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THE QUATERNARY CLIMO–ENVIRONMENT CHANGES IN CHAIWOPU BASIN OF XINJIANG REGION

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ABSTRACT: This paper describes the paleoclimatic changesoccurring in the Chaiwopu Basin since 730,000 yr.B.P., together with theformation and evolution of Chaiwopu Lake based on the chronology and characteristics of a core drilled in the basin. Analysis of the drilling core provides information on the climate and environment of the area. It would appear that the paleoclimatic changes that occurred in the basin during the Pleistocene was controlled by the relationship between the sun and the earth and by Long–term (10,000 yr.) climatic cycles. The climate tended to cold–dry during the glacial period (ice age) and warm–moist during the interglacial. Following the warm period of the Holocene, short–term (1,000 yr.) climatic cycles occurred in cool–moist periods, similar to the "Little Ice Age", alternated with warm–dry periods.

KEY WORDS: paleoclimate, environment changes, Quaternary, Xinjiang

I. INTRODUCTION

Chaiwopu Basin with a length of 120 km in the E–W direction and a width of 18–30 km is located southeast of Urumqi City; geographical coordinate is 87° 15′ –88° 00′ E and 43° 25′ –43° 40′ N (Fig.1). It is composed of the Chaiwopu depression in the west and the Dabancheng depression in the east. The basin is adjacent to the Bogeda Mountain on the north and the Kalawuchen Mountain (South Mountain) on the south. In this basin drilling a deep bore hole was determined for learning the climo–environment changes and hydrogeologic condition of deep underground water.

