers of open lake basins. At the depth of 95—123 cm, the grain sizes were characteristic of coarse-fine-coarse from bottom to top. The average median size was 7.526 μm. The average coarse sand content was 8.347% and the highest content was 20.64% at the depth of 100 cm. The average clay content was 34.76% with the highest content at the depth of 105—114 cm, where there was no coarse sand. From this character, we infer that the wind storm was severe in the early and late period but weak in the middle period (about 1850 aB.P., which is corresponding to the archeological date of Loulan Culture in the Eastern Han Dynasty). At the depth of 39—95 cm, the coarse sand content increased but showed some changes from bottom to top, thereinto, the middle part was finest, coarse sands were not found, with 0.114% medium sands and 37.348% clay, showing natural lacustrine sediments, which indicates the depositional environment during the MWP was very stable and the wind storm was rather weak. From 39 cm to the ground, the sediments became coarse and contained rock salt with 30—40% medium and coarse sands, belonging to sediments during drying of the West Lake.

3.2.2 Microfossils and plant seeds. There were plenty of microfossils, snails, and plant seeds at the depth of 30—80 cm of the profile (Figure 4), especially in the middle part (Table 3). The dominant species of ostracods were *Eucypris inflata* and *Limnocythere inopinate* Baird and the next was *Darwinula Stevensoni* (Brady et Robertson). Additionally, some other species were *Candoniella albicans* Brady, *Candona compressa* Koch and large amount of stonewort (*Chara* ssp.).

The plant seeds found in the sediments were *Potamogeton Pectiatus* L, *Lucens* L., *Scirpus tabernaemontani* C.C. Gmel, bulrush, etc. The dominant species of snail fossils was *Radix auricularia* and then *Lymnaca scaynalis* and *Planorbidae* sp. Besides, some diatom fossils were also identified.

Limnocythere inopinate and *Darwinula Stevensoni* were always seen in the bottom of fresh lake, sometimes in saline or brackish lakes. *Eucypris inflate* is a widespread species and can resist low temperature, which can be found in less-supersaline lakes, marshes, ponds, and other still water in the Qaidam Basin. And in the much-supersaline lakes it is the dominant species. It can also be found in the puddles or lakes near the Qinghai Lake and the individual amount reaches a peak in the mesohaline water. "*Candoniella*" *albicans*, a fresh and cold

1) Wang F B. Environment records from the sediments of Lop Nur since nearly ten thousand years. In: Arrangement Group of the 254th Academic Symposium of Xiangshan Science Meeting, ed. Environmental evolution in Lop Nur region and future development in arid areas in West China. The 254th Academic Symposium of Xiangshan Science Meeting, 2005. 28—33

