ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11

Late Pleistocene Paleoclimate Oscillations in the Northeast Tarim Basin: Insights from Multi-Proxy Lacustrine Sediment Analysis (72-51 ka B.P.)

Youliang Bai [a], Yuanying Liu [b], Hui Chen [c], Jinming Zheng [d], Wei Xiao [e], Chuan Wang [f], Jianshe Liu [g]

The Northwest Institute of Nuclear Technology (NINT), Xi'an 710024,China

[a] baiyouliang008@126.com, [b] lyy1988@mail.ustc.edu.cn , [c] chensilin0413@126.com,

[d] 13899012052@163.com, [e] 358214236@qq.com, [f] 1373601267@qq.com,

[g] 13051818955@163.com

Abstract. This study elucidates the high-resolution paleoclimatic oscillations within the northeastern Tarim Basin during the Late Pleistocene epoch, specifically spanning from 72~51 ka B.P. . A multi-proxy analytical approach was employed, with Optically Stimulated Luminescence (OSL) dating utilized to establish the chronological framework of the LX02 sedimentary sequence. Subsequent analyses encompassed grain size distribution, clay mineral assemblages, geochemical constituents, and pollen spectra to decipher the paleoenvironmental dynamics. Our findings reveal a cyclical transition between cold-dry and warm-humid climatic conditions, with particular emphasis on three distinct intervals: 72.4-66.8 ka B.P. characterized by cold-dry conditions, 66.8-56.1 ka B.P. marked by a warm-humid interval, and 56.1-51.0 ka B.P. reverting to cold-dry conditions. These paleoclimatic patterns are congruent with regional environmental records, indicative of the complex interplay between various climatic systems throughout geological time. This research enhances our understanding of the paleoclimatic narrative in the Xinjiang region, underscoring the imperative for further investigation into the internal driving mechanisms of climate change.

Keywords: Paleoclimatic Fluctuations;Northeast Tarim Basin; Late Pleistocene; Multi-Proxy Analysi; Lacustrine Sediment Records

1. Introduction

With the successive pushing of the Indian Plate in Late Cenozoic and the remarkable global cooling, the inland region of Xinjiang in China on Asiatic plate has attracted more and more attention from geoscientists due to the strong uplift of mountains and abundant sedimentary records[1-4]. On tectonic scale, the paleo-environmental reconstruction in Xinjiang area is usually dominated by the establishment of chronostratigraphic framework through paleomagnetism[5-8]. Since the Holocene, most environmental studies in Xinjiang have focused on archaeology[9-11] and the investigation of water resources[12-15]. The northeastern part of Tarim Basin is located in southeastern Xinjiang, for which the studies on Quaternary is not sufficient. The studies of Zhao et al.[16], Lin et al.[17], Wang et al.[18], and Yan et al.[19] reveal the climatic and environmental evolution of the Quaternary in this area, but the resolution is not high enough. Luo et al.[20] and Jia et al.[21] have studied the climatic and environmental evolution since the Late Pleistocene. In general, the high-resolution records during the early and middle stages of the Late Pleistocene in eastern Tarim Basin are studied quite little. In addition, there are intense debate in the research of climatic evolution since the Pleistocene in eastern Tarim Basin. Luo et al.[22-25] have studied lacustrine sediments from CK-2 borehole in Lop Nur through multi-environmental proxies, it is concluded that the climatic and environmental changes in eastern Xinjiang are closely related to the high latitude of Northern Hemisphere, which is characterized by the cold-humid and warm-dry climate. Such climatic characteristics have also appeared in Xinjiang and other areas of Northwest China[26-28]. However, during the period of 7.0~6.0 ka B.P., relatively warm and humid environment has appeared in the Taitema Lake in eastern Tarim Basin[29]. Likewise, the Optically

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11

Stimulated Luminescence (OSL) and 14C chronological studies show that three steps of lacustrine terrace on the northern and eastern coasts of Lop Nur Salt Lake have formed in 90~130ka B.P., 30 ka B.P., and 7.0~7.5 ka B.P., respectively. These three stages seem probably correspond to the 5th stage of deep-sea oxygen isotope, 3rd stage of deep-sea oxygen isotope and the Holocene Megathermal in time, reflecting the evolution mode of high humidity and high water level during the warm period[30]. It is still not clear whether the eastern Tarim Basin is dominated by cold-humid and warm-dry mode or by warm-humid and cold-dry mode during the Pleistocene.

In view of the above situation, the lacustrine sediments located in northeastern Tarim Basin is studied in this paper, and the LX02 profile of this area is taken as the target profile to establish the chronological framework by OSL dating. On this basis, a method of multi-proxy comprehensive analysis of grain-size, clay minerals, geochemistry and pollen assemblage is used to construct a high-resolution sequence of paleo-climatic evolution in northeastern Tarim Basin during 72~51ka B.P., and to explore the characteristics of climatic evolution. Finally a comparison with historic records near the study area is made for further analysis.

2. Materials and Methods

The study area is located at the intersection of the Kongqi River fault and the Altun fault in Tarim Basin. The above two groups of faults have formed a lake basin by strike-slip movement. The lake basin is sandwiched between fault-uplifts of Kuluktak and Altun, the west of which is adjacent to the Yingjisu depression, and the east is connected with Beishan fault block. The lake basin is a typical closed inland playa lake, covering an area of about 1.0×105 km2. Restricted by the regional environment, the lake basin is characterized by continental arid climate such as low precipitation, high evaporation, large temperature difference and strong wind. There is a lot of strong wind in this area, mainly in NE and NEE direction. Common landforms are desert, Yardang and valley. The desert located in the southeast of the lake basin is dominated by the Kuluktak Desert. The Yardang landforms with an area of 3.0×103 km2 are distributed in the northern, eastern and western parts of the lake basin, these Yardang landforms are mainly distributed in the lower reaches of the Kongqi River, in the Bailongdui, in the vicinity of Sanlongsha, and scattered in the Aqik Valley. In terms of landform type, the study area is located in the area of Yardang landform and belongs to the lacustrine sedimentary plain, which is located the northwestern margin of the lake basin and is in the lower reaches of the Kongqi River. Due to the uplifting effect of Kuluktak faulted-uplift in later period, the area has formed a muti-level platforms of lacustrine terrace. The LX02 section is located in the lacustrine terrace, with an elevation of about 813m. Its position is shown in Fig 1.