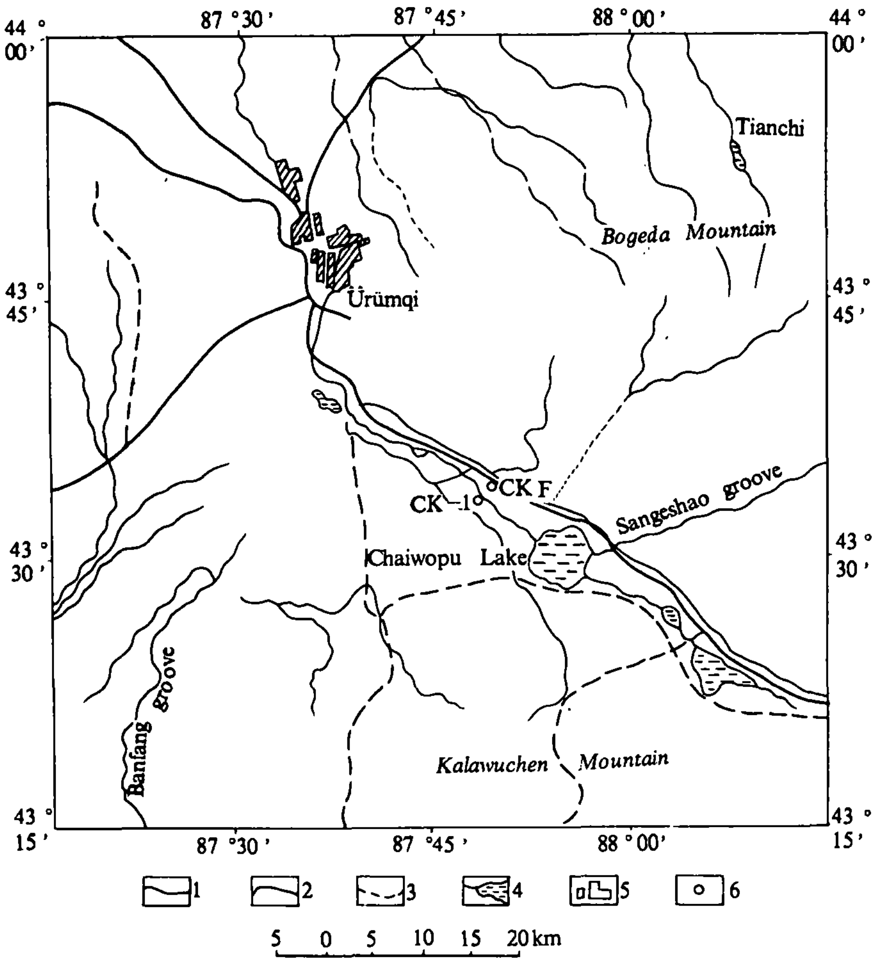

Fig.1 The map showing localities of bore hole in Chaiwopu Basin

1. Railway; 2. Highway; 3. Simple highway; 4. Lake rivers; 5. City; 6. Bore hole

II. MATERIALS AND METHODS

The core (CK−1) was drilled to a depth of 500.68 m at a site 7 km northwest of Chaiwopu Lake (Fig.1) (43 km southeast of Urumqi City) at an elevation of 1,115 m a.s.l. Systematic sampling were carried out for this drilling core. Its sampling interval is 50 cm in general, but for some variation strata density would be increased to sampling, conversely for very homogeneous strata decreasing sampling density. The collection samples are 217 altogether. The sample numbers were marked at the map of core section (Fig.2).

For these samples we carried out the magnetostratigraphy and chronologic determination using radiocarbon dating (^{14}C) and U−series ages of the core sediments. The ^{14}C dating

