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Vegetation Changes and Environmental Evolution in the Urumqi River Head, Central Tianshan Mountains Since 3.6 ka BP: a Case Study of Daxigou Profile

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Abstract: A relatively high resolution pollen record and data of loss of ignition (LOI), grain size and susceptibility of the Daxigou profile in the head area of the Urumqi River, central Tianshan Mountains, revealed new information about vegetation changes and environmental evolution since 3.6 ka BP. Results showed that from 3.6 ka BP to present, climate was unstable with multi-changes of warming-cooling and wetting-drying. From ca. 3.6 to 3.2 ka BP, climate was warmer and more humid than today. Climate changed to cooler and drier between ca. 3.2 and 2.0 ka BP, coinciding with a glacier advance in the head area of the Urumqi River. From ca. 2.0 to 1.4 ka BP, climate became warmer and more humid again. From ca. 1.4 to 0.5 ka BP temperature and humidity went on increasing and a period of Climatic Optimum since 3.6 ka BP might occur. A few limnetic hydrophytes pollen are counted for all zones, indicating a freshwater habitat since 3.6 ka BP in this region. Based on synthetically analysis of ecological characteristics and dispersal of spruce pollen, the abundance of *Picea* is influenced by treeline moving upward, valley wind and glacier ablation. Statistics of charcoal concentration and susceptibility further suggest that fires may have occurred in this region since 0.5 ka BP and the peak value of charcoal might be related to human activities.

Key words: Tianshan Mountains; vegetation changes; climatic change; pollen record; charcoal; multiproxy data

Reconstruction of past environment and vegetation is an important task for studying past global and regional changes in climate, environment and vegetation. Pollen data often provide detailed information concerning regional vegetation and climate as well as their dynamics and changes. Studies of fossil pollen can be palaeoecologically informative and are used worldwide to reconstruct Holocene environments (Elenga *et al.*, 2000; Muller *et al.*, 2003). Recently, researchers emphasized the importance of higher time resolution of pollen data (Popescu, 2001; Pokomy, 2002). Results showed that multiproxy records including pollen data are very important to research of environmental evolution (Mann, 2002; Schmidt *et al.*, 2002).

The semi-arid and arid areas are sensitive belts of global change in the world, and the palaeoclimatic importance of pollen research has been long recognized in such regions (Newsome, 1990; Zhang *et al.*, 2000). For example, vegetation types in two regions of semi-arid southwestern Australia were studied using pollen traps (Newsome, 1990). Pollen data from sediment stratums in the arid northwestern China recorded abundant palaeoclimatic information. Periglacial and mountain tundra in the head area of the Urumqi River in the central Tianshan Mountains have a profound effect on historical and modern environments, hence it is complicated to study palaeoenvironment and vegetation changes by pollen data from surface soils, air, stratum and archaeological sites. However, many Quaternary pollen works in this region since the 1980's provided us with more information to accelerate such kind of research (Zhou *et al.*, 1981; Yan and Ye, 1983; Pan, 1985; Yan and Xu, 1989, 1995; Yan, 1991; Yan *et al.*, 1991; Xu and Yan, 1996). But it is still lack of studies based on periglacial geomorphy, glacier change, and vegetation and environmental evolution in the Holocene through pollen records, especially the pollen data in high temporal resolution. Furthermore, study on the relationship between vegetation change and human activity is still needed in this region.

Spruce (*Picea* spp.) is one of the most widespread tree

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species, and it is an important component of boreal conifer forests in the study area. Several studies have indicated that the shift of spruce is influenced by climatic change and human activity (Markgraf, 1970; Tsukada, 1983; Kullmann, 1986). On the other hand, local-scale pollen diagrams often give the most detailed information concerning local vegetation history and human interference on vegetation. Interpretations of anthropogenic activity in pollen diagrams have often been revealed by arboreal (AP)/non-arboreal (NAP) relations and also by the occurrence of charcoal (Hjelle, 1997). Recently, change of charcoal content in pollen diagram has significance in research of natural fire and human activity (Swain, 1973; Singh, 1981; Clark, 1988; Chen, 1990; Figueiral and Mosbrugger, 2000; Sun *et al.*, 2000).

In this study, we choose the Daxigou profile in the Urumqi River Head area of central Tianshan Mountains, Xinjiang Autonomous Region, as the target area. The aim is to discuss the dynamic changes of vegetation and environmental evolution since 3.6 ka BP using pollen records and some auxiliary environmental indices such as loss of ignition (LOI), grain size and susceptibility. Relationship of the charcoal content with environmental change and human activity is also discussed in this study.