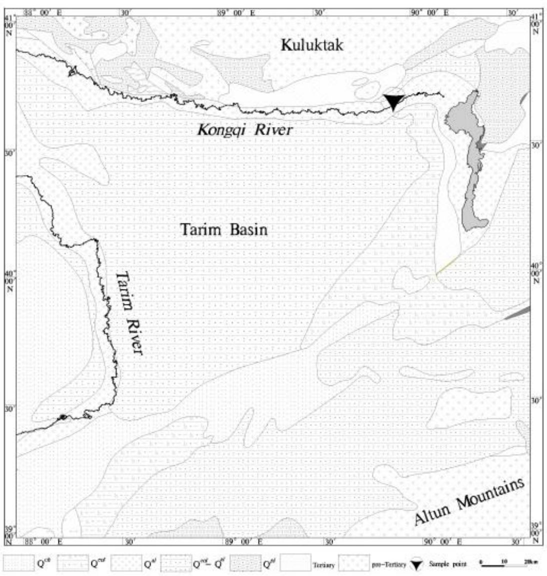

Fig.1 Geomorphology and location of the study area

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11

The LX02 profile is located in Tarim Township, Yuli County, Xinjiang, with coordinates (89°55'E, 40°40'N) and a thickness of 5.4 m (Fig. 2). The profile contains 15 natural sedimentary layers, which can be divided into three units from top to bottom: (1) 0～1.28m, of which 0～0.67m is Earth yellow Mid clay, and 0.67～1.28m is greyish-green Mid clay, and OSL samples are collected at 0.18m and 1.19m; (2) 1.28～4.25m is Earth yellow Mid clay intercalated between thin layers of silty sand, and the OSL data are sampled at 2.21m, 3.10m and 3.71m. (3) 4.25～5.41m, of which 4.25～4.68m is light-gray and light greyish-green silty sand, 4.68～5.41m is Earth yellow Mid clay, sandwiched with thin layers of silty sand, and OSL sample is collected at 4.69m. In terms of sedimentary lithology, there is no sign of sedimentary discontinuity in the entire section. 93 samples of grain size, 18 samples of clay minerals, 57 samples of elemental geochemistry and 80 samples of pollen assemblage are collected for laboratory analysis from LX02 profile from top to bottom at intervals ranging from 1.5 cm to 13 cm, 6.0 cm to 76.0 cm, 0.5 cm to 26.0 cm, and 1.5cm to 15cm respectively.

The chronological measurement of the OSL samples was conducted at the State Key Laboratory of Earthquake Dynamics, Institute of Geology, China Earthquake Administration.

The grain-size of the samples was measured at the Key laboratory of Western China's Environmental Systerms, Lanzhou University using a computer-operated Malvern Mastersizer 2000 laser grain-size analyzer, the relative error for repeated measurements is less than 2%.

The measurement for clay mineral dating was carried out at the State Key Laboratory of Earthquake Dynamics,Institute of Geology, China Earthquake Administration. Each sample was weighed 100 g. Before the experiment, proper amount of H2O2 and HCl were added to remove organic matter and carbonate. According to the principle of Stoke deposition, clay minerals with $d < 2$ μm were extracted from the sediments and made into three types of "N flake", "EG flake " and "T flake ". After the above preparations, the X-ray diffraction analysis of the sample was conducted. The test instrument is D/MAX2500 diffractometer of Rigaku Industrial Corporation, using Cu as a target. The working state of the instrument is: tube pressure and tube flow are 40kV, 100mA, scanning speed is 4°/min, scanning range is 2.6~15° (N, T flake) and 2.6 ~ 30 ° (EG flake).

The geochemical sample was completed by Beijing Research Institute of Uranium Geology, China National Nuclear Corporation. The test instrument of major elements is AB-104L and PW2404X ray fluorescence spectrometer, and the relative error is ±1%～±4%. The test instrument of trace element is ELEMENT XR plasma mass spectrometry with relative error ranging from ±3% to ±12%.

The analysis and identification of pollen assemblage were completed at State Key Laboratory of Earthquake Dynamics, Institute of Geology, China Earthquake Administration.. Each sample was weighed 100g, identified and counted through the recently published procedure of pollen anslysis[33].

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11

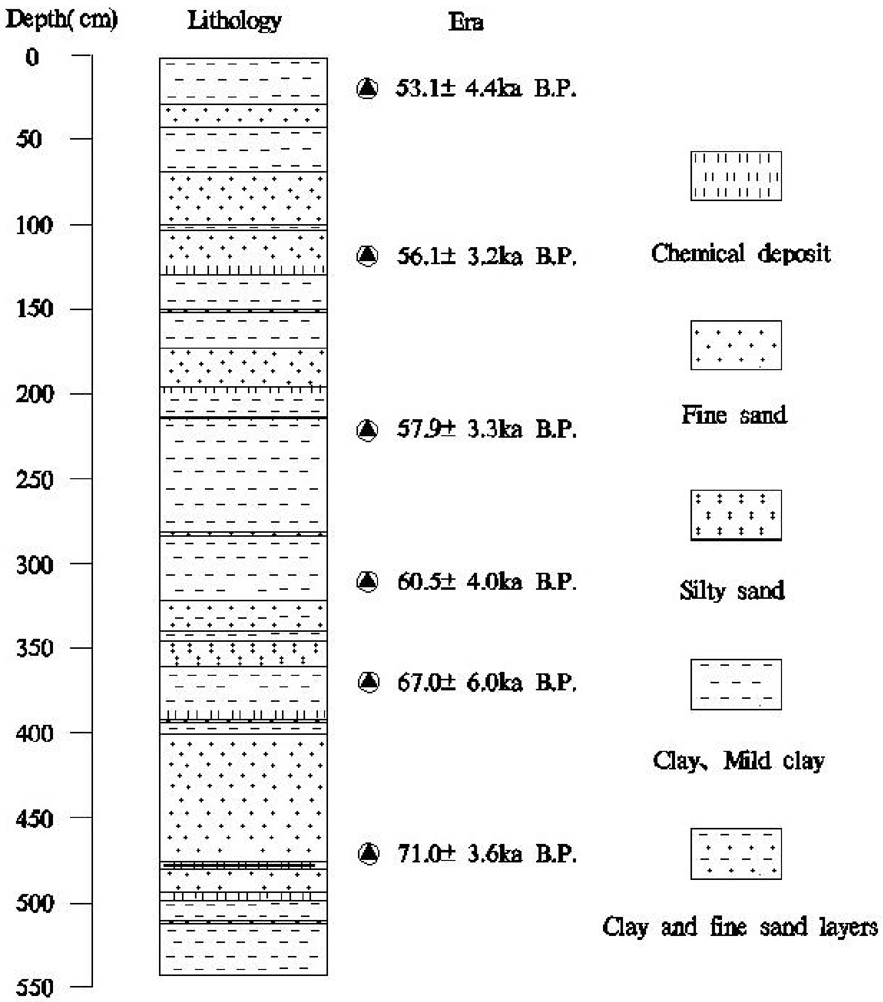

Fig.2 Histogram of the profile

3. Analysis and Results

3.1 Years

A total of 6 OSL samples (Table 1) are obtained from the profile. The sampling positions of each age are respectively in distances of 0.18m, 1.19m, 2.21m, 3.10m, 3.71m, and 4.69m from the top(Fig.2). The regression equation of age and soil depth obtained by data simulating is Y=3.950X+51.007, the correlation coefficient is R2=0.9087, both the data and fitting curve matches well (Fig. 3). As a result, the profile age can be obtained by linear interpolation. According to the deposition rate, the ages of the top and bottom in the profile are 72.4ka B.P. and 51.0 ka B.P., respectively.

