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Pollen record and environmental evolution of Caotanhu wetland in Xinjiang since 4550 cal. a BP

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This paper presents a multi-proxy reconstruction of the climate change in Caotanhu wetland using pollen, phytolith and charcoal records, and the data of loss of ignition (LOI), grain size analysis, and susceptibility. Results reveal that between 4550 and 2500 cal. a BP, a dry climatic condition was not favorable for the accumulation of peat. Since 2500 cal. a BP, the climate became humid and the wetland developed with abundant freshwater aquatic plants, which contributed to peat accumulation. Nevertheless, alternate periods of rain and dry climate occurred during that period. Between 2500 and 1810 cal. a BP (550 BC－140 AD), the climate was more humid than at present. A lot of emerged plants, such as *Phragmites*, *Typha* and *Sparganium*, and freshwater green algae grew in the wetland which was surrounded by desert-steppe vegetation composed mainly of Chenopodiaceae, *Artemisia*, Compositae and *Thalictrum*. However, from 1810 to 1160 cal. a BP (140－790 AD), the water level started to decrease and hydrophyte species reduced greatly, but some *Phragmites* still grew in the wetland and around it was desert vegetation with high proportion of Chenopodiaceae and *Artemisia*. Then from 1160 to 650 a BP (790－1300 AD), it entered a period of desert-steppe with abundant mesic and xerophytic plants. And a lot of aquatic plants prevailed in the wetland. Here, what is noticeable is that percentages of arboreal pollen, consisting mainly of *Betula* and *Picea*, increased greatly and reached a maximal value of 27.2%, in which, *Betula* percentages rose to 23.2%. Hence, it is reasonable to conclude that *Betula* grew in the highland of the wetland, or *Picea* timberline shifted downward resulting in the increase of percentages of *Betula* and *Picea* pollen, which were transported into the wetland by flood or wind. But since 650 cal. a BP, desert vegetation prevailed around the wetland again with dominant Chenopodiaceae and *Artemisia*, and the climate was similar to modern one. Despite some aquatic plants still growing in the wetland at that time, their amounts diminished greatly.

Caotanhu wetland in Xinjiang, pollen, phytolith, 4550 cal. a BP, environmental evolution

As a key component of the earth ecosystem, wetlands play an important ecological role in many aspects such as in maintaining regional ecosystem balance, mitigating the impacts of climate change, protecting human survival environments, and preventing flooding by holding water much like a sponge[1]. The great change of wetland is a natural law, but the interaction between human and nature can accelerate this change. In the past 2000 years, especially in the last few decades, the overexploitation and utilization of wetlands led to a remarkable change of the structure and functions of wetland ecosystem, which affected the regional climate system or even larger area. Therefore, the natural evolution process of

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GEOLOGY

wetland and the reconstructing paleoenvironment have been the focus for researchers both at domestic and abroad[2].

Being a dry pole of the Asia Highland, environment in Xinjiang are especially sensitive to the climatic change due to relative simplicity of ecological and environmental component. Wetlands in Xinjiang with important information of hydrology transition and regional climatic changes have become the suitable objective for studying the paleoenvironmental change. The total area of present wetlands in Xinjiang is about 1.48×10^4 km^2, which only accounts for 0.89% of total Xinjiang area[3]. But it plays a critical role in the historical civilization of northwestern region. However, a lot of oases and wetlands, consisting of river, marsh and lake, have been reclaimed into farmland due to the rapid increase of population and reclamation regions in the past 2000 years, especially in the last several decades. As a consequence of increasing contradictions between economic development and ecological environment[4], a lot of wetlands have degenerated gradually and even disappeared[5]. According to the investigation, the Xinjiang wetlands, which occupied about 2.8×10^4 km^2 in the early 1960s, have rapidly decreased to 1.48×10^4 km^2 at present[3]. Being the main body of China's West Region, Xinjiang plays a special role in the development and environmental protection in this region. Therefore, it is necessary to strengthen the research on the long-term environmental evolution of wetlands.

In the last few years, scholars have accumulated abundant research information regarding water resource, eco-environment and sustainable development[4–7] of some major wetlands in Xinjiang, such as Manas Lake[8] Ebinur Lake[9,10], Barkol Lake[11], Bosten Lake[12,13] and Lop Nur Lake[14]. By analyzing these research results, however, it is found that a lot of problematic issues, such as time resolution, pollen source and dispersal mechanism should be discussed in detail.

Consequently, in order to study the evolutional characteristics and formation mechanism of wetland environment, the Caotanhu wetland in Shihezi City, located at the transitional zone between central Tianshan Mountain and the Junggar Basin in northern Xinjiang, was selected as the research area. Using multiproxy records including the higher resolution record of pollen, charcoal and phytolith data, together with the secondary data of geochemical and granularity, the information of climate and environment change was extracted to reconstruct paleovegetation and paleoclimate. Accordingly, this study can provide a scientific support and reference basis for the protection and rational exploitation of wetland source in western China.

1 Materials and methods

1.1 Study area

The study area (Figure 1), about 9 km north of Shihezi City, is situated at the northern low-lying belt of the first branches of Shihezi General Farm, the Fifth Company of Xinjiang Military Construction Unit. The type of wetland is reed marsh, with an area of 27.6 km^2, located in the spring water-overflowing belt of alluvial fan. It is continental temperate arid climate with mean annual temperature of about 6.6℃, annual precipitation of about 201 mm and annual theoretic evaporation of 1538 mm. Uncultivated marsh vegetation was dominated by *Pragmatism* and accompanied by *Scirpus tabernaemontani* and *Najas* sp. with the vegetation coverage of about 80%—90%. Despite a lot of wetlands have been reclaimed into farmlands with cotton and soybean, a large area of reed lake still presents (for details please see *the Wetland Database in China, CAS*). Additionally, Caotanhu is one of concentrating distribution regions of peat resource in Xinjiang. Peat, a crucial resource in wetland, is an excellent information carrier of paleoenvironment and paleocilmate with higher time resolution[15]. In 1997, scientists from China and Japan surveyed this region and estimated that peat resourse