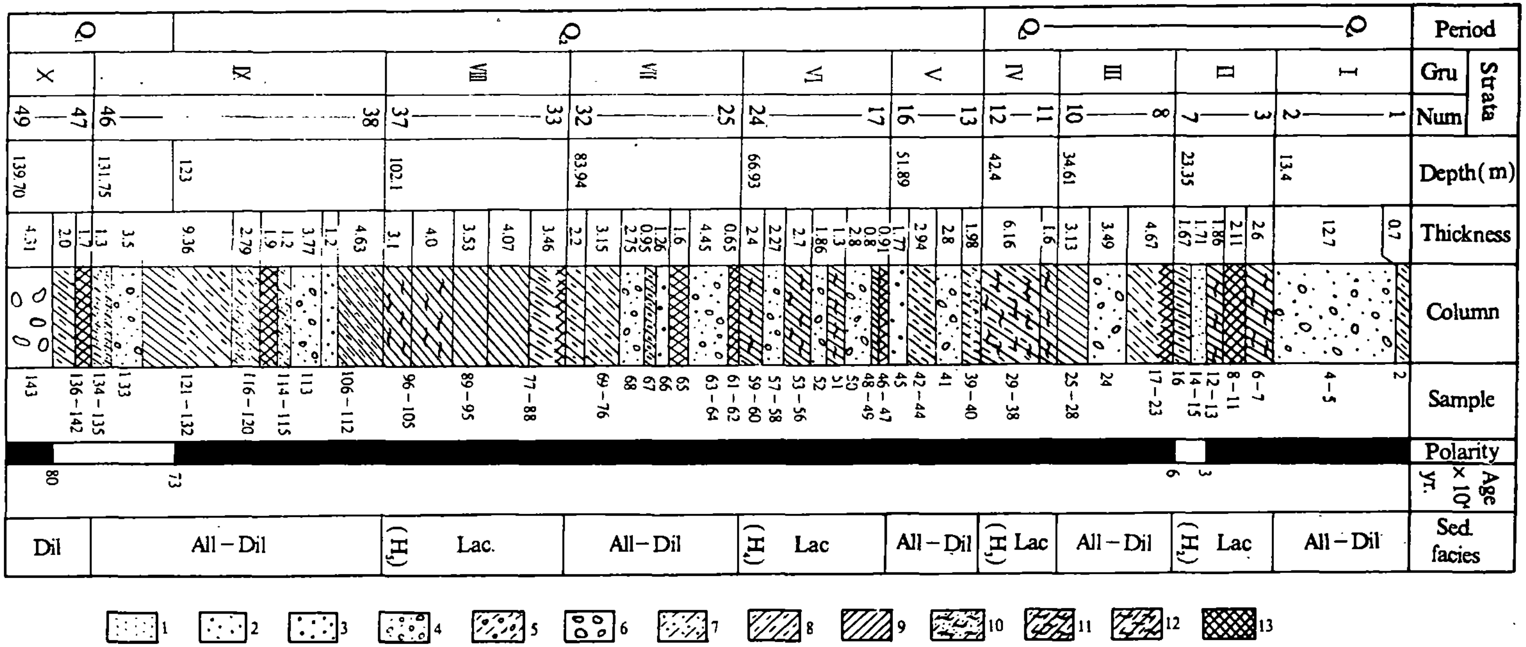

Fig.2 Stratigraphic section of core CK−1 in Chaiwopu Basin of Xinjiang region

1. Fine sand, 2. Medium sand, 3. Coarse sand, 4. Sand and gravel, 5. Earth−bearing gravel, 6. Pebble and gravel, 7. Sand soil, 8. Silty clay, 9. Clay, 10. Ooze sandy soil, 11. Ooze silty clay, 12. Ooze clay, 13. Paleosol and weathering bed

applied organic carbon extracted from the samples to determination; the U–series method was employed to determine the ages of the small calcareous nodules found at the different depths of core CK–1.

In addition, the spore–pollen, Ostracoda, clay minerals, heavy minerals, oxygen and carbon isotopes, chemical elements and organic materials were analysed as well.

III. Results and Discussion

1. The Structure and the Time Scale of Core CK–1

1.1 Core Structure

From the surface down to 135 m the core is mainly composed of fine–grained sediments (Fig.2), which include four beds (H2–H5) of dark grey and grey–black sandy clay (clay) and silt of lake and limnological facies and five interbeddings of earth–like yellow sand clay, silt and sand–gravel, among which eight beds of paleosol or weathering layer were developed. From 135 m down to the bottom of the core, coarse–grained sediments predominate. The section from 135 to 215 m consists of pebble, sand and gravel, intercalated with thin beds of fine sand or sandy clay. The section from 215 to 500.68 m is made of earth–bearing pebble and sand and gravel interbeds. The continuous sediments from the beginning of the Pleistocene to the Holocene can be divided into 98 natural beds belonging to 23 stratigraphic groups depending on the sedimentary facies and cyclothems. Only that part of the core to a depth of 135 m was studied in detail.

In the gravel of the top 13.4 m of the core, there is no material for dating. Therefore, an additional core (CKF) with a depth of 14.6 m was drilled, which is 300 m northeast of CK–1 (Fig.1). The top 1.1 m of CKF consists of grey–yellow sandy clay of alluvial and diluvial facies while the section from 1.1 to 3.62 m is made up of dark grey muddy clay of limnological facies (bed H1). The bottom of bed H1 has a ^{14}C dating of 9,860 yr.B.P. and represents the boundary between the Holocene and the Late Pleistocene. The beds of sandgravel and earth–bearing pebble below 2.62 m can be compared with those of sand–gravel in the main core CK–1.

1.2 Time Scale of Paleoenvironment

The paleomagnetic result indicates that the boundary between Brunhes normal polarity chron and Matuyama reversed polarity chron lies at the depth of 123 m in core CK–1 (Fig.2), the B / M boundary occurs at 730,000 yr. B.P. At approximately 135 m depth a normal polarity zone was recorded, probably corresponding to the post–Jaramillo subchron with an age of 800,000 yr. B.P., the parts of 176–189 m and 470–475 m are the Jaramillo (900,000–970,000 yr. B.P.) and Olduvai (1.67–1.87 mil.yr. B.P.) subchrons, respectively, and the reversed samples appearing at the depth of 21 m could be the Laschamp subchron of 30,000–60,000 yr. B.P.

The ^{14}C ages of the clays in the cores are 3,690 ± 90 yr. B.P. at 0.2 m, 3,852 ± 245 yr. B.P. at 0.7–1.3 m, 23,821 ± 766 yr. B.P. at 16 m for CK–1 (Fig.3) and 5,705 ± 142 yr. B.P. at 2.85–3.6 m, 9,860 ± 295 yr. B.P. at 3.6 m for CKF.