Tab.1 Relationship between the depth of LX02 profile and the age of OSL

depth/m	0.18	1.19	2.21	3.10	3.71	4.69
age/ka B.P.	53.1±4.4	56.1±3.2	57.9±3.3	60.5±4.0	67.0±6.0	71.0±3.6

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11

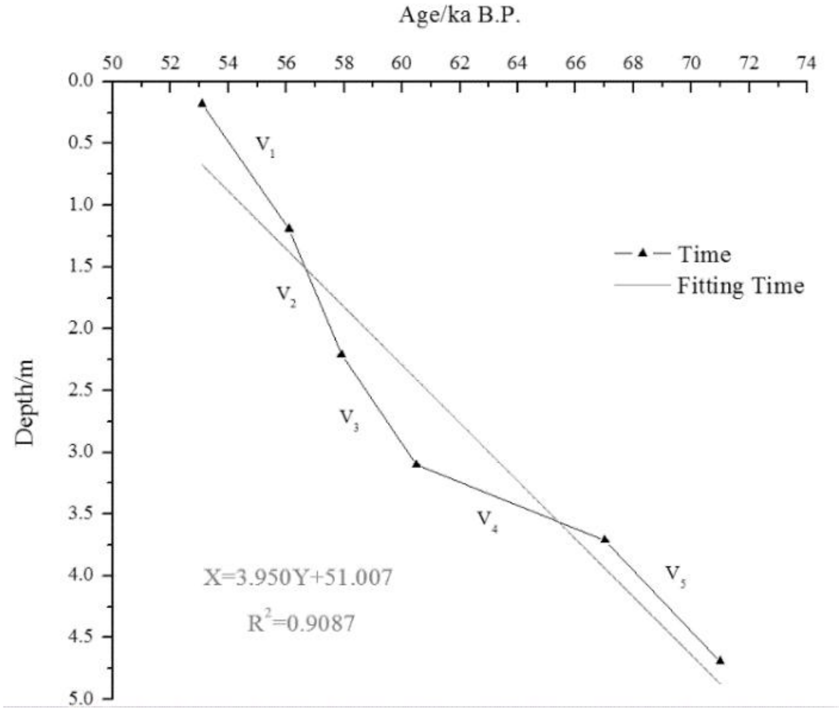

Fig.3 Age versus stratigraphic thickness of the LX02 section

3.2 Grain Size

The solid particles are composed of silty sand, fine sand and clay, which is dominated by silty sand. The silty sand constitutes 32.97%~84.08% of the whole profile, with an average of 67.59%. The fine sand accounts for 0.07%～65.67%, with an average of 16.60%. The clay content is from 0.30% to 34.30% with an average of 15.81%. In terms of grain size, the mean grain size is 3.76Φ~7.57Φ, with an average of 5.98Φ; and the mode is 6.10μm ~88.90μm, with an average of 30.74μm; the skewness is -0.10~0.44, with an average of 0.20; the kurtosis is 0.75~1.83, with an average of 1.18; the sorting coefficient is 0.70~2.59, with an average of 1.47. Fig 4 is shown for details.

Figure 4 Sedimentary grain size parameter and size composition curve

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11

3.3 Clay Minerals

The clay minerals in the sediments are composed of illite(I), chlorite(CH), kaolinite(K), illite/smectite(I/S) etc., accounting for 7.9%~41.5% of the total profile, with an average of 29.9%. Among them, I accounts for the absolute predominance (56%-64%, with an average of 61%), CH takes the second place (18%~25%, average 22%), K (7%~12%, average 8%) and I/S (5% to 15%, average 9%) are less than chlorite. The characteristics of the type and composition are shown in Fig 5.