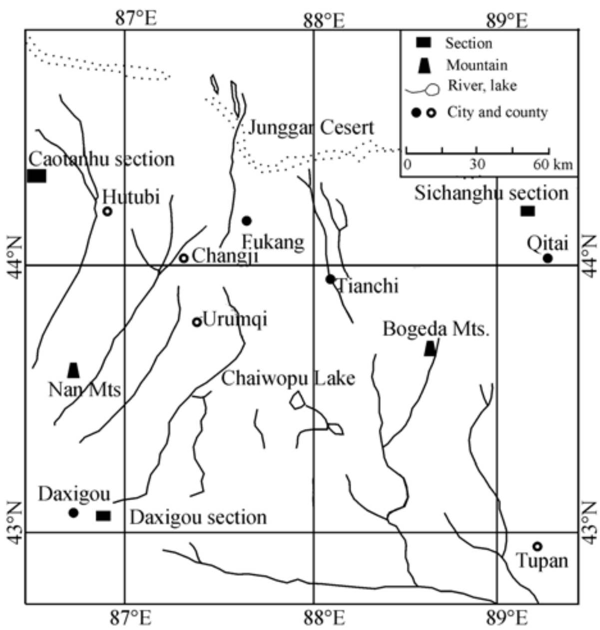

Figure 1 The geographical location of study area.

occupied an area of $1km^2$ with the depths of 0.3—1 m[16].

1.2 Field survey and sampling

A 175-cm-deep manual excavated section I (44°25.06′N, 86°01.26′E, 380 m) was collected at Caotanhu wetland in July 2002, which is located at the transitional zone between central Tianshan Mountain and the Junggar Basin in northern Xinjiang (Figure 1). In August 2003, another 228-cm-deep section II (44°25.03′N, 86°01.27′E, 385 m), 500 m southeastern away from section I, was also excavated. In this paper, section I was selected as the research subject. The top stratigraphy of section I is composed of barren peat, i.e. turf, and the middle and the lower parts are clay and clayey silt (Figure 2). Five subsamples (at the depths of 28—25 cm, 45—42 cm, 76—73 cm, 112—109 cm and 175—172 cm) were selected for ^{14}C datings, respectively. Here, ^{14}C age dating was analyzed at the ^{14}C Laboratory of Institute of Geology, China Seismological Bureau. Below are the dating results of those samples: 1210±70 a BP (1140±100 cal. a BP), 1420±60 a BP (1310±30 cal. a BP), 2890±70 a BP (3000±135 cal. a BP), 4960±190 a BP (5660±210 cal. a BP) and 8240±575 a BP(9240±735 cal. a BP), respectively. Ages of the remaining samples were interpolated by assuming that the sediment rate was constant between the two dated samples. Then the chronology for this section was established on the basis of those five dating data. Results showed that ^{14}C ages of section I started from 9240 cal. a BP, and at depths above 96 cm were dated to since 4550 cal. a BP.

We collected 33 samples at 3 cm intervals in the upper 99 cm. Each sample (30 gram) was treated with 10% HCl and 10% NaOH, followed by flotation using specific-gravity liquid and acetolysis after sieving and chemical treatments. More than 56743 pollen-spore grains were counted from each sample using 10×40 magnification with an Olympus microscope (Figure 2). Among those, 10000 pollen were identified as terrestrial pollen and belonged to 56 sporopollen taxa. At least 300 terrestrial pollen grains were counted for each sample in peat layers, but not for samples from 96 to 66 cm. However, thousands of Polypodiaceae spores can be found in non-peat layers. Pollen percentages for tree, shrubs, herbs and A/C (*Artemisia*/Chenopodiaceae) ratio were calculated using a denominator of total sum of terrestrial plant. Mass concentration (grains per gram dry weight, grains/g) was calculated by the method of direct concentration without adding *Lycopodium* spore[17,18]. Additionally, abundant phytoliths were recorded with a total number of 22807 grains. Ten phytolith types were identified, including fan-shaped (*Phragmites* fan-shaped, other fan-shaped), square, rectangle, elongate (smooth-bar and indented bar), point-shaped, hat-shaped, dumbbell, saddle, tooth and irregular types. Charcoal particles were divided into three categories according to the length of the long axis: >100 μm, 50—100 μm and <50 μm. Percentages and concentration of pollen diagrams were plotted with the TILIA and TILIAGRAPH Program (Figures 2 and 3). For samples collected from above 66 m at 3 cm intervals, following measurements were operated besides the pollen analysis: grain size measurement (Mastersizer2000 laser particle distribution analyzer), loss on ignition (LOI) and susceptibility (determined by MS2 susceptibility analyzer). All these measurements were performed by the National Key Laboratory of Chinese Ministry of Education, Lanzhou University.

2 Results and interpretations

2.1 Mean accumulation rate of peat

Mean accumulation rate of peat is the thickness of peat accumulation in unit time. Following expression is employed:

$$r = h/t,$$

where h is the thickness of peat layer, and t is the carbonization time, respectively[19]. Taking the example of this peat section, the depth is 0—66 cm and the carbonization time is since 2493±102 cal. a BP. So the mean sedimentation rate is 0.265 mm/a, which is lower than that in northeast China (0.395 mm/a) and Changbai Mountain region (0.721 mm/a) during the Late Holocene (since 2500 cal. a BP). Generally, the higher accumulation rate of peat indicates that the growths of vegetation is faster than the decomposition, that is to say, vegetation either flourish or decompose very slowly. On the contrary, the low accumulation rate reflects that either cold-dry or warm-dry climate[19]. Therefore, since 2500 cal. a BP the dry climate variability in Shihezi city of Xinjiang is larger than that of the northeast China and Changbai Mountain region.