The results of U–series ages are basically similar to those obtained by the ^{14}C method (Fig.3).

The data derived from magnetostratigraphy, ^{14}C and U–series dating, and from analysis of the oxygen isotopic stages (Fig.3) demonstrate that the sediments in core CK–1 were formed in the Quaternary, the B / M boundary at 123 m can be taken as the boundary between the Early and Middle Pleistocene (Q_2/ Q_1), the level of 43 m depth (about 130,000 yr.) separated the Middle Pleistocene from the Late Pleistocene (Q_3/ Q_2), and the Holocene (Q_4) bottom lies at a depth of 3.6 m in core CKF.

2. Climate and Environmental Information on the Quaternary Sediments

2.1 Spore–Pollen Assemblages

Eleven spore–pollen zones can be identified in core CK–1 (Fig.3). In the Early pleistocene bed, the spore–pollens are dominantly those of *Artemisia*, Chenopodiaceae and Gramineae . In the bed of earth–like yellow silty clay, and the sandy clay of alluvial–diluvial facies of the Middle Pleistocene, the spore–pollens are mainly those of *Artimisia* and Chenopodiaceae with the latter being more plentiful. In the dark grey and black clay and silty clay beds of lacustrine facies most of the spore–pollens are of the shrub and herbage, and of the woody plants account for 4–5 percent, sometimes up to 11 percent. The spore–pollens of deciduous and broad leaved trees of *Picea, Betula, Ulmus, Populus, Salix* and so on in the core imply a desert grasslands or grasslands environments. In the Late Pleistocene the region was desert–grasslands and had the desert vegetation, the climate was dry and cold. The spore–pollens in core CKF indicate a desert vegetation and a dry–cool climate during the Early Holocene, vegetation of deciduous and broad–leaved trees was associated with a warm moist climate in the Middle Holocene, while in the Late Holocene the vegetation was mainly composed of Chenopodiaceae, *Artimisia* and the climate (warm dry) was similar to that at present.

2.2 Ostracoda

A great number of Ostracoda fossils were found in the shallow–water lacustrine beds H3 and H5 of core CK–1 (Fig.3). This would indicate that Xinjing region had a high rainfall at the period of deposition, especially in the period of sample CK104 i.e. bed H5. Compared with the present temperature of the region, the temperature at the formation period of sample CK104 was higher, while the temperature with respect to samples CK35 (40.3–40.4 m in the core), CK92 (93.2–93.3 m) and CK94 (94.3 m) was similar to that of present northwest China.