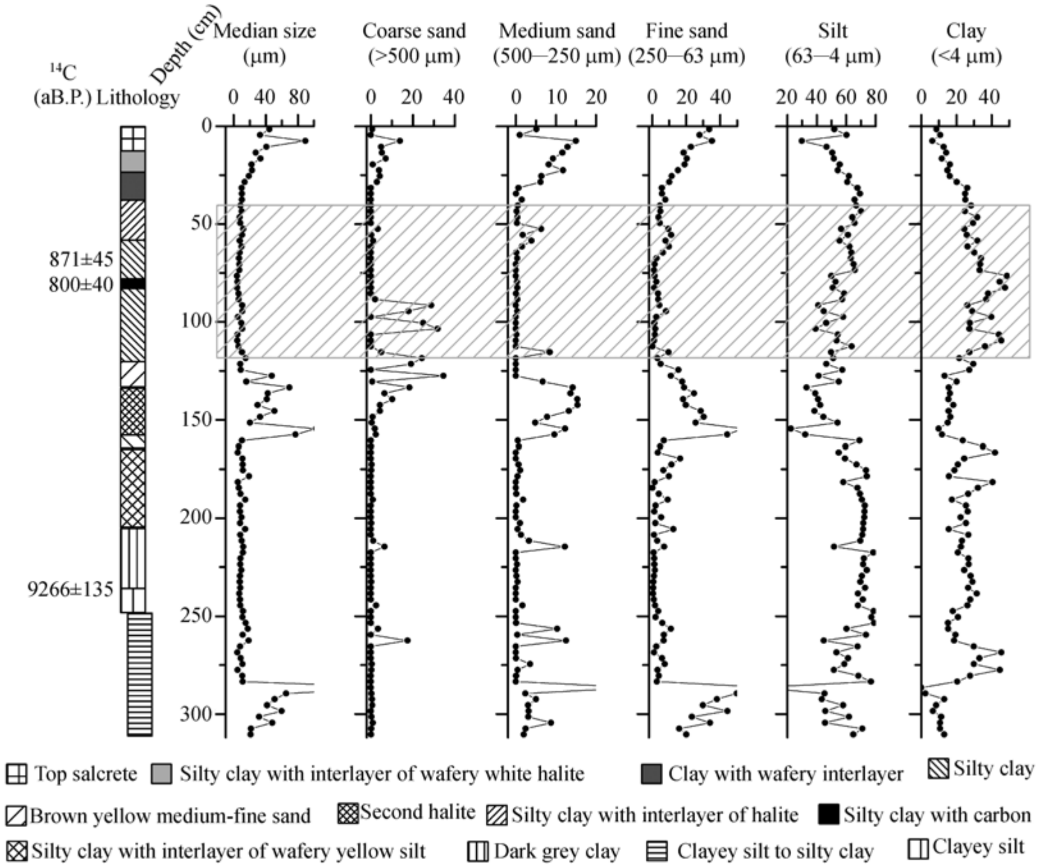

Figure 3 Grain size distribution of the profile from the center of Lop Nur.

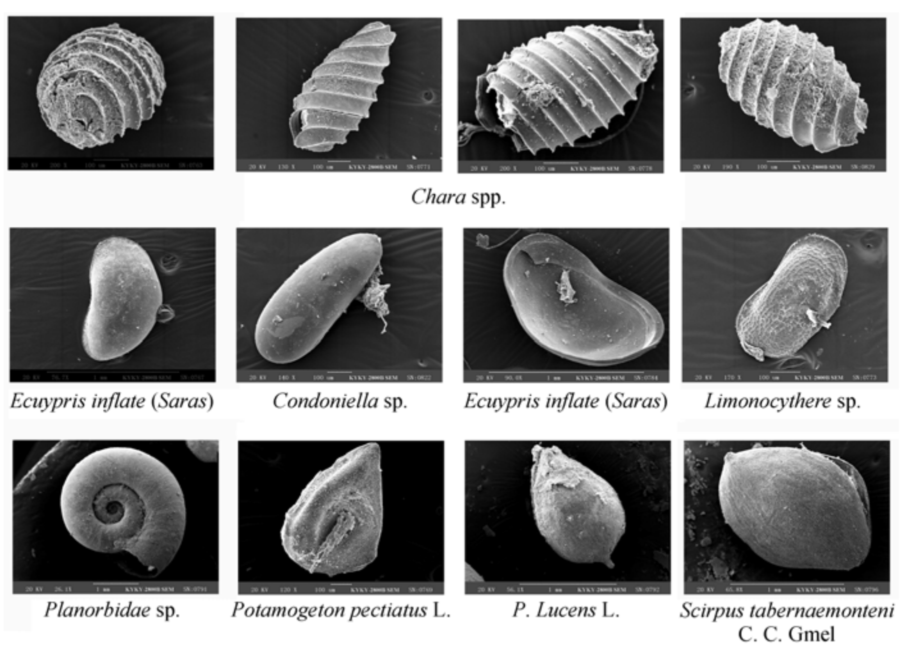

Figure 4 Microfossils and plant seeds in the sediments during and around the Medieval Warm Period for the profile from the center of Lop Nur.