2.2 Pollen and phytolith assemblages

Fifty-six genera and families were identified in 33 sam-

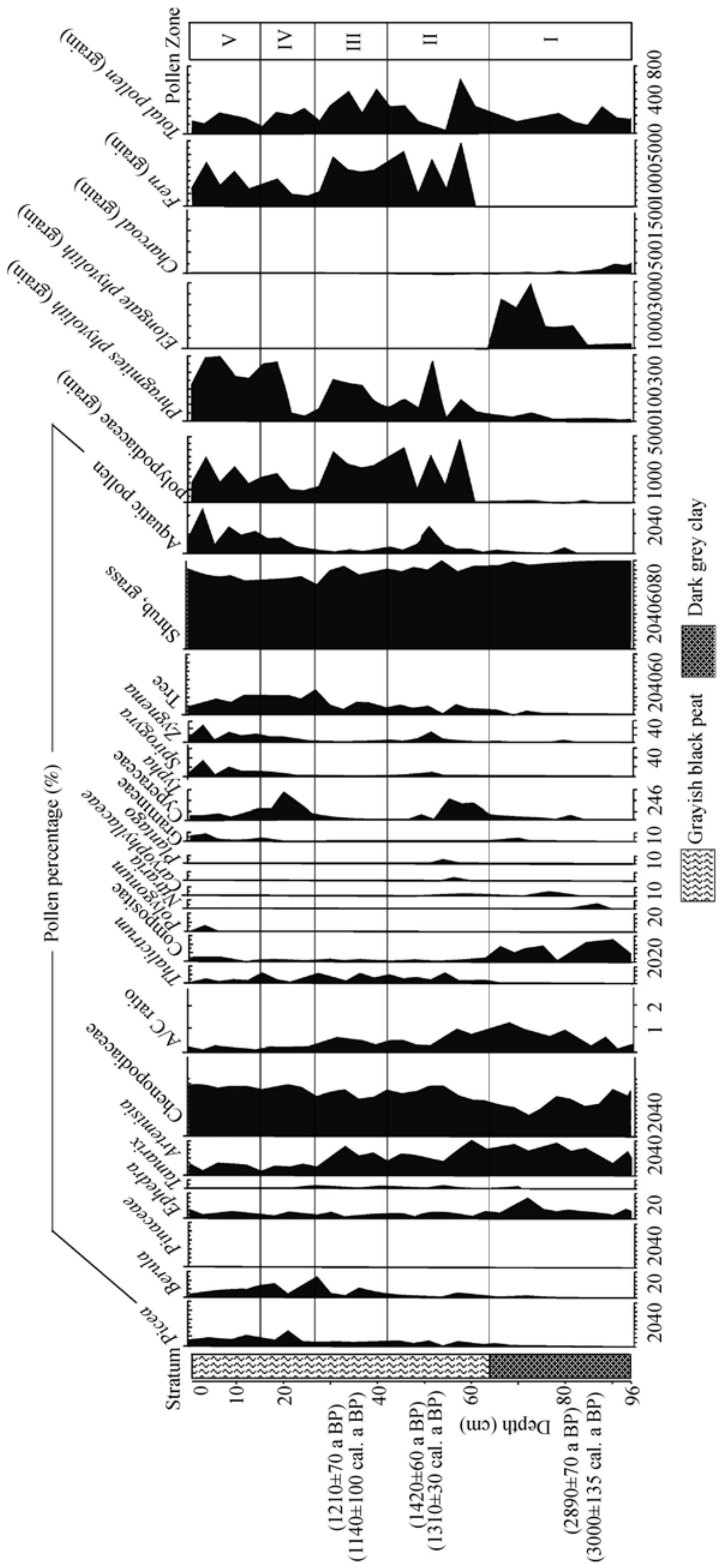

Figure 2 Pollen and phytolith assemblage of section I, Caotanhu wetland in Xinjiang.

ples. Among them, dominant arboreal pollens are *Picea schrenkiana* and *Betula*, but *Pinus*, Cupressaceae, *Larix*, *Tsuga*, *Abies*, Pinaceae, *Ulmus* and *Salix* are occasionally accounted. Main mesic and xerophytic shrub and herb pollens are Chenopodiaceae, *Artemisia*, *Ephedra*, Leguminosae, Rosaceae, *Nitraria* and *Tamarix*. *Thalictrum*, *Polygonum*, Gramineae, *Plantago*, Caryophyllaceae, Umbelliferae, Cruciferae, Labiatae, Convolvulaceae, *Scabios, Geranium*, Liliaceae and Cyperaceae dominated in mesic and hygrophytes herb pollens. Aquatic vascular hygrophytes pollen types are *Potamogeton*, *Sparganium*, *Typha*, *Alisma* and *Hydrocharis*. Fresh water green alga pollen include *Spirogyra*, *Zygnema*, and *Chlamydomonas*. Fern pollen type is only Polypodiaceae.

Based on variations in pollen concentration and main pollen percentages of Caotanhu section at depths above 66 cm was categorized into five pollen zones (Figure 2, Figure 3). Different pollen zones can be characterized as follows.

Zone I (96—66 cm, 4550—2500 cal. a BP). The predominant taxa in this zone are shrub and herb pollen with mean percentages of above 95%, dominated by Chenopodiaceae (22.3%—69.2%), *Ephedra* (10.3%—33.8%) and *Artemisia* (5.4%—22.9%) pollen. Not only pollen percentages of arboreal and aquatic plants (less than 6%) but also grains of Polypodiaceae spore (16—113 grains) are at their lowest values in the section. Similarly, remarkable lowest concentrations of total pollen (177—3264 grains/g), aquatic plants (0—106 grains/g), Polypodiaceae spore (28—853 grains/g), trees (0—42 grains/g), shrub and herb (191—2988 grains/g) are recorded in the section. However, the A/C (*Artemisia* /Chenopodiaceae) ratio reaches its highest value (1.2) in the section. In addition, the phytolith assemblage is characterized by relatively lower values of fan-shaped and square phytolith (99—213 grains) and higher values of elongate and point-shaped phytolith (175—3189 grains) as an indicator of a cold and dry climate[20].