2.3 Oxygen Isotope

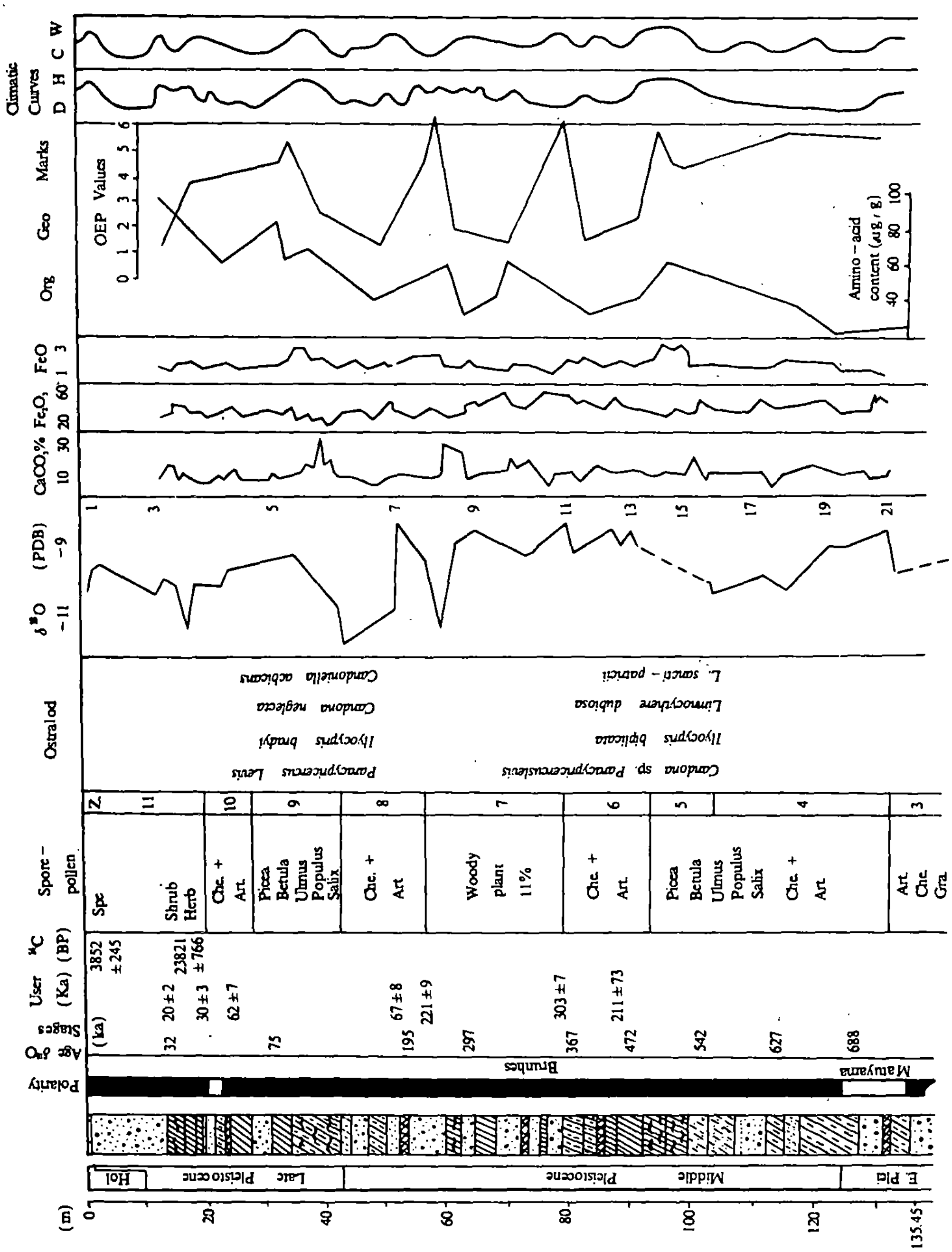

Fig. 3 Synthetical analysis data of core CK-I in Chaiwopu Basin

Eleven cycles were identified on the oxygen isotopic curve of the top 135 m of core CK−1. The peaks of the curve represent higher $\delta^{18}O$ and lower $\delta^{13}C$ contents and hence, higher temperature than at present. It is interesting to note that the peaks of odd stages: 3, 5, 9 and 15 on the curve coincide with 4 lacustrine beds: H2, H3, H4 and H5, respectively (Fig.3). Oxygen isotopic stage 7 corresponds with the paleosol layer at 51.89 m depth, while stages 17, 19 and 21 correspond to paleosolsat 112.9, 123 and 131.75 m, respectively. Stage 1 of the curve for the lacustrine−limnological bed H1 in core CKF implies a warm time in the Holocene.

2.4 Element Geochemistry and Organic Geochemistry

The contents of FeO, SrO, MnO, P_2O_5 and $CaCO_3$ are generally higher in the lacustrine beds than in the alluvial−diluvial beds (Fig.3), whereas the contents of Fe_2O_3 and BaO, pH values show opposite trend.

The content of organisms as well as the OEP (odd−even preference) value of normal alkane (> 4.5) are higher in the dark−grey and black−grey clay (silty clay) of lacustrine facies than in the yellow silty clay and sandy clay of alluvial−diluvial facies (Fig.3). This would indicate that the organic materials were well preserved and the normal alkane still keeps the odd−carbon predominance after decarboxylation of fatty acid in a moist reducing environment. In a dry and oxidizing environment the organisms were not well preserved and the odd−carbon predominance was reformed hence the value of OEP went to 1.