Table 3 Fossils of ostracoda and algae during and around the Medieval Warm Period for the profile from the center of Lop Nur

Depth (cm)	Ostracoda (grain/50 g)							Algae
	"*Candoniella*" *albicans*	*Candona compressa*	*Dawinula stevensoni*	*Imnocythere inopinata Baird*	*Candona* sp.	*Eucypris inflata*	*Cyprideis torosa*	*Chara* spp.
33	1	1	4	8	1(broken)			70
42[a)]						3		
48						8		
51						6	2	1
66						22		
72						2		

a) Additionally, many fragments of freshwater diatom (*Navicula* sp.) were found.

water species, is often found in float grass lands of Europe. *Cyprideis torosa* of this profile is no verruca type and can be found in the rivulets and lagunas around the marshes near the lakes of the Qaidam Basin. *Candona compressa* lives in fresh water. Most *Limnocythere inopinata* lives in the mud of the lake bottom. *Darwinula stevcensoni* are mainly found in the bottom of fresh lakes, also are found in the bottom of less-mesohaline lakes. *Chara* sp., *Radix auricularia*, and *Lymnaca scaynalis* mainly lives in fresh or saline waters.

Potamogeton Pectiatus usually lives in fresh water, saline lakes, ponds, and canals of the oasis. *Potamogeton Lucens* is a common hydrophyte that lives in fresh water or saline lakes, river bands and plashes. *Scirpus tabernaemontani* lives in the waterlogged marshes, watersides, and paddy lands in the oasis and mountainous areas of North and South Xinjiang.

From these fossils and their habitat, we conclude that the West Lake was fresh to brackish lake at that time. A lot of *Chara* sp. were found around the depth of 33 cm, indicating that the water then was clear, calm, shallow and fresh.

3.2.3 Geochemical elements. The content of organic matter in sediments is closely related with the plant biomass around the lake. Large amounts of biomass lead to high content of organic matter in the sediments, and *vice versa*. So the content of organic matter could indicate the productivity and the nutrition condition of the lake. It is usually thought that the content of carbon and nitrogen and their ratios are determined by the content of clastic sediments and the different contents of water and terrigenous plants. When the content of clastic sediments is high, the ratio of carbon to nitrogen is high, too. For instance, in the mud, the nitrogen content is 0.08 and the carbon content is 0.55, so the ratio of carbon to nitrogen is 6.9. The average content of nitrogen in plants is 3% with a ratio of 15. The content of nitrogen in freshwater plants is 3.2% and that of carbon is 29.8%, the ratio is 9.3. But the ratio of carbon to nitrogen is 20—30 for terrigenous plants[40]. As a result, the content of carbon and nitrogen and their ratio could be used to trace the different plants and confirm their proportion.

As is shown in Figures 5 and 6, the content of organic matter is very low with significant fluctuations. The highest value appears at the depth of 50—80 cm, which was the best climate period in the Middle Ages. The next highest value represents the Loulan Culture period, about 2000 aB.P.. We can see that the content of organic matter is closely related with the desiccation degree. The content of carbon and organic matter is closely correlated. It is analyzed that the sediments contained more or less Ca^{2+} even if they were mainly chloride. It is because in the extremely dry climate condition, the carbonate coming from rivers could be deposited in the lake within a short time, some of which was even mixed with rock salt. Therefore the ratio of carbon to nitrogen could reflect the content of carbonate to a certain extent. On the other hand, the content of carbonate was determined by the sedimentation rate. The faster it was deposited, the more carbonate it had. Meanwhile, the content of nitrogen is also related to that of organic matter. High nitrogen content was accompanied with high organic matter content. As we have mentioned, the content of carbon is also related with the content of organic matter, so the ratio of carbon to nitrogen in the Lop Nur area is too complex to contrast with the climate. However, we could still say that at the depth of 39—123 cm, there were high contents of organic matter, carbon and nitrogen, indicating a rather warm and humid climate from Loulan Culture to the MWP.