Zone II (66—42 cm, 2500—1810 cal. a BP). High proportion of shrub and herb pollen (89.2%—100%) still dominate in the pollen assemblage, but the mean percentage of arboreal pollen begin to increase to 11.4%. In particular, pollen percentages of aquatic plants increase greatly to 28% (using a denominator of total terrestrial pollen sum) with dominant *Spirogyra*, *Zygnema* and *Typha*. Similarly, spore grains of Polypodiaceae (941—4778 grains/g) are also higher than those in other zones. In particular, the highest concentrations of total pollen (349—6784 grains/g), aquatic plants (10—640 grains/g), Polypodiaceae spores (565—50965 grains/g), arboreal pollen (26—736 grains/g) and shrub and herbs (326—6506 grains/g) are recorded at the depth of 60—57 cm (2150—2000 cal. a BP, corresponding to 200 BC—50 AD). At the same time, A/C ratio is also at its higher value (0.3—1.0). In addition, grains of *Phragmites* phytolith reach their higher values (19—360 grains) as a proxy for warm and humid climate[20], with lower values of elongate and point-shaped phytolith.

Zone III (42—27 cm, 1800—1160 cal. a BP). The dominant taxa in this zone are still shrub and herb pollen (72.8%—94.1%) with high proportion of Chenopodiaceae (36%—52.3%) and *Artemisia* (9.3%—32%). But percentages of arboreal pollen increase again, while grains of Polypodiaceae spores decrease slightly as compared with Zone II. Similarly, pollen percentages of aquatic plants also reduce to 5% with a few *Spirogyra*, *Zygnema*, *Typha*, *Sparganium*, Cyperaceae and *Hydrocharis*. When compared with Zone II, concentration of total pollen (629—5482 grains/g), aquatic plants (24—74 grains/g), arboreal pollen (80—378 grains/g), shrub and herb pollen (542—5115 grains/g) and Polypodiaceae spores (6960—30816 grains/g) reduce, but at depths of 33—30 cm (1210—1190 cal. a BP) they reach a small peak value except aquatic pollen. Seconly, higher percentages of arboreal pollen than that in Zone II are recorded, on the contrary, its concentraion reduce. In addition, not only A/C value (0.2—0.6) but also amounts of *Phragmites* phytolith (82—250 grains) are lower than those in Zone II.

Zone IV (27—15 cm, 1160—650 cal. a BP). The pollen assemblage is still characterized by abundant shrub and herb pollen. But percentages of arboreal pollen increase rapidly and reach a maximal value of 27.2% at the depth of 27 cm (1160 cal. a BP), in which, *Betula* percentage accounts for 23.2% while that of *Picea* rises to 16.6% at the depth of 21 cm (970 cal. a BP). Similarly, percentages of aquatic plants with dominant *Spirogyra*, *Zygnema*, *Typha* and *Sparganium* also increase to its higher values (7%—23%). In particular, at the 24—21 cm depths (1140—970 cal. a BP) higher concentration

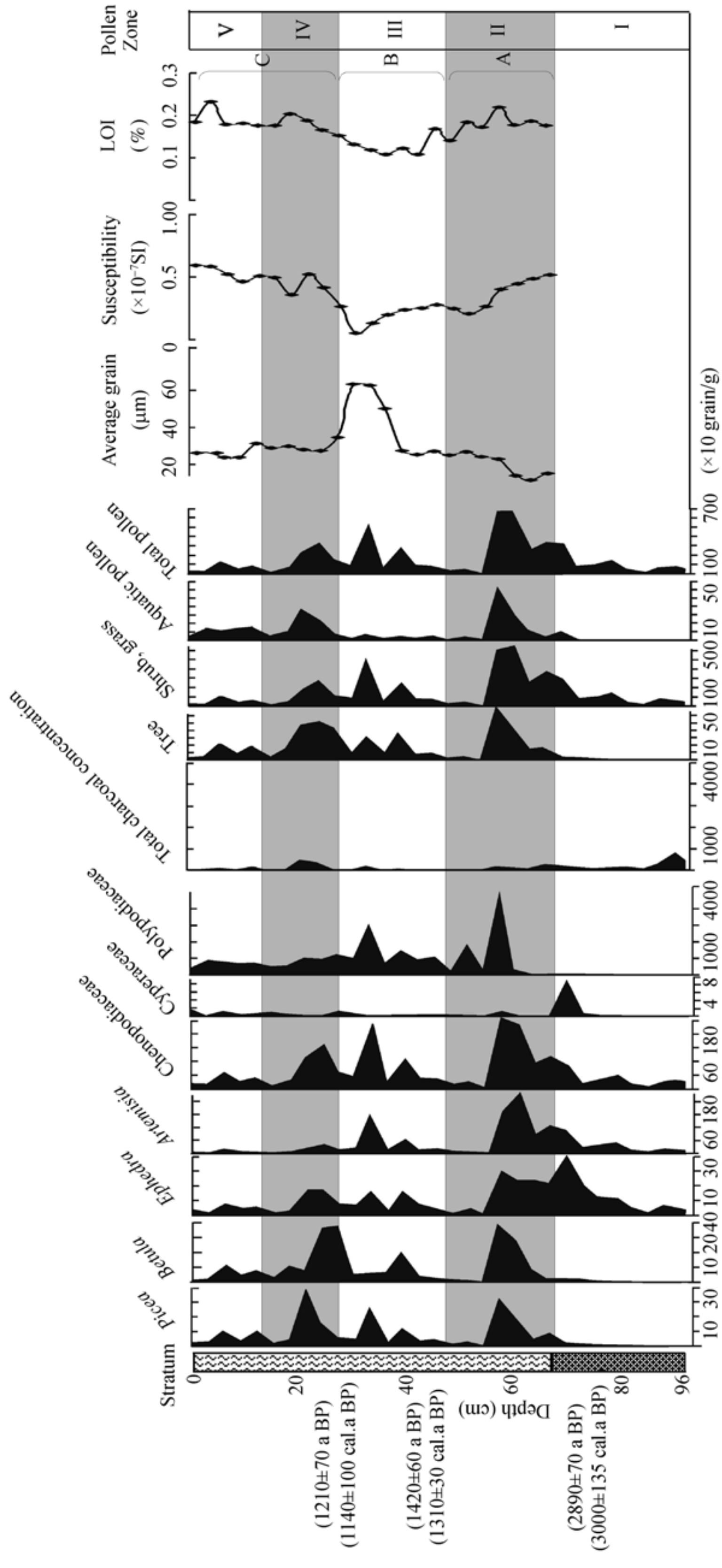

Figure 3 Pollen concentration, average granularity, susceptibility and LOI of section I, Caotanhu wetland in Xinjiang.

of total pollen (218—3328 grains/g), aquatic plants (53—373 grains/g) and arboreal pollen (45—522 grains/g) are also recorded. Furthermore, it is noticeable that pollen concentrations of *Picea* and *Betula* increase and reach the most abundance (384 grains/g and 373 grains/g, respectively), while those of shrub and herb (178—2775 grains/g) reduce a little. In addition, A/C value (0.1) and spore concentration of Polypodiaceae (5706—12586 grains/g) decrease sharply as compared with Zone III. However, typical *Phragmites* phytolith increases to its maximal value (389 grains) from 21 to 18 cm.