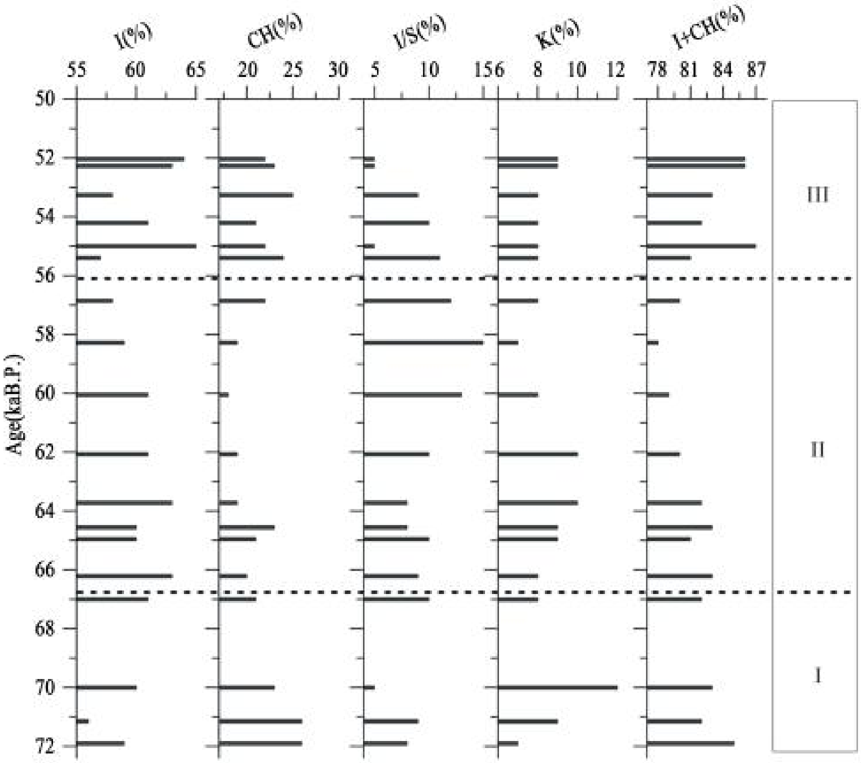

Fig.5 Distribution curves of clay mineral content

3.4 Geochemistry

Si, Al, Ca, Fe, K, and Mg constitute the majority of the deposition profile. Among them, the percentage of Si is 14.26%~28.81%, for which the average is 22.98%; the percentage of Al is 3.24%~7.59% with an average of 6.00%; the content of Ca is 5.64%~14.86% with an average of 8.56%; Fe accounts for 2.05%~6.01% with an average of 4.53%; K is 1.05% to 2.80% with an average of 2.15%; Mg is 0.94% to 4.16% with an average of 1.82%; the loss on ignition(LOI) is 8.64% to 18.43% with an average of 12.77%. Meanwhile, the variation trend of Al, Ca, Fe, K, Mg and LOI is the same, contrary to that of Si (Fig. 6). The ratio of Fe/Mn is ranging from 48.71 to 84.98, with an average of 71.88; Rb/Sr is between 0.06 and 0.58, with an average of 0.40; (Fe+A1+Mn)/(K+Ca+Mg) is in the range of 0.33~0.98, with an average of 0.85; CIA is ranging from 10.94 to 64.43, with an average of 52.57; and C is from 0.12 to 0.40, with an average of 0.32. The specific changes are shown in Fig 7.

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11

Fig.6 Geochemical element contents of the LX02 section

Fig.7 Geochemical elements ratio of the LX02 section

3.5 Pollen Assemblage

The results of pollen assemblage analysis are shown in Fig 8. Among the 80 samples, 13541 pollen grains have been identified and counted, with an average of 169 capsules per sample, which can be divided into 47 types of spore pollen: The pollen assemblage is dominated by the arbor pollen which accounts for 18.91 ~ 91.03% (An average of 58.20%) of the assemblage. Followed by shrubs and herbaceous, the pollen percentage of shrubs and herbaceous is 8.97 ~ 60.12% (An average of 35.02%). The ferns spores and algae share a relatively small amount, ranging from 0.00% to 13.64% (An average of 6.78%).Fig.8 shows the composition of sporopllen in details: The main pollens of arbor plants are Pinus, Quercus and Castanea, and the rest part is consist of Picea, Betula, Juglans, Ulmus, Carya, Alnus, Abies, Tsuga, Cupreseae, Cedrus, Tilia, Peterocarya, Acer; the pollens of shrubs and herbaceous plants are mainly Corylus, Ephedra, Artemisia, Cyperaceae, Chenopodiaceae, Gramineae, Ericaceae, Caprifoliaceae, Polygonaceae, Rosaceae, Elaeagnaceae, Nitraria, Compositae, Leguminosae, Humulus, Ranunculaceae, Thalictrum, Liliaceae, Labiatae,

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11
Impatiens, Caryophyllaceae, Umbelliferae, Typha , Myriophyllum, etc.; the main pollens of fern spores and algae are Polypodiaceae, Selaginella, Lycopodium, Pediastrum, Concentricystis, etc.

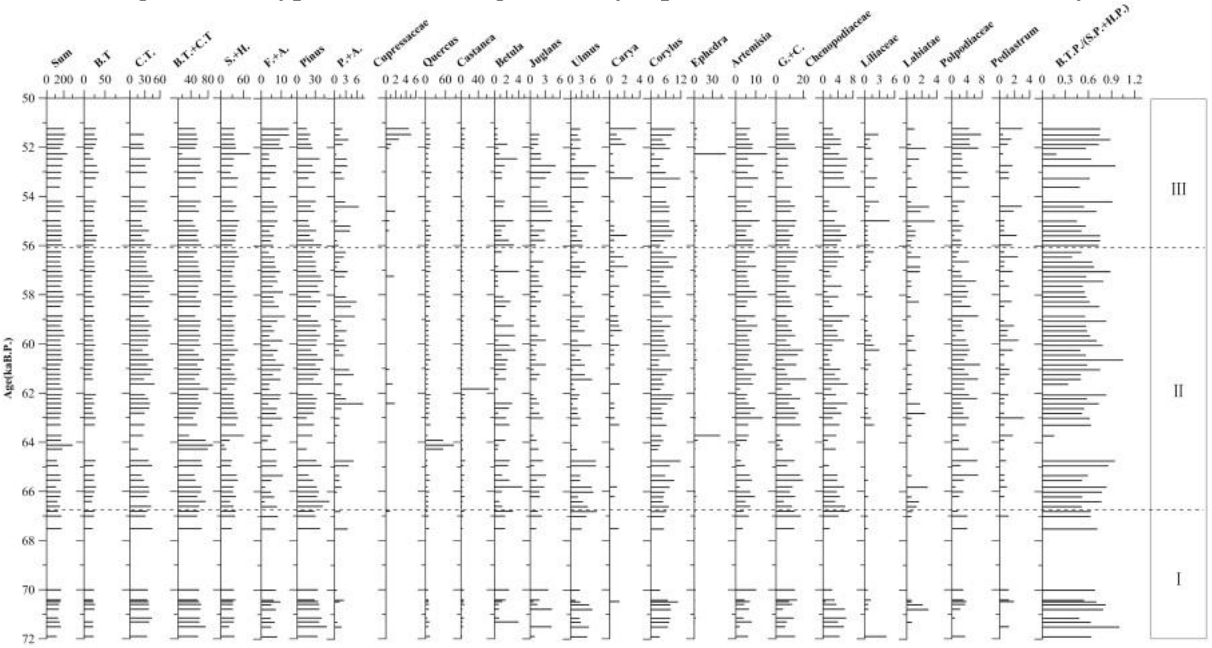

Fig.8 Spore and pollen percentage diagram for the LX02 section

4. Discussion

4.1 Analysis of Climatic Significance of Environmental Proxies

Gain size

The northeastern part of Tarim Basin has the characteristics of low precipitation, high evaporation, large temperature difference and strong wind. The precipitation is of little importance on grain size. The grain size composition of the deposits in the study area is determined by the hydrodynamic conditions and the changes of lake size. The increase of grain size reflects decrease of sampling distance from the lakeshore and decline of lake water level, indicating drying climate; on the contrary, the decrease of grain size reveal increase of sampling distance from the lakeshore and rise of lake water level, indicating humid climate [34].

Clay minerals

The formation and evolution of clay minerals record abundant information of climate change. It is generally believed that the warm and humid climate is conducive to the formation of kaolinite[35]; the alternating of dry and humid climate is easy for the formation of S, thus S's existence can be a reflection of cold climate; the I/S is generally formed in an environment of moderately chemical-weathering, indicating that the climate is gradually changing into a humid environment[36]; I is generally formed in dry and cold weather conditions, if the climate is warm and humid, and the chemical weathering is sufficient, I is further decomposed and forms K[37]; CH is only preserved in areas where chemical weathering is inhibited[38]. Increased CH and I generally reveal a gradually drying climate[39].