On one hand, the trace elements in sediments were determined by their own physical and chemical property; on the other hand, they were influenced by climate, environment, and geomorphological conditions. So the component of elements in the stratum could well reflect the climate and environment[41]. The stability of the

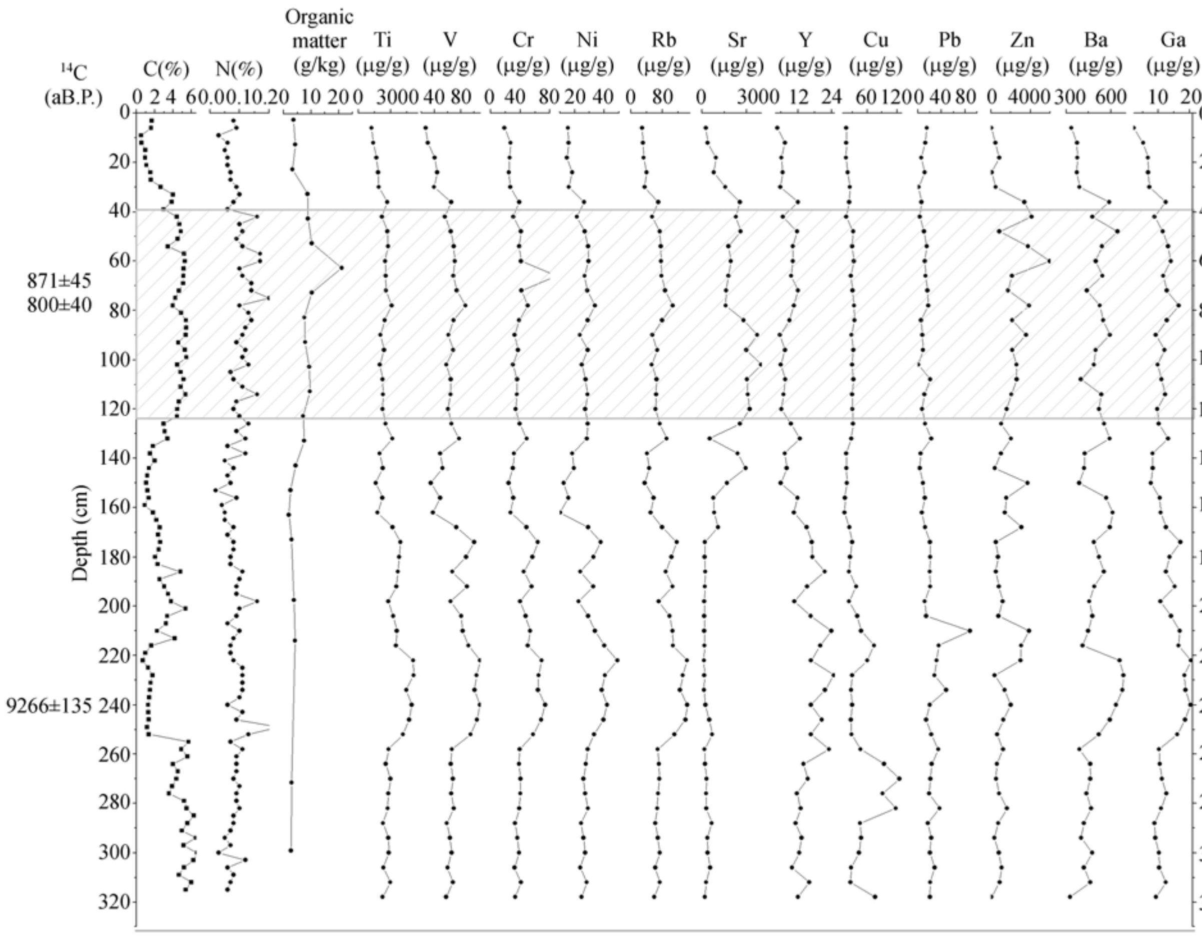

Figure 5 Curves of geochemistry elements for the profile from the center of Lop Nur.