Zone V (15—0 cm, about since 650 cal. a BP). Higher percentages of shrub and herb (77%—90%) prevail in the pollen assemblage. But percentages of arboreal pollen decrease greatly to 9.1%, in which, those of *Betula* and *Picea* are lower than 12%. When compared with Zone IV, Chenopodiaceae percentages increase slightly to 50%—58%. Similarly, grains of Polypodiaceae spores and percentages of aquatic plants are higher as compared with Zone IV. However, concentration of total pollen (218—1248 grains/g), arboreal pollen (32—218 grains/g), shrub and herb (258—1068 grains/g) and aquatic plants (53—160 grains/g) reduce greatly to their lower values in the section, so is A/C value (0.1—0.3). In addition, abundant *Phragmites* phytolith still prevails in the zone.

2.3 Variability of LOI, grain size and susceptibility

According to the vertical change of LOI, grain size and susceptibility, three zones were distinguished, as shown in Figure 3. Characteristics and types of three zones are described as follows. In Zone A (66—42 cm, 2500—1810 cal. a BP, corresponding to pollen Zone II), lower value of average grain size (11.5—27.4 μm) than that in other zones suggested a weak sediment movement during that period. However, the LOI (14%—21%) and susceptibility ($(0.21-0.52)\times10^{-8}$ m^3 kg^{-1}) values of Zone A were higher than those of Zone B. In Zone B (42—27 cm, 1810—1160 cal. a BP, corresponding to pollen Zone III), the average granularity increased greatly and reached a peak (63.6 μm) at the depth of 36 cm, indicating a strong sediment-interacting environment. However, the LOI (10.8%) and susceptibility (0.06×10^{-8} m^3 kg^{-1}) values of Zone B were much lower than those in Zones A and C, reaching the lowest level in the peat layers especially at the depth of 36 cm. In Zone C (above 27 cm, since 1160 cal. a BP, corresponding to pollen Zone IV and V), the average granularity decreased slightly to 23.8 μm at the depth of 9 cm when compared with Zone B, suggesting a weaker sediment dynamics. However, LOI (0.59×10^{-8} m^3 kg^{-1}) and susceptibility (23%) values increased gradually, and reached their maximal levels in the peat layers at depths of 0—3 cm.

Organic carbon can be estimated from LOI value in sediments, and there is a close relationship between organic content and paleoenvironment. Generally, higher organic carbon content indicates a relative humid climate, while dry climate is not favorable for the accumulation of organic matter. Therefore, in the region with relatively low human disturbance, the variation of LOI value can be regarded as an indicator of the climate variability to a certain extent[21,22]. As shown in Figure 3, from 1810 to 1160 cal. a BP, LOI value decreased rapidly, suggesting a dry climate. But during other periods, higher LOI value reflected a humid climate with higher vegetation cover. Therefore, humid climate is an important factor for the accumulation of organic matter[21,22].

Being a substitute index for environment change and climate change, contents of magnetism mineral, especially in the continental strata, can be used to reconstruct paleoenvironment and paleoclimate[23]. In the normal condition, susceptibility value can reflect the precipitation because high precipitation may result in high biomass and active biochemistry reaction, which favors the generation of magnetism mineral. Thus, to a certain degree, the variation of susceptibility can be used as the index for the paleoclimate at the time[22]. As shown in Figure 3, from 1810 to 1160 cal. a BP, lower susceptibility and LOI values but higher average granularity indicated a dry climate. However, from 2500 to 1810 cal. a BP and since 1160 cal. a BP, susceptibility, LOI and amounts of aquatic plants became higher but average granularity was lower, indicating that the climate in these two stages were humid.

It is remarkable that a small peak of charcoal concentration occurred at the depth of 21 cm (977 cal. a BP) since 2500 cal. a BP, which corresponded well to the susceptibility curve. It is generally believed that magnetic oxides generate from the combustion of soil. As a result, susceptibility should increases[24]. Therefore, to some extent it can be regarded that high charcoal concentration might be correlated with fire. Additionally, biomass should increase if the fire is caused by nature. In Figure 3, the LOI values in Zone IV were quite high, indicating a higher biomass during the period.

3 Discussion and conclusions

3.1 Paleovegetation and paleoenvironment reconstruction

The pollen assemblage revealed that from 4550 to 2500 cal. a BP, 1988 terrestrial pollen grains with averagely 198 pollen grains in each sample were counted in the lithology of dark grey clay from 96 to 66 cm. 27 pollen-spore taxa with dominant shrub and herb pollen were identified in the sporopollen assemblage. Not only percentages of arboreal pollen but also concentration of total pollen, aquatic plants, shrub and herb were at their minimal levels in the section. However, contents of elongate, rectangle and point-shaped phytolith as an indicator of a cold and dry climate reached to their highest levels. Hence, the pollen and phytolith assemblages reflected that a dry climate with sparse vegetation. Furthermore, a big fault appeared at the mouth of Taeryayilake Channel, which was covered by salt crust and salts during the period of the eastward shift of the Urumqi River. It resulted from high temperature and dry climate during the late stage of the Middle Holocene and the Late Holocene[25,26], which corresponded to 4550—2500 cal. a BP.