2.5 Clay Mineralogy

The clay minerals are illite, hydromica, montmorillonite and vermiculite, but the content of montmorillonite is higher in the lacustrine and paleosol beds than in the alluvial−diluvial beds. The maxima of the content curve for montmorillonite roughly coincide with the occurrence of lacustrine and paleosol beds. The curve of the ratio of montmorillonite of kaolinite is similar to that of montmorillonite content. The assemblage and contents of clay minerals in the core point to a climatic alteration of dry−moist with cold−warm. The gradual increase of illite from the bottom to the top of the core shows a drying tendency in this direction.

3. Climatic and Environmental Changes in Chaiwopu Basin since the Last 730,000 Years

The Early Pleistocene was a transitional period from a cold−moist to a warm−dry climate.

Since 730,000 yr. B.P., five longer cycles of climatic fluctuation of dry−moist and cold−warm were detected (Fig.3). In the period of 730,000−550,000 yr. B.P. (when the alluvial−diluvial bed between 123 and 102 m was formed) the climate was dry and cold;550,000−400,000 yr. B.P. (bed H5) would indicate that there was a warm−moist; 400,000−300,000 yr. (the alluvial−diluvial bed of 83−66 m) the climate was cold and dry; 300,000−200,000 yr. B.P. (bed H4 of 66−52 m) the climate was cold−dry; 120,000−75,000 yr. (bed H3 of 42–34 m) the climate was warm andmoist; 75,000–120,000 yr. the climate was cold and dry in which there was ashort climatic subfluctuation of a little moist and warm that was theinterstadial of the last glaciation.

In the lacustrine bed H5, the appearance of *L. Sancti–patricii brady et Robertson*, the existence of the spore–pollens of *Betula, Ulmus, Populus and Salix*, the high contents of organisms and $CaCO_3$ and the large values of ^{18}O and OEP, all show that the moisture and temperature at that time were higher than those at present. Evidently, from 550,000–400,000 yr. B.P. the climate in Xinjiang region was warm and moist. It was a climatic optimum during 730,000–100,000 yr. B.P. and synchronous with the Holstein interglacial of Northern Europe. During this period the brown–red 5th paleosol bed (S5) formed and developed in the Loess Plateau of China, [1–2]while the Huanghua transgression appeared in the east part of the Hebei Plain.[3]The second warm moist period coincided with the deposition of the lacustrine bed H3. This was the last interglacial and corresponds with the Eemian interglacial in Northern Europe.[5]During the same period the first paleosol bed (S1) was formed in the Loess Plateau and the Qingxian transgression bed was deposited in the Hebei Plain.[3]

Several climatic stages in the last 12,000 yr. could be deduced from spore–pollen analysis: 12,000–10,000 yr.B.P. a cold–moist stage, and grassland landscape; 10,000–8,500 yr., a warm–dry stage, and desert vegetation; 8,500–6,500 yr., a warm–moist stage, the most suitable climate for deciduous plants and broad leaved trees of *Ulmus* and *Salix;* Cyperaceae also appeared; 6,500–5,000 yr., a warm–dry stage, Ephedraceae and desert vegetation further developed; 5,000–3,000 yr., a warm–moist stage with *Picea* decreasing; in the last 3,000 yr., the warm–dry stage, Chenopodiaceae increasing rapidly and *Artimisia* and Ephedraceae as well. The natural environment reflected during this period was similar to that at present.

4. Evolution of Chaiwopu Lake

4.1 Formation of Chaiwopu Lake and Changes in Lake Level in the Middle Pleistocene

The study of cores CK–1 and CKF demonstrates that Chaiwopu lake was formed in the Middle Pleistocene. This conclusion was based on the 5th (oldest) lacustrine bed H5 at 83.94–102.10 m in core CK–1. This bed has an age of 542,000 yr. estimated from the oxygen isotope stage and synchronous with "Beijing Man" [4] and the Holstein interglaciation of Northern Europe[5]. At that time Chaiwopu Lake was larger and its level was higher.