original minerals is the major factor that affects their geochemical behavior. Generally, stable elements are separated out in the later part of the chemical weathering process but deposited in the early part of differentiated process of surface geochemistry. For the active elements, the process was reverse. Because of chemical weathering, the stable elements were concentrated in the stratum but the active ones went away, leading to the negative correlation for the content of the two kinds of elements. For example, in a warm and humid climate, some stable elements such as Ti, V, Cr, Ni, Ba and so on became active and went with water, constituting a relatively high content in the sediments. It was reverse in a cold dry climate. As a result, we could get the law of environmental evolution by understanding the spatiotemporal distribution of elements in the stratum. It could be seen from Figure 5 that the content of every element has distinct changes along the depth. At the depth of 39—123 cm, the average contents of Cr, V, Ni, Zn and Ba were higher than the average value of the section. It was because the climate was warm and humid from the Loulan Culture period to the Warm Stage of the Middle Ages, leading to the leaching and transfer of some trace elements. The small-amplitude changes of Ti, V, Ni, Cu, and Pb contents indicate a relatively stable sedimentary environment. In this period, the content of Rb was as high as 80 μg/g, and that of Sr was 2474.31 μg/g, the secondary peak of the whole section. High content of Rb may be related to the increasing sorption caused by the finer grain size and more organic matter. The increase of Sr might be related to the increasing temperature and precipitation.

For the obvious difference between Rb and Sr in the surface geochemical process, the contents of Rb and Sr are quite different in continuous sediments formed in various climate conditions in different closed basins, so the Rb/Sr ratios in sediments can reflect the chemical weathering process and climate evolution of drainage

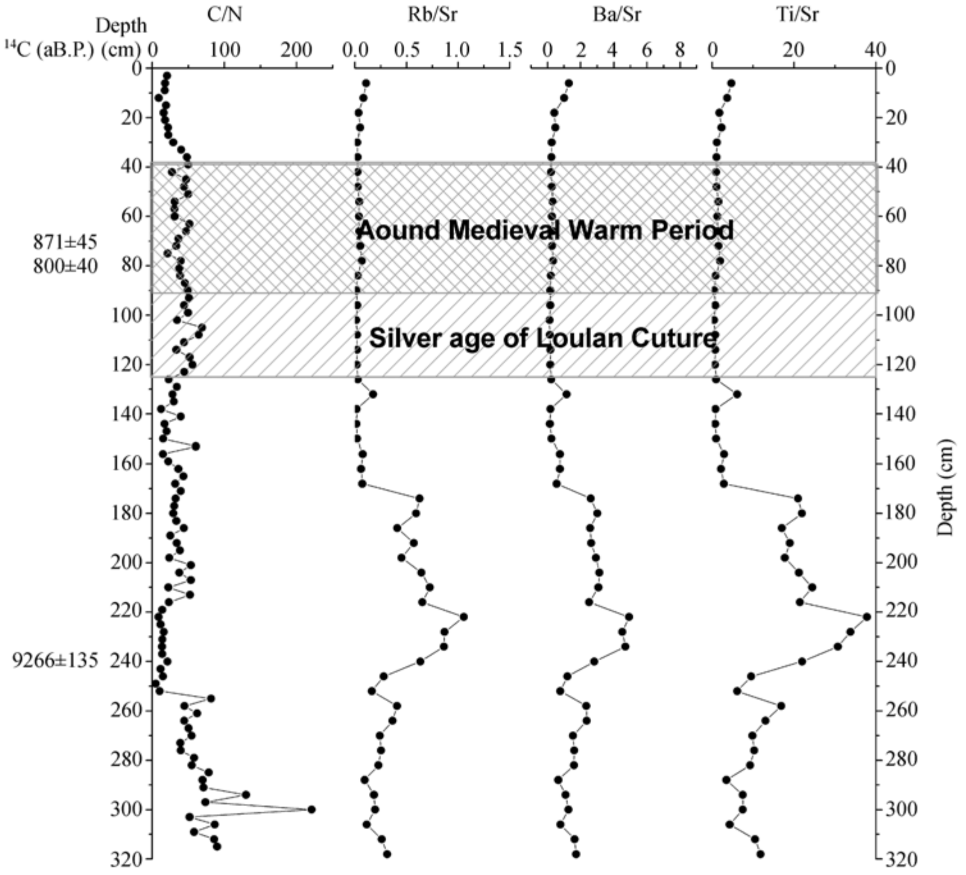

Figure 6 Curves of the geochemical element ratios of the profile.

basins[42]. Researches have shown that high Rb/Sr ratios are determined by low content of Sr, which indicates a cold climate condition against the rock weathering. Conversely, low Rb/Sr ratios indicate a warm climate[42]. Moreover, the research on archaeological stratum showed similar changes for Rb/Sr, Ba/Sr and Ti/Sr[43]. Figure 6 shows that the three curves take on clear positive relation and concurrent changes. The curves can be divided into two parts with the boundary at 168 cm and the upper part is a rather straight line but the lower part shows bigger fluctuation with stable low value at the depth of 39—123 cm, reflecting a warm and humid climate.