But at depths above 66 cm (since about 2500 cal. a BP), 43 families and genera of pollen and spore were identified and counted with total pollen sum of 56000, accounting for more than 90% of the total pollen sum. Of the 33 analyzed samples, 5934 pollen grains were identified as terrestrial pollen, 60% of the total sum. Averagely, 300 pollen grains contained in each sample were identified with a few exceptions. Higher concentration of total pollen, aquatic plants, shrub and herb and arboreal pollen than during the period of 4550—2500 cal. a BP and high content of fan-shaped phytolith suggested that since 2500 cal. a BP the climate was humid with abundant species and prosperous aquatic plants dominated by *Phragmites*. Generally, peat generates from abundant marsh and aquatic plants, so in arid region it could indicate a humid climate[27]. According to recent researches, peat in other regions of Xinjiang mainly developed in the suitable climatic periods of Holocene and the remarkable humid period during 3—2 ka BP[28]. Additionally, plant residues collected from the section were identified as the typical marsh vegetation such as *Carex* and *Phragmites*. Therefore, it was obvious that since 2500 cal. a BP, the climate was humid. Moreover, charcoal concentration in the peat layers decreased greatly than that in the non-peat layers. It was likely that since 2500 cal. a BP the biomass was higher, but the climate was so humid that not favorable for the formation of fire. Nevertheless, it should be pointed out that since 2500 cal. a BP, the pollen assemblage dominated by desert plants such as Chenopodicaceae, *Artemisia* and *Ephedra*, suggesting that regional vegetations were desert vegetation all the time.

According to the above pollen data and assemblage feature, together with average granularity, susceptibility and LOI values, paleoclimate and environment evolution of Caotanhu section since 2500 cal. a BP was particularly analyzed as follows.

From 2500 to 1810 cal. a B.P (550 BC—140 AD), concentration of total pollen, aquatic plants, shrub and herb and arboreal pollen were at their highest values. Secondly, content of fan-shaped phytolith dominated by *Phragmites* and other types of phytolith as indicators of a warm and humid climate were also very high. Moreover, the highest content of shrub and herb pollen, aquatic plants and Polypodiaceae spore and higher susceptibility and LOI values but lower grain-size indicated the climate was humid than at present. A lot of freshwater aquatic plants (*Phragmites* and *Typha*) and green alga grew in the wetland surrounded by desert-steppe vegetations with high proportion of Chenopodiaceae, *Artemisia*, Composite and *Thalictrum*. Sediment record from Boston Lake in southern Xinjiang[29] and the Niya section in the south edge of Tarim Basin[30] also showed a humid climate during that period. Reconstructions of decadal averages of annual mean temperature and precipitation fluctuations were derived from variations of $\delta^{18}O$ and net accumulation rates in the Guliya ice core. They revealed a period of higher temperatures and higher precipitation than today, which affected vast areas of northwestern China during the period of 2.2—1.8 ka BP[31]. During the period corresponding to Qin and Han Dynasty, the ancient state of Loulan with the population of 14000 also thrived with flourishing forest and plentiful fields and gardens, indicating a humid climate[6,25,26].

But from 1810 to 1160 cal. a BP (140—790 AD), the climate was different from that of the former period. The concentration of total pollen, aquatic plants, shrub and herb, arboreal pollen, amounts of aquatic plants, Polypodiaceae spores and typical fan-shaped phytolith were lower than those in Zone II, indicating a dry climate, which was confirmed by the surrounding desert plants such as Chenopodiaceae and *Artemisia*. Aquatic plants decreased greatly except some reeds, and the water level dropped down. Excavated Kharosthi Documents recorded that Loulan Kingdom disappeared in the 4th Century. Some scholars thought that the reason of Loulan's disappearance was due to the drought and water shortage[25,26].

From 1160 to 650 cal. a BP (790—1300 AD), concentrations of total pollen, aquatic plants, shrub and herb, arboreal pollen were high. Secondly, fan-shaped phytolith as the implication of a warm and humid climate increased again. Compared with Zone III, percentages of shrub and herb decreased again, while those of arboreal pollen composed by *Betula* and *Picea* increased greatly with a peak value of 27% at the time of about 1160 cal. a BP, in which, *Betula* percentages reached to 23.2%. The pollen assemblages showed a high plant diversity and biomass with abundant aquatic plants. Regional vegetation was desert during that period. A total of 80 surface pollen samples in 86 vegetation quadrats were collected by Yang[32] from an altitudinal transect at intervals of 20—100 m from 460 to 3510 m on the northern slopes of central Tianshan Mountains. Results showed that *Betula* percentages were lower than 3%. Secondly, results of 14 modern pollen samples collected at 100 m intervals from Glacier No.1 to the mouth of valley at the headwater of the Urumqi River revealed that the highest *Betula* percentage was only 0.1%. Furthermore, 114 airborne pollen samples were collected from the Tianchi Weather Station (1980 m), Fukang Research Station of the Chinese Academy of Sciences (460 m) and Beishawo Field Station (400 m), respectively from July 2001 to July 2002. Results also demonstrated that the peak of *Betula* percentages was 3%. Moreover, the maximal *Betula* percentage did not exceed 10% for the samples colleted from 5 sections at different elevations and vegetation zones on the north slopes of central Tianshan Mountains, namely, Daxigou section (3450 m)[33] located at the head source of the Urumqi River, Huashuwozi (1320 m) and Xiaoxigou (1360 m) section located at the west ridge of Huashuwozi Village, Quanzijie Township, Jimusaer County[34], Sichanghu section (589 m) located in the southeastern margin of the Gurbantunggut Desert[35] and Dongdaohai section (430 m) located a terminal lake of the Urumqi River[36]. Therefore, palynological researches from not only modern but also in the stratum showed that high *Betula* percentage should not appear in the Tianshan Mountains. High *Betula* pollen percentage in Caotanhu wetland suggested that *Betula* might grow at the highland of wetland because its tolerability to salt and drought was stronger than *Picea's*, indicating that a more suitable natural climate than today. At present, *Betula humilis* and *Betula halophila* grow in the permafrost swamp in the Altay Valley[37], which can provide evidences for *Betula* growing in low elevation. Another reason may be that high precipitation and humid climate resulted in the increase of *Picea* and *Betula* pollen, which were transported by wind or flood. According to the historical documents, in the first year of Yonglong period (939 AD), wind and snow disasters became very serious. In the third year of Kaibao period in the Northern Song Dynasty (970 AD), heavy rainfalls flooded a lot of farmhouses in Gaochang (i.e. Turpan in Xinjiang) (*The Historical Book of Song* written by Shen Yue, who lived in the Southern Dynasties)[25,26].