The two alluvial–diluvial beds sandwiching the lacustrine bed H4 show that the lake underwent three stages of contraction–extension–contraction in the time span from its formation to the end of the Middle Pleistocene.

4.2 Extension of the Lake in the Last Interglaciation

The 7.5 m thick lacustrine bed H3 in the core and the extension of the lake in the early part of the Late Pleistocene indicate a globally warm and moist climatic environment during the last interglacial stage.

4.3 Fluctuation in Lake Level during the Last Glaciation

At the beginning of the last glaciation the lake began to contract and the sediment was not lacustrine but alluvial–diluvial. In the interstadial of the last glacial period the lake was again enlarged and the lacustrine bed H2 of 9.95 m thick was formed. The age of the upper part of bed H2 determined by ^{14}C dating, is 23,821 ± 766 yr. B.P. and the time when the fine sand bed of the bed H2 was formed corresponds to the Laschamp subchron. Obviously the lacustrine bed H2 was formed in the interstadial [5]. After the interstadial, the climate became colder and glaciers rapidly developed. The snow line on the southern side of Bogeda Mountain went down to an altitude of about 3,400 m a.s.l., that is 600 m lower than at present. The front of the large glaciers extended to an altitude of 2,300 m a.s.l. and the area covered by ice was five times as large as that at present. The wide distribution of loess deposits indicates that the climate was dry at that time. Wang Jingtai et al.[6]discovered a lacustrine built terrace formed in 15,000–12,000 yr.B.P. which is 25–28 m higher than the present lever of Chaiwopu lake and joined together to the 3rd fan below the terminal moraine formed in the last glaciation. They concluded, therefore, that the level of the lake was higher in the last glaciation than at present and considered the former period to be moist. This view of Wang Jingtai et al.[6]seems contrary to ours discussed above (dry–cold climate and the contraction of the lake), however, on closer inspection, we found that the higher level of the lake appeared not at the time of the last glaciation maximum (LGM) but during the followinginterglaciation. Maximum ice thaw and deposition of ice–born materials (sediment) took place not in the coldest glacial age but in the time whenthe climate was getting warmer, the ice melted faster, and the glaciers were getting thinner andretreated. The increase in runoff due to ice thaw does not mean that the climate becomes moist. The LGM occurred in 18,000 yr.B.P. so the period of 15,000–12,000 yr.B.P. was obviously post LGM. We should note that dry climates and large runoff are peculiar to glacial area. When glaciers with draw to a certain extent, ice thaw rapidly decreases and changes in lake level occur.

4.4 Changes in Lake Level in Post–Glaciation Period

Although the climate was cool–moist in 12,000 yr.B.P. than today, the level of Chaiwopu Lake began to descend from that time and was 10 m lower[6]. From 10,000 to 8,500 yr.B.P., the climate was warm and dry, and lake area contracted. Coming to the middle period of the Holocene, the lake again extended forming the widely distributed second terrace which is 7–8 m higher than present level of the lake. The ages of the mud and the peat on this terrace are 6,690 ± 200 and 6,640 ± 80 yr.B.P., respectively[6]. The dark–grey muddy clay of 1.1–3.6 m thick in core CKE indicates a limnological environment and warm and moist climate. We suppose that the glaciers were drawn back to the much higher altitude than at present, and the higher lake level was caused not by ice thaw but by the large rainfall at that time.

After the moist time of the middle Holocene, 5,000–4,000 yr.B.P. the climate was warm–dry, the lake became smaller; 3,800–2,900 yr.B.P., the climate was cold and moist, the first lacustrine–built terrace was formed, the spore–pollens in the sediments are characterized by a great quantity of *Betula* and a few of *Salix* and *Ulmus*, glacial advance took place in the Tianshan new ice age.