The geochemical element curves indicate that sediments at the depth of 39—85 cm had high contents of organic matter, carbon, nitrogen, and stable elements but low Rb/Sr, Ba/Sr and Ti/Sr, indicating a warm and humid climate during and around the MWP.

3.2.4 Evidence of archaic culture and paleobotany. The paleoenvironment during and around the Medieval Warm Period in the Lop Nur area could also be reflected from the archaic culture and paleobotany. In the site of ancient Loulan City, there were quite a lot of pottery fragments on the ground. We dated some pottery fragments by TL (Thermal Luminescence) method1). The two pieces of grey potteries were dated as 720±150 aB.P. and 1400±280 aB.P., the two pieces of red potteries showed ages of 900±190 aB.P. and 1210±250 aB.P. and the piece of black pottery was dated back to 670±140 aB.P.. These dates show that these potteries were made in the Tang and Song Dynasties, which means that people began to settle in Loulan City as the environment turned better. The name of Lop Nur started from the middle Tang Dynasty, when the local people called it “Nafu Bo”2). Besides, plenty of ancient Tang Dynasty coins were found on the ground of Aqik Valley

1) Measured by Xia Dingjun from the Thermoluminescence Laboratory of Shanghai Museum
2) He D X. Activities of ancient people in Lop Nur region. In: Arrangement Group of the 254th Academic Symposium of Xiangshan Science Meeting, ed. Environmental evolution in Lop Nur region and future development in arid areas in West China. The 254th Academic Symposium of Xiangshan Science Meeting, 2005. 58

and the piedmont of the North Mountains in northeast Bailongdui, showing that merchants came and went again by way of the Silk Road of Lop Nur. In addition, in the literature recorded there were many villages and millions of soldiers stationed in this area. All the above evidence indicates that the natural environment turned better during the Tang Dynasty.

The better environment during the Tang Dynasty can also be reflected in the paleobotany. There were a lot of carbonized red willow roots inserted in the soil horizon on the top of the isolated loess hillocks to the east and the circumjacent regions of the ancient Milan City. Besides, many lightly carbonized red willow branches and roots were also found on the tops of some Yardang at the south and southeast of ancient Loulan City. Based on ^{14}C dating, these red willows died at 700±70 aB.P. and 680±70 aB.P., which means that there were large amounts of red willows living in this area 700 years ago. However, after that, they began to dry and die and became the desolation sights at present without enough water for the decline of groundwater level.

4 Discussion

The MWP (700—1100 aB.P.) is a very important period in the study of climate reconstruction in the recent 2000 years. At that time, the influence of human activities on the climate change is far less significant than that of today, but the climate was warmer and more humid than today's. The Warm Period was first introduced by European scholars according to historical records. Later, scholars in China referred to the literature and indicated that it was a warm and humid climate period from the Sui and Tang Dynasties to the Northern Song Dynasty[22]. The MWP of the Lop Nur area was first proposed by Hundington in 1907. He pointed out that there was a warm and favorable climate period from the 9th to the 16th century and that the Lop Nur expanded again in the Middle Ages[37]. After researching the core 95-6 in the north of the West Lake, Wang[26] thought that it was a warm period in the early Tang Dynasty (620—750 AD). Researches by Zhang[25] in the North Tianshan Mountains and by Chen[44] in the downstream of the Keriya River also thought the climate was warm and humid from the Sui and Tang Dynasties to the Early Song Dynasty. Dong[45] figured out that the climate was cool and humid at 1300—800 aB.P.. And Zhong[46] thought that the climate of the south Tarim Basin was mainly cold and wet about 1000 years ago. Li[47] also thought that 2/3 of the time from 581—907 AD was cold and wet. Moreover, the sedimentary facies and the pollen analysis of Ebinur Lake also showed that the water level of the Ebinur Lake changed because of climate fluctuations[48]. During about 300—1400 AD, the water level was high. In the period of 1500—500 aB.P., some lakes (the Chaiwopu Lake, the Barkol Lake, the Qinghai Lake, etc.) in western China were also in a high water level period, indicating a wetter climate[49−51]. A 0.15—0.6-m-deep profile[52] in the east of ancient Beiting City in the Jimsar region of Xinjiang was dated as 590±80 aB.P. by the ^{14}C method, belonging to the end Yuan Dynasty and early Ming Dynasty. Pollen and sedimentary facies in the section showed that there was a lot of hydrophyte, mainly bulrush, and also lots of swamp-living sedges. Lately, Zhang[53] did research on the marsh section in Caotanhu village, Shihezi City in Xinjiang by radiocarbon dating, pollen, phyolith, and charcoal analyses. The comprehensive analysis on multi-proxy indexes showed that between 790—1300 AD, the herbaceous plant grew well and hydrophyte also began to thrive.