In addition, the period corresponded in time with the Medieval Warm Period (900—1300 AD) (MWP), which had been recorded in Dulan tree-ring[38]. A 2326-year tree-ring chronology of *Sabina przewalskii* Kom. for the Dulan area of northeastern Qinghai-Tibetan Plateau showed that the North Atlantic MWP was accompanied by notable wet springs in the study region during 929—1031 AD[39]. Secondly, based on a relatively high-resolution pollen record of the Sichanghu profile, the highest A/C ratio, total concentration and pollen percentage of aquatic plants indicated a humid climate during that period of $1000\pm65—665\pm50$ cal. a BP[35]. From 1400 to 600 cal. a BP, the prominent peaks of pollen concentrations of total pollen, arboreal, shrub, aquatic and herb in the Daxigou section suggested a more humid climate condition[33]. Yan et al. thought that water level fluctuation in the Ebinur Lake reflected the variations of the regional climate and environment since the last 2500 years according to the pollen record. Results showed that its water level kept rising and reached a higher level during the period of 300—1400 AD[9]. Moreover, during the period of 1500—500 a BP, lake levels of some lakes such as Chaiwopu and Barkol Lake in Xinjiang were at an ascending stage, indicating a humid climate[40−42]. At depths of 60−15 cm of the Dongheba section in Beiting ancient town, Jimsar County on the north slopes of Tianshan Mountains with the ^{14}C dating of 590±80 a BP, pollen and sediment data showed that percentages of aquatic plants grains of dominant *Typha* and *Phragmites* were higher than those in other layers, suggesting a humid climate during that period[43]. Wang[1)] collected a lot of plant seeds from the center of the Lop Nur Lake, which were identified as some submerged and emergent aquatic plants, such as *Potamogeton pectinatus*, *Potamogeton lucens*, *Scirpus tabernaemontani* and *Phragmites*. Furthermore, ostracods such as *Condoniella albicans*, *Condona copessa*, *Eucrypris inflata*, *Limonocythere inopinata*, *Darwioula stevenoni*, Charophytes such as *Lamprothaminiom*, and snails such as *Blanorbidae*, *Radix auricularia*, *Lymnaea staynalis* were also recorded. The ^{14}C age of vegetation remains at depths from 67 to 74 cm was dated to 871±45 ^{14}C a BP[1)]. From the above evidence, we can conclude that during the period, approximately corresponding to the Medieval Warm Period (900−1300 AD), the climate was humid on the north slopes of Tianshan Mountains in Xinjiang. But the relationship between water and heat in the study area during the past time is not very clear, which should be discussed in the future.

Since 650 cal. a BP (1300 AD until now), concentration of total pollen, aquatic plants, shrub and herb, arboreal pollen decreased again to their minimal values. However, pollen percentages of shrub and herb increased when compared with Zone III, while those of arboreal pollen decreased rapidly, which reflected that the climate was drier and vegetation became sparser than in the earlier stage. In addition, historical record also reflected that the climate became dry and people were relieved fund from Gansu Province in East Xinjiang. Thus it is known that the drought degree was more prominent in the earlier stage of Pollen Zone V.

3.2 Influences of alluvial fan on pollen transportation

As a bulky and soft fan-shaped accumulation body, alluvial fans in arid and semi-arid area form at the front area from the accumulation of stone and sand transported by temporal flood. Sometimes groundwater emerges and forms the bunchy spring or marsh at the edge of fan cone roof[44]. The Caotanhu wetland formed in this typical region during the past of 2500 year. In addition, alluvial fans in arid and semi-arid areas are probably influenced by seasonal rivers. During the wet season, a lot of streams flow into alluvial fans. However, during the dry season, rivers become dry and surface water seep into the underground of alluvial fans. Therefore, during the wet season flood has a great influence on pollen deposition. And the influence of flood should be carefully discussed in the studies on pollen assemblage in the peat layers[45,46]. During the periods of 1160−650 cal. a BP corresponding to MWP, the climate became humid and the timberline of *Picea* shifted downward in central Tianshan Mountains of Xinjiang[34]. So it was likely that *Picea* and *Betula* pollen were transported into Caotanhu wetland by flood, and as a result *Picea* percentages reached a peak value of about 17.6%.

In addition, the appearance of a large amount of Polypodiaceae spores in the section also indicated the possible influences of the flood of alluvial fan. High content and concentration of Polypodiaceae spores occurred in the peat layers, while those in the clay layer decreased greatly and even disappeared for some samples. There were two types of Polypodiaceae spores identified in the section of Caotanhu wetland: one was the Monoletes bean pollen with round strumae exine and the other was the one with slippy exine (Figure 4). Despite they play an important role in pollen assemblage, it is difficult to identify their types[47,48]. According to the first volume of *Xinjiang Flora*, there are two types of Polypodiaceae in the Tianshan Mountains: *Lepisorus albertii* and *Polypodium vulgare*. The former is suitable to grow in the stony crevice at the forest edge of middle and subalpine mountains at an elevation of 1500−2500

Figure 4 Two types of Polypodiaceae spores.