Geochemistry

It is generally believed that when the percentage of Al, Fe, Ti, K, and Si is low, it reflects the drying climate, the decreasing precipitation, and the weakening of chemical and biological effects[40]. The method of LOI has been widely used in the study of climatic and environmental changes in lake sediments[41-42]. The study of modern sediments in Taihu Lake[43] shows that there is a close relationship between the LOI and organic content, the organic content has the same trend as the LOI, a high organic content is along with a high LOI, and vice versa. The study of Hulun Lake[44] suggests that the humid conditions correspond to the high values of organic matter

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11
in closed lakes of arid and semi-arid inland areas. During the paleo-climatic evolution of the Chaerhan Salt Lake, the high value of organic carbon indicates a warm and humid climate, meanwhile the low value corresponds to cold and dry climate[45]. The chemical index of weathering (CIA) is of great importance on weathering-degree, The larger ratio corresponds to the stronger chemical weathering, indicating that it is formed in warm and humid conditions, and vice versa[46]; paleoclimate index (C) is the ratio of the residual enriched elements of iron group to leached alkali (soil) metal element, the greater value reveals stronger weathering effect of soil leaching and more humid climate[47]. The research by Wang[48] on the relationship between Rb/Sr and Fe in the sediments of Huahai Lake indicates that the environmental significance of Rb/Sr in arid deserts is different from that of humid and semi-humid areas, which increases with the strengthening of the leaching effect and decreases with the weakening of the leaching effect. The results show that Rb/Sr is positively correlated with weathering degree, in addition, the degree of weathering and leaching is controlled by climatic and environmental changes, especially temperature and precipitation. That is, in warm and humid environment, there is abundant rainfall and strong weathering, which causes Sr easily leached, thus the ratio of Rb/Sr is higher than that of cold and dry climate[32].The ratio of (Fe+A1+Mn)/(K+Ca+Mg) has been used to study the climatic conditions of the lake area by Yang[49], the results show that large ratio corresponds to the more humid climate than that of small one. The ratio of Fe/Mn is of importance in investigating the changing of lakes, large Fe/Mn ratio reflects the expansion of lakes, and the small Fe/Mn ratio indicates the contraction of lakes and the increase in salinity[50].

Pollen assemblage

Pine pollen has the characteristics of carrying airbag, long transmission distance, high yield and convenient maintenance. As a result, the pine pollen needs to constitute over 20%~30% of pollen assemblage to reveal local pine forests[51-52]. As the pine pollen in this study area is mainly higher than 20%, the highest is 53.23%, and the average is 29.79%, which is an evidence of pine forests in this area. In many areas, the increase of pine pollen content in different geological periods indicates a decrease in temperature[53]. In addition, broad-leaved trees in temperate regions need better temperature and humidity than shrubs and herbs generally. Broadleaved tree pollen (B.T.P.), shrub pollen and herbaceous pollen (S.P.+H.P.) can indicate the change of temperature and humidity, that is, the B.T.P./(S.P.+H.P.) indicates a change in temperature and humidity, i.e. the large ratio indicates a warmer and more humid environment than that of small one[54].

4.2 72~51ka B.P. Evolution of Climatic Environment in Northeastern Tarim Basin

According to the above results and analysis, the evolution of the climatic environment in the northeastern part of Tarim Basin during the 72~51ka B.P. is divided into the following three stages:

Stage I: 72.4～66.8ka B.P.

In terms of grain size, this stage is characterized by the largest amount of fine sand, the smallest mean grain size, the largest mode number of the whole sequence. The skewness and kurtosis are basically a little higher than the average of the whole sequence, and the sorting coefficient is smaller than the average, which have wide variation range. As for clay minerals, the total amount of I and CH ,and CH content are higher than the average value of the whole profile; both the average amount of K(except for one sample) and the amount of I/S are lower. The contents of Al, K, Ti, Fe, Ca, Mg, Fe/Mn, Rb/Sr, (Fe+A1+Mn)/(K+Ca+Mg), CIA and C values are lower than the average, revealing a weak weathering during this period.The vegetation is characterized by high pollen percentage of woody plants, low pollen percentage of shrub and herbaceous, and low content of fern and algae. Among them, the coniferous pollen accounts for the highest (average: 38.31%), and the broad-leaved tree has the lowest pollen content (average 22.22%), with no Carya and a little amount of Liliaceae. The results show the study area was covered by coniferous and broad-leaved mixed forests, under which there were shrubs and herbs, and ferns and algae appeared in low-lying and humid places. The vegetation fluctuations were stable, and climate of the hillsides and highlands around the study area was relatively dry, thus Ephedra appeared in a small amount. The

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11
B.T.P./(S.P.+H.P.) varies from 0.48 to 1.00 with an average of 0.69. All proxies comprehensively reveal that this stage was generally in cold-dry climate, and after the cold-drying effect further intensified, the climate improved, and gradually transitioned to the warm-humidity climate of the stage II.

Stage II: 66.8～56.1ka BP

For grain size, stage II is marked by significantly decreased amount of fine sand (average 8.90%), the increase of the average grain size, the decrease of the mode number, the skewness and kurtosis, and the increase of the sorting coefficient, for which the range of variation are small and tend to be stable. For clay minerals, Stage II is characterized by the lowest amount of I and CH, and CH, the content of K and I/S is a bit higher. Both the elemental content of Al, K, Ti, Fe, Ca, Mg and the LOI increase, reflecting the warming climate, such as increased temperature, biological development, increased evaporation, water concentration, etc. The values of Fe/Mn, Rb/Sr, (Fe+A1+Mn)/(K+Ca) +Mg), CIA, C increase obviously, indicating the strong weathering during this period.The vegetation is characterized by the decrease of pollen content in woody plants and the increase of pollen content in shrubs and herbs, as well as ferns and algae. Among them, the pollen content of broad-leaved trees increase significantly (average 25.61%), while that of conifers decrease obviously (average 33.94%). Carya and Liliaceae appear steadily. In general, the vegetation landscape in study area was still coniferous and broad-leaved mixed forests, with a remarkable fluctuation of vegetation, and warmer and more humid climate than previous period. The B.T.P./(S.P.+H.P.) varies from 0.15 to 9.74 with an average of 1.03. The proxies comprehensively reveal that the stage was generally warm and humid, with the feature of fluctuation to a certain degree.