1 Data and Methods

1.1 The study area

The source region of the Urumqi River is located on the north slope of Tianger Peak (43°04′–43°08′ N, 86°48′–87°00′ E) in the central Tianshan Mountains (Fig.1). The Urumqi River originates at an elevation of 4 486 m on Tianger II peak, the highest point in the eastern Tianshan Mountains, and flows northward to the city of Urumqi, the capital of Xinjiang Uygur Autonomous Region, China. The altitudes of main ridges are 4.1–4.3 km, the modern snowline at 4.0–4.1 km, the bottom of glacier tongue 3 650–3 700 mm, and the lower limit of permafrost 3.2–3.3 km, respectively (Zhu and Cui, 1992) and the upper limit of treeline is 2.6–2.8 km (Editorial Committee of Xinjiang Forest, 1989). This mountain is mainly composed of Paleozoic granites and metamorphic rocks. With regard to geotectonic unit it is the Tianshan folding belt belongs to the middle part of the Tianshan geosyncline folding system. Incised river valleys developed greatly for the geotectonic movement. The present climate is continental mountainous climate with obvious vertical zonality. It is very dry at the lower altitudes, but climate becomes cold and humid upwards. The temperature reduces quickly with increasing altitude. The Daxigou weather station is located at an elevation of 3 588 m. The mean annual air temperature is −5.4 °C, with mean temperature in January of −15.9 °C and in July of 4.7 °C. Mean annual precipitation is 430.2 mm. But at the elevation of 4.0–4.5 km mean annual temperature is −8 to 12 °C (Zhu and Cui, 1992). Snow and ice exist at above 3.8 km. The natural vegetation changes with increasing altitudes. Alpine meadow and subalpine meadow dominate between

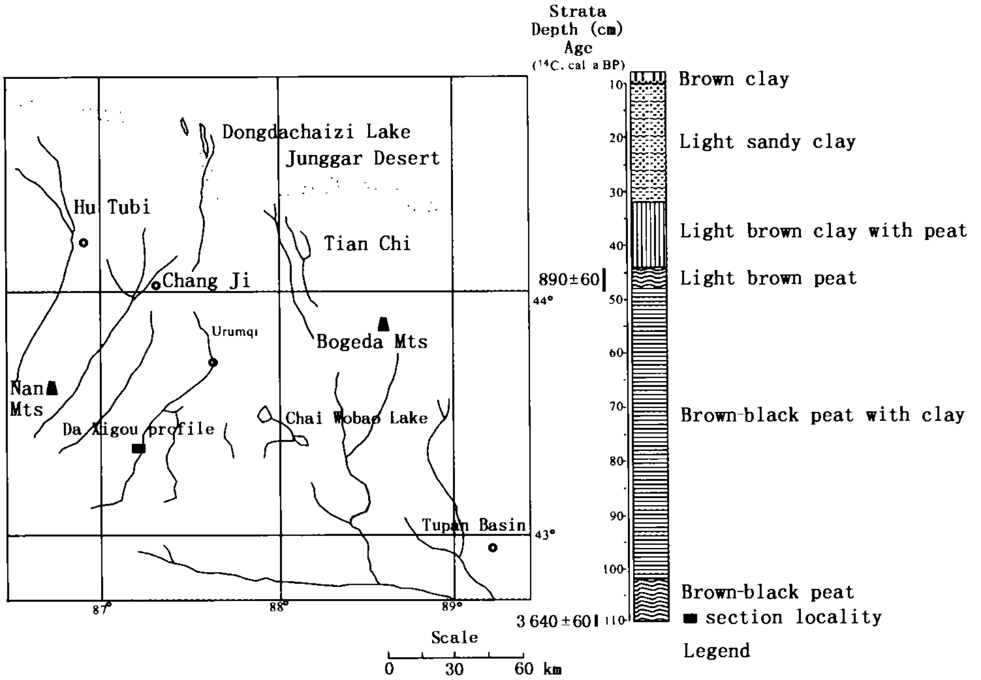

Fig.1. Location and stratigraphy of the Daxigou profile.

2.8 and 3.8 km in elevations. Between 1.6 km and 2.8 km there are forests, and steppe and desert are in lowland below 1.6 km (Yan, 2002).

1.2 The Daxigou profile

The Daxigou section (43°07′ N, 86°51′ E), a manual excavated profile in July 2001 with 110 cm thick, is situated in the head area of the Urumqi River, central Tianshan Mountains at an elevation of 3 450 m (Fig.1). Main vegetation in this area is alpine meadow. The profile is composed of clay and barren peat (it is also called turf) with continuous deposition and better stratification.

Two samples at the depth of 44−48 cm and 108−110 cm were collected for ^{14}C dating (^{14}C dating was analyzed by the ^{14}C Laboratory of Institute of Geology, China Seismological Bureau, but it was not calibrated by tree rings). They are (890 ± 60) a BP and (3 640 ± 60) a BP, respectively. Age calculations are based on