1) Wang F B. Environment and sediments record of Lop Nor Lake since 10000 years. In: The Preparation Group of 254th Xiangshan Symposium. Environment Changes in Lop Nor Region and Future Development in the Arid Land of West China (254th Xiangshan Symposium), 2005. 28−33

m, the latter is fond of the forest or the stony crevice at the forest edge at an elevation of 1700—2000 m[37]. But no Polypodiaceae was found in desert steppe. In general, according to the past researches on palynology, the flying capability of fern spores with wind is poorer. It can be transported mainly by the flowing stream. Based on Xu's twice pollen analyses of air pollen in the Yellow Sea, only one grain of *Pteris* spore was found[49]. After the discussion on the long-distance transporation of air pollen in the drainage area of Shiyang River Basin in northwest China, Zhu et al. thought that amounts of fern spores in air decreased and even disappeared with the increase of distance from the pollen source[50]. In addition, no Polypodiaceae was identified by Yang[32] from the above-mentioned 80 surface pollen samples on the northern slopes of central Tianshan Mountains. Secondly, a few polypodiaceae spores (only 2—3 grains) were accounted from above-mentioned 14 modern pollen samples at the headwater of the Urumqi River. Moreover, it was not also found in the above-mentioned 114 airborne pollen samples from 3 sets of airborne pollen in central Tianshan of Xinjiang[32]. But in section I of Caotanhu weland, its concentration was very high at depths above 66 cm since 2500 cal. a BP, as opposed to that below 66 cm. In particular, at depths of 66—42 cm it reached a peak value (50965 grains/g). Pollen data also showed that during that stage the climate was humid. Therefore, according to its growth elevation and thermophilic and hygrophilous habit, it is reasonable to conclude that it belongs to the foreign pollen transported from other regions. But their values are not identical with those of aquatic plants, mainly because the sediment environment is not completely closed and pollen of wetland sediment is the outcome of local flood for many years. Moreover, aquatic plants only reflect the local wetland environment, and cannot be used to reconstruct the regional vegetation in larger area. So it is necessary to refer other environment indices to discuss together. Furthermore, the environmental significance of Polypodiaceae in arid area is very special. It is often found in the mountainous area with high attitude and high humidity during the field investigation, whose habitat reflects a relative humid environment. Therefore, during the period of humid climate, amounts of Polypodiaceae spores carried into the phreatic overflow zones by flowing water might be far higher that those in dry season. Xu et al. showed that most of the fern spores, which appeared at the alluvial sediment in north china plain, were transported by river from mountainous area[45]. The Fengshan section at the Fangshan district in Beijing is situated at the edge belt of alluvial fan, where is also favorable for the deposition of zonal and regional pollen carried by flowing current[46]. Furthermore, as to this section, in order to discuss the source and the vegetation representation of abundant Polypodiaceae, it is necessary to acquire more evidences from other pollen data. Hence, surface pollen samples should be collected from different elevation of the alluvial fan. If a lot of Polypodiaceae spores appear in the way, it might be inferred that they are transported from high elevation by flowing water. Otherwise, it should be analyzed differently.

A/C ratio was first used by El-Moslimany[51] to be an indicator of climatic aridity in the arid area[12,52]. Sun[53] concluded that it could be used as an index to distinguish steppe and desert vegetation after the discussion of distributing law of *Artemisia* and Chenopodiaceae in semiarid and arid areas. In the typical arid area, A/C value is lower than 0.5, while that is higher than 1 in the grassland area. But in section I of Caotanhu wetland, from 4550 to 2500 cal. a BP A/C ratio was at the highest value (1.2), from 2500 to 1810 cal. a BP it reduced to 1.0, and from 1810 to 1160 cal. a BP it decreased again when compared with Zone II (0.2—0.6). Then it continued to reduce to 0.1 from 1160 to 650 cal. a BP. And since 650 cal. a BP it remained low. It seems that it cannot be used as the index to distinguish the steppe or desert vegetation and to indicate climatic aridity. Liu et al.1) proposed that the significance of A/C ratio as the indicator of environment might be weaken if the terminal lake flowing the whole altitudinal belts of vegetation[54]. It is obvious that the typical landform of alluvial fan also has a great influence on it. Therefore, an increase of A/C is not necessarily linked to climatic drying; on the other hand, an increase of Chenopodiaceae percentage caused by human disturbance on a local scale can lead to an increase of A/C[54]. Consequently, when human disturbance is involved in interpreting pollen data from sediment sequences, the A/C ratio should be used carefully.

1) Liu H Y. Spatial distribution pattern and the indicative significance to the desertification driving factors of surface pollen in semi-arid area in the central Inner Mongolia. In: The Branch of Palynological Societies of Chinese Society of Paleobiology, ed. The First Session of Seventh Annual Academic Symposium of the Branch of Palynological Societies of Chinese Society of Paleobiology, 2005. 61

Wang et al.[55] also thought that the A/C ratio can reflected the human disturbance to some extent. The Caotanhu section located in the phreatic zone of alluvial fan and the A/C value decreased gradually from above 99 cm, reflecting that it was disturbed by human to some extent. A/C value should be used as an environmental indicator within a certain range. Accordingly, it is necessary to combine with pollen results to reconstruct paleoclimate in semi-arid and arid areas.

3.3 Comparisons between section I and section II of Caotanhu wetland

Study results of pollen and phytolith in two sections of Caotanhu wetland showed that types and amounts of pollen and concentration of total pollen and aquatic plants were very higher in the peat layers than those in the clay layers. Moreover, *Phragmites* fan and other fan-shaped phytolith dominated in the peat layers, while point-shaped and elongate classes prevailed in the clay layers. Hence, all these results revealed that after peat formation in Caotanhu wetland, the climate became humid and wetland developed with abundant freshwater aquatic plants, while the climate was dry before it.

The depth of peat layer in section I was 66 cm, and the formation date of peat started from 2493±102 cal. a BP. The depth of peat layer in section II was 56 cm, and the time of peat formation was dated to since 2445±170 cal. a BP. Since the two dates of peat formation in two sections were quite similar, it is reasonable to estimate that the formation age of peat in this region was since 2500 cal. a BP. And it was likely that a climate shift from dry to wet occurred in this region during the period of 3—2 ka BP.

In the pollen assemblage, the relative contents and absolute concentrations of Polypodiaceae spores were very high in these two peat layers of two sections, while those decreased remarkably in these two non-peat layers. Moreover, higher *Betula* percentages occurred at the upper stratum of sections I and II at the same time. Could it reflect the local native vegetation or the influence by flowing water and airborne transportation? In arid area, the natural phenomena of strong wind and temporal flood are very common[50]. Since Caotanhu wetland is located at the spring water spill belt at the edge of alluvial fan, undoubtedly, it can influence the pollen transportations and depositions. Accordingly, these basic pollen issues should be clarified in the future.

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