Stage III: 56.1～51.0ka BP

For grain size,stage III is characterized by obvious increase of fine sand content (average 23.00%), the decrease of the mean grain size, the increase of the mode number, skewness and kurtosis, and the decrease of the sorting coefficient, which are in a wide variation of range and amplitude, but the variation trends are entirely smaller than stage I. In terms of clay minerals,the total content of I and CH increases, meanwhile the CH content also increases, the content of K and I/S is lower. The elemental content of Al, K, Ti, Fe, Mg and LOI decrease, reflecting the environmental information of cold and dry climate, such as low water injection and low temperature. The values of Fe/Mn, Rb/Sr, (Fe+A1+Mn)/(K+Ca +Mg), CIA, C slightly decrease, revealing the weak weathering during this period.The vegetation is characterized by the continuous decline of pollen percentage of woody plants, and the increase of shrubs, herbs, fern and algae, among them, the pollen content of broadleaf plant (average 25.11%) and coniferous (average 28.47%) decrease. In general, this assemblage still indicates a landscape of coniferous and broad-leaved mixed forests, for which the vegetation fluctuation is obvious. Though the decrease of pine pollen content shows an increased temperature, the warm and humidity conditions ultimately deteriorate, which is revealed by the decrease of woody plant pollen, and the increase of shrub and herbs. As a result, the temperature and humidity are lower in this stage than those in the previous period. The B.T.P./(S.P.+H.P.) varies from 0.18 to 1.35 with an average of 0.69. The proxies comprehensively indicate that the overall stage was a cold-dry climate with gradually decrease of cold-drying.

4.3 Characteristics and Comparisons of Different Environmental Evolution Stages

A large amount of deciduous broad-leaved trees in pollen assemblages of the early Pleistocene in Lop Nur region was discovered by Yan et al.[19]. This total amount (the total amount of coniferous and broad-leaved pollen) was over 40%, which was considered to be an exist evidence of forests. It was pointed out that this situation was first discovered in the Quaternary of plain area in Xinjiang, which was of great significance. The total amount of coniferous and broad-leaved pollen in most samples of LX02 profile is more than 50%, the highest is 91.03%, with an average of 58.20%, these data of LX02 profile reveal the vegetation type and climate, which is similar to that of Yan et al.

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11
through pollen assemblage in the early Pleistocene, both characterized by a warm and humid climate, the difference is that the climate in our research is superior.

Through the study of Organic Carbon Isotopes in plain areas of Beijing[55],the climate during 76~67 ka B.P. was dry and cold, and the transition from interglacial to glacial period was abrupt, which belonged to the transition period, and this process was also a sudden cooling event. 67～56ka B.P. δ^{13}Corg was stable and maintained a relative upward trend, with an average value of -22.48%, indicating a rebound in temperature. 56～48ka B.P. δ^{13}Corg had a small fluctuation range, tiny percentage of grain size curve, and dry-cold climate. The abundance characteristics of two major ostracods (*Ilyocyprisinermis* and *Cyprideistorosa*) in the borehole No. 1 in eastern Qaidam Basin was studied by Jing et al.[56], it was concluded that the abundance of ostracods was very low in the early stage of the last glacial stage (i.e. 75~69ka), indicating that the climate was cold and unsuitable for biological development; after 69ka, the abundance of ostracods had fluctuated twice, and transitioned to the interglacial stage at about 57ka, indicating that the climate was slightly warmer than the previous stage; 57～32ka was a slightly warm period. These are consistent with the results of this study.

YANG et al.concluded that winter monsoon in the late MIS4 stage of Beijing area was weakening and the climate was mild[57]. Fan et al.[58]studied the OSL chronology of the high lake level of the paleo-lake in eastern Qaidam Basin, and considered that the high water level of paleo-lake appeared in the Gahai Lake during 63 to 55ka, indicating warm and humid climate. The Guliya ice core and the pollen records in several areas reveal that at about 55ka B.P., the temperature of the Qinghai-Tibet Plateau reached the warmest level of the middle Holocene[59]. The environmental proxies in this study also reveals that a sudden change of warm and humid climate occurred at 55.0ka B.P.. Yao et al.[60]through the study of the Guliya ice core considered that the end of the MIS 3 was the warmest, and the peak appeared around 35ka B.P. Li et al.[61] considered that the 58~32 ka B.P. was an abnormally high temperature period during the interglacial period. These favors the results that the climate got warm and humid through a transition from cold-dry to warm-humid in this paper.

5. Conclusion

The comprehensive multi-proxy analysis of lacustrine sediments from the northeastern Tarim Basin provides a robust record of paleoclimatic changes during the Late Pleistocene epoch, spanning from 72 to 51 ka BP. Our findings delineate a complex pattern of climate oscillations, characterized by alternating phases of cold-dry and warm-humid conditions, which are instrumental in understanding the regional climatic dynamics of the Late Pleistocene.

The paleoclimatic reconstruction based on grain size, clay mineralogy, geochemistry, and palynology reveals three distinct climatic intervals within the study period. The initial phase from 72.4 to 66.8 ka BP is marked by cold-dry conditions, suggesting a period of reduced precipitation and lower temperatures. This is followed by a transition to a warm-humid interval between 66.8 and 56.1 ka BP, indicative of increased moisture availability and higher temperatures, likely due to changes in regional and global climate forcings. The final phase, from 56.1 to 51.0 ka BP, reverts to cold-dry conditions, signaling a return to aridity and cooler climatic regimes.

These climatic oscillations are corroborated by regional environmental records, highlighting the interplay between various climatic systems and their influence on the paleoenvironment of the Tarim Basin. The observed climatic patterns do not conform to a single climate mode, indicating that the paleoclimatic evolution in Xinjiang is influenced by multiple factors and does not adhere to a simplistic model.

Our study underscores the necessity for further research into the internal mechanisms driving these climate changes. Understanding the complex interactions between different climate systems and their responses to geological and historical periods is crucial for developing a more nuanced comprehension of past climate variability. This knowledge is not only fundamental to paleoclimatic

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11
science but also has implications for predicting future climate scenarios and informing climate change adaptation strategies in arid regions like Xinjiang.