It could be seen that there are still some uncertainties about the starting and ending time of the MWP in the Northwest drought areas. It may be a result of the regional difference in environmental changes. Thus, it is necessary to further investigate the problem in the area.

Researches in this paper show that the natural environment around the West Lake of Lop Nur came to be good at about 2200 aB.P.. Meanwhile, the Loulan Culture and Silk Road began to thrive. Later in the 4th century, Loulan Culture disappeared because the Konqi River changed its path and oasis disappeared. But the sedimentary environment in Lop Nur still turned better and reached the best in the Tang and Song Dynasties. After that, it began to get worse. While in the early period (2200—900 aB.P.), the sediments had coarse grain size and dust storm layers, indicating strong storm effect. The lake was a salty or semi-salty lake with few kinds of hydrobiology. From 900 to 700 aB.P., the environment was the best. Temperature was almost the same or a little higher than nowadays and the precipitation was much more. The Tarim River went into Lop Nur again by the Konqi River, which expanded the areas of the lake. The lake water changed into fresh or saline water, more limnic plants could survive in the lake and more plants grew on the west bank of the lake. People came back to live and the Silk Road got busy again. In the late period (700—350a B.P.), the environment turned worse, storm effect was intensified with coarse sediments and aeolian bedding and the climate began to dry, leading to shriveling and death of many plants such as red willows on the tops of Yardang. Since then, it went into the modern environmental evolution.

In a word, the climate turned better in Xinjiang and some other areas during the Middle Ages when precipitation increased, but whether the temperature went higher or lower is still a question.

5 Conclusions

The sediments from the profile in the central West Lake of Lop Nur archived the climate and environment changes since the Last Pleniglacial. In this paper, multi-proxy indexes including ^{14}C, grain size, microfossil, plant seeds, and geochemical elements were analyzed to amply discuss the climate and environment changes during the MWP (65—85 cm of the profile), combined with ancient culture characteristics. The results are indicated as follows:

(1) The grain size of sediments suggested that sedimentary environment was stable around the MWP, with weak storm effect. While the upper and lower sediments showed frequent strong storm effect, especially the lower parts.

(2) Microfossils and plant seeds were abundant in this stage, which indicated a warm and humid fresh or brackish lake environment.

(3) C, N, and stable elements were high in content in the sediments while Rb/Sr, Ba/Sr, and Ti/Sr were in a steady low point. Besides, a large amount of red willow lived here at about 700 aB.P., also indicating a favorable environmental condition.

(4) Based on the multi-proxy data, we conclude that the environment in Lop Nur and its west bank turned better at about 2200 aB.P.. The Loulan Culture began to thrive. The climate and environment went into the best in Tang and Song Dynasties, when storm effect became weaker, rainfall increased, saline lake water turned into brackish or fresh lake water. Hence, limnic biomass increased with more species. Collapse of the Loulan Culture was caused by diversion of the rivers and Silk Road, not by the environmental depravation. Whereas, because of deficient date data, we cannot make sure the starting time of the best climate period in the Middle Ages and its lasting time, which needs further research.

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