In the last 2000 yr., in the Chaiwopu Basin the climate was very dry, the lake level descended, the lake was drawn back towards the east and disintegrated completely at last. The present locality of the lake is as far as 7 km from the drill core CK–1. Desertification happened and a series of sand dunes were formed on the higher terraces. From the 16th to the 18th centuries, the lake level lightly fluctuated, corresponding to the small glaciation in the Tianshan Mountain.

Thus it can be seen that Chaiwopu Lake apparently formed in the moist climatic period of the Brunhes chron in the Middle Pleistocene, and underwent four large extensions and contractions coinciding with warm–moist and the cold–dry periods, respectively. The glacial area of the last glaciation was five times as large as at present. In the late period of the last glaciers to thaw over large areas, and the lake level to rise. In the middle period of the Holocene, the climate was again warmer and wetter than today leading to another rise in lake level. Evidently, the fluctuations in climate and lake level over a wide area closely correlate with alternating of global glacial and interglacial ages, radiation of the sun and the circulation of the atmosphere. After the high temperature time of the Holocene, the climate generally tended towards the dry, but there were still several small alternations of coo–moist and warm–dry climates in between.

IV. CONCLUSIONS

Based on the analysis mentioned above, we propose that the climate in the Chaiwopu Basin was cold and dry during the glacial ages, and warm and moist during the interglacial ages in the Pleistocene. The climatic fluctuation (1,000 yr. as cycle, > 5 as range) was controlled by the Milankovich theoryabout the relationship between the sun and the earth. The five alternationsof lacustrine and alluvial–diluvial beds in the drill core would indicatefive cycles of warm–moist and cold–dry climate in the Brunhes chron. Therise in temperature caused by the radiation of the sun and the atmosphericcirculation resulted in an increase in rainfall, an extension of the lake,and a rise in lake level. Following the general warming in the Holocene,the temperature and the atmospheric circulation did not change very much,but small climatic fluctuation (1,000 yr. as the cycle and 1℃ as the range)occurred. The fluctuations were similar to the climate of the "Little IceAge" (LIA); the lake level rose when the climate was cold and moist, and thelake contracted during the warm–dry period. A high beach (1–1.5 m) ofChaiwopu Lake was formed during the LIA. Depending on the information ofthe growth ring of the trees and the extension of the small glaciers ofUrumqi River near Chaiwopu Lake during the LIA maximum, the annual average temperature was about 1℃ lower and the annual rainfall 50—100 mm more than those at present. Likewise, the level of IssyK—Kul Lake in the former Soviet Union was 13.5 m higher, the annual rainfall 10—20 percent more, and the temperature 1—2℃ lower than today[7]. Thewarmest and wetter climate in the Middle Holocene was recorded in Qinghai Lake to the east of Chaiwopu Basin and in IssyK—Kul Lake to the west. The first lake—built terrace on the southern coast of Qinghai Lake is 65 m higher than the level of the present lake and has an age of 6,860 ± 130 yr.B.P. This fact and the discovery of *Piecea purpurea* in the terrace indicate that the temperature in the Qinghai Lake area was probably 2.5℃ higher and the rainfall 200 mm greater than today[8]. The existence of 30—35 m high lake—build terrace with an age of 6,000—4,000 yr.B.P. in the area of IssyK—Kul Lake also implies a warm and moist climate period of the Holocene. The higher level of Qinghai, Chaiwopu and IssyK—Kul Lakes in the Holocene shows that the Asia—African monsoon was much stronger than that at present, reaching the interior of Asia[8-9]. The climate getting warmer, thaw and retreat of the glaciers after the last glaciation maximum (LGM) resulted in a higher level of Chaiwopu Lake in the period of 15,000—12,000 yr.B.P., which can be compared with 120 m high lake—built terrace formed in about 12,000 yr.B.P. in Qinghai Lake. However, during the LGM, when the glaciers advanced and few thaw of the ice, both Chaiwopu and Qinghai lakes had a relatively low level.

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