Reference

[1] Sun Jimin,Zhu Rixiang.Cenozoic deposits in the northern Tianshan Mountains and its implications for neotectonics and environmental changes[J].Quaternary Sciences,2006, 26(1):14-19

[2] Li Youli,Si Supei,Lü Shenghua et al.Tectonic and climatic controls on the development of the Kuitun River terraces in the northern piedmont of Tianshan Mountains[J]. Quaternary Sciences,2012,32(5):880-890

[3] Lü Honghua,Li Youli.Tectonic deformation of active fault-related fold belts in the north piedmont of the central Tianshan Mountains,NW China[J].Quaternary Sciences,2010, 30(5):1003-1011

[4] Yang Haijun,Li Yuejun,Shi Jun et al.Tectonic characteristics of the Late Cenozoic south Tianshan fold-thrust belt[J].Quaternary Sciences,2010,30(5):1030-1043

[5] Tang Zihua, Ding Zhongli, White Paul et al. Late Cenozoic central Asian drying inferred from a palynological recond from the northern Tian Shan. Earth and Planetary Science Letters, 2011, 302(3/4): 439-447

[6] Chen J, Heemance RV,Burbank DW et al.Magnetochronology and its its implications of the Xiyu conglomerate in the southwestern Chinese Tianshan foreland[J].Quaternary Sciences,2007,27(4):576-587

[7] Lü Honghua,Li Youli,Liu Yunming et al.Sedimentary environment evolution since 8 Ma B.P. in the Taxihe area, Xinjiang, Northwest China and its tectonic significance[J]. Quaternary Sciences,2008,28(2):243-252

[8] Chen Jie,Lu Yanchou,Ding Guoyu. Records of Late Cenozoic mountain building in western Tarim basin:molasses,growth strata and growth unconformity[J]. Quaternary Sciences,2001,21(6):528-539

[9] Ma Chunmei,Wang Fubao,Cao Qiongying et al.Climate and environment reconstruction during the Medieval Warm Period in Lop Nur of Xinjiang,China[J].Chinese Science Bulletin,2008,53(19):3016-3027

[10] Lü Houyuan, Xia Xuncheng, Liu Jiaqi et al. A preliminary study of chronology for a newly-discovered ancient city and five archaeological sites in Lop Nor, China[J]. Chinese Science Bulletin,2010,55:63-71,doi:10.1007/s11434-009-0586-4

[11] Zhao Keliang, Li Xiaoqiang, Zhou Xinying et al. Characteristics of agricultural activities and its impact on the environment at Xintala site, Xinjiang, reconstructed from archaeological plant remains[J].Quaternary Sciences,2012,32(2):219-225

[12] Li Baoguo, Ma Lichun, Jiang Pingan et al. High precision topographic data on Lop Nor basin Lake “Great Ear” and the timing of its becoming a dry salt lake[J].Chinese Science Bulletin, 2008, 53(6): 905-914

[13] Fan Zili, Alishir Kurban, Xu Hailiang et al.Changes of Tarim river and evolution of Lop Nur[J].Quaternary Sciences,2009,29(2):232-240

[14] Li Zhongqin,Li Kaiming, Wang Lin. Study on recent glacier changes and their impact on water resources in Xinjiang,North Western China[J].Quaternary Sciences,2010,30(1): 96-106

[15] Wu Jinglu, Zeng Haiao, Ma Long et al. Recent changes of selected lake water resources in arid Xinjiang,Northwestern China[J].Quaternary Sciences,2012,32(1):142-150

[16] Zhao Zhenhong,Hou Guangcai,Qi Wanqiu et al.Discussion of the lowerlimit of Quaternary in Lop Nur, Xinjiang[J].Arid Land Geography, 2001,24(2):130-135

[17] Lin Jingxing,Zhang Jing,Ju Yuanjing et al.The lithostratigrapuy,magnetostratigra -phy,and climatostratigraphy in the Lop Nur region, Xinjiang[J].Journal of stratigraphy,2005,29(4): 317-322

[18] Wang Yong,Zhao Zhenhong,Lin Jingxing.Pleoclimate and geochemical composition of AK1 core sediments in Lop Nur, Xinjiang[J].Acta Geoscientica Sinica,2004,25(6):653-658

[19] Yan Shun,Mu Guijin,Xu Yingqin et al.Quaternary environmental evolution of the Lop Nur region,China[J].Acta geographica sinica,1998,53(4):332-340

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11
[20] Luo Chao.The environmental change in Lop Nur,Xinjiang during late last glacial and response to global change[D].University of science and technology of China,2008

[21] Jia Hongjuan,Qin Xiaoguang,Liu Jiaqi.Environmental change of the past 10.84ka in LOULAN,Xinjiang[j].Quaternary Sciences,2010,30(1):175-184

[22] Luo Chao,Yang Dong,Peng Zicheng et al.Climatic and environmental records in the sediment of the Luobei Billabong in Lop-Nur,Xinjiang in recent 32 ka[J].Quaternary Sciences,2007, 27(1):114-121

[23] Luo Chao,Peng Zicheng,Liu Weiguo et al.Evidence from the Lacustrine sediments of Lop-Nur Lake,Northwest China for the Younger Dryas Event[J]. Earth Science-Journal of China University of Geosciences,2008,33(2):190-196

[24] Luo Chao,Liu Weiguo,Peng Zicheng et al.Stable carbon isotope record of organic matter from the Lop-Nur lacustrine sediment in Xinjiang,Northwest China[J].Quaternary Sciences,2008,28(4):621-628

[25] Luo, C., Peng, Z.C., Yang, D. et al. A lacustrine record from Lop Nur, Xinjiang, China: Implications for paleoclimate change during Late Pleistocene[J].Journal of Asian Earth Sciences,2009,34:38-45

[26] Li Jijun.The patterns of environmental changes since Late Pleistocene in northwestern China[J].Quaternary Sciences,1990,10(3):197-204

[27] Yan Shun,Li Shufeng,Kong Zhaochen et al.The pollen analyses and environment changes of the Dongdaohaizi area in Urumqi, Xinjiang[J].Quaternary Sciences, 2004,24(4): 463-468

[28] Zhong Wei,Shu Qiang,Xiong Heigang.Pollen assemblages of Niya section in southern Xinjiang and paleoenvironmental evolution[J].Geographical Research,2001,20(1):91-95

[29] Zhong Wei,Tu erxun,Ke Yimu et al.Paleoclimatic and paleoenvironmental evolution since about 25 ka BP in the Taitema lake area,South Xinjiang[J].Arid Land Geography,2005, 28(2):183-187

[30] Wang Fubao,Ma Chunmei,Xia Xuncheng et al.Environmental evolution in Lop Nur since Late Pleistocene and its response to the global changes[J].Quaternary Sciences,2008,28(1): 150-153

[31] Feng Xiaohua,Yan Shun,Ni Jian.Pollen-based reconstruction of vegetation in Xinjiang during the Holocene[J].Quaternary Sciences,2012,32(2):304-317

[32] Xia Xuncheng ed.,China Lop Nur[M]. Beijing: Science Press,2007,20-54

[33] Xu Hongyan,Jiang Hanchao,Mai Xueshun et al. A new processing method for the pollen samples from Palaeogene red beds in the Liguanqiao Basin, Hubei Province, and Pleistocene loess from the Chinese Loess Plateau[J].Quaternary International,2013,286: 45-55

[34] Dearing J A. Sedimentary indicators of lake-level changes in the humid temperate zone:A critical review[J].Journal ofPaleolimnology,1997,18(1):1-14.

[35] Singer. The paleoclimatic interpretation of clay minerals in sediment. Earth-Science Reviews, 1984, 21(4): 251-293

[36] Chamley H, Robert C, Muller DW. The clay mineralogical record of the last 10 million years off northeastern Australia. Proceedings of the Ocean Drilling Program, 1993, 133: 461-470

[37] HONG Han-lie. A Review on Paleoclimate Interpretation of Clay Minerals. Geological Science and Technology Information, 2010, 29(1): 1-8

[38] Jain M, Andon SK. Quaternary alluvial stratigraphy and palaeoclimatic reconstruction at the Thar margin. Current Science, 2003, 84(8): 1048-1055

[39] Winkler A, Wolf-Welling TCW, Stattegger K. Clay mineral sedimentation in high northern latitude deep sea basins since the middle Miocene (ODP Leg 151, NAAG). International Journal of Earth Science, 2002, 91 (1): 133-148

[40] ZHANG Hucai, ZHANG Linyuan, MAHANEY WC.Element geochemistry of the Jiuzhoutai Loess section,Lanzhou[J]. Geochimica, 1991, 20(l): 79-86

[41] BRAUER A, MINGRAM J, FRANK U et al. Abrupts environmental oscillations during the Early Weichselian recorded at Lago Grande di Monticchio, southern Italy[J]. Quat.Int, 2000, 73: (74): 79-90

[42] CHEN Zhong, MA Haizhou, CAO Guangchao et al. Climatic-environmental evolution in Gahai lake area since the lake glacial period from loss-on-ignition[J]. Marine geology＆Quaternary geology, 2007, 27(1): 131-138

ISSN: 3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.5.1.P11
[43] YUAN Xuyin, CHEN Jun, JI Junfeng et al. Compositions and the formative condition of sediments in Taihu lake, Eastern China[J]. Journal of Nanjing University, 2002, 38(6): 756-765

[44] XUE Bin, WANG Sumin, SHEN Ji et al. Total organic carbon and its stable carbon isotope and paleoenvironmental evolution of Dongloutian coalfield profile of Hulun lake[J]. Journal of Lake Sciences, 1994, 6(4): 308-316

[45] HUANG QI,MENG Zhaoqiang,LIU Hailing.Preliminary investigation of Climatic fluctuation modal in Lake Qarhan, Qaidam Basin[J].Science in China(Series B),1990, 652-663

[46] BAI Daoyuan, LI Chang-an, CHEN Duping et al. Chemical weathering index and magnetic susceptibility of deposits and their responses to the Quaternary climate in Dongting Basin[J]. Geology in China, 2011, 38(3): 779-785

[47] JIN Heling,LI Mingqi,SU Zhizhu et al.Geochemical Features of a Profile in Salawusu River Valley and Their Response to Global Climate Changes since 220 ka BP[J]. Journal of glaciology and geocryology, 2005, 27(6): 861-868

[48] WANG Chenhua. Environment changes documented by geochemistry in Huahai Lake[D]. Lanzhou University, 2008

[49] YANG Zhirong.A Comprehensive Study on the Environmental Changes of Zigzag Zone of Farming and Animal Husbandry since the Holocene in Northern China.Beijing:China Ocean Press, 1999. 75-87

[50] ZHANG Zhenke, WANG Sumin, WU Ruijin et al. Environmental Changes Recorded by Lake Sediments from East Juyanhai Lake in Inner Mongolia During the Past 2600 Years[J]. Journal of Lake Sciences, 1998, 10(2): 44-51

[51] Willis K J,Sumegi P, Braun M et al.The late Quaternary environmental history of Batorliget, N.E. Hungary[J]. Palaeogeography,Palaeoclimatology,Palaeoecology,1995,118:25-47

[52] Sun Xiangjun,Song Changqing,Wang Fengyu et al.Vegetation History of the Loess Plateau of China During the Last 100,000 Years Based on Pollen Data[J].Quaternary International,1997,37:25-36

[53] Hanchao Jiang,Xue Mao,Hongyan Xu et al.Last glacial pollen record from Lanzhou (Northwestern China) and possible forcing mechanisms for the MIS3 climate change in Middle to East Asia[J]. Quaternary Science Reviews,2011,30:769-781

[54] Bai Youliang,Jiang Hanchao,Chen Jianjie et al. Preliminary study on the palynoflora from the mid-Pleistocene lake sediments in the northern margin of the Peacock River, Xinjiang Province[J]. Quaternary Sciences, 2013, 33(5): 856-865

[55] NI Zhiyun, YANG Guifang, HUANG Junhua et al. Organic Carbon Isotopic Characteristics of Beijing Plain Since Late Pleistocene and Their Paleoenvironmental Implications[J]. Acta Geoscientica Sinica, 2011, 32(2): 171-177

[56] JING Minchang, YANG Gelian, SUN Naida. Study on the climatic changes between the last interglacial age and the last glacial age recorded by ostracoda in eastern Qaidam Basin[J]. Journal of Earth Sciences and Environment, 2004, 26(3): 83-87

[57] YANG Gui-fang, GE Zhi-liang, DAI Qing et al. A grain-size record from Beijing Region in Northern China:Late Quaternary paleoclimate oscillation in response to global change[J]. Frontiers of Earth Science, 2009, 3(2): 164-170

[58] FAN Qishun, LAI Zhongping, LIU Xiangjun et al. Luminescence Chronology of High Lake levels of Paleolakes in the Late Quaternary eastern Qaidam Basin[J]. Acta geologica sinica, 2010, 84(11): 1652-1660

[59] Shi Yafeng, Liu Xiaodong, Li Bingyuan et al. A very strong summer monsoon event during 30-40 Ka BP in Tibet Plateau and its relation to processional cycle[J].Science Bulletin, 1999,44(14): 1475-1480

[60] Yao Tandong, Thompson L G, Shi Yafeng et al.Climate variation since the last interglaciation recorded in the Guliya ice core[J].Science in China(Series D),1997,27(5):447-452

[61] LI Chaoliu， KANG Shichang.Review of Studies in Climate Change over the Tibetan Plateau[J]. Acta Geographica Sinica, 2006,61(3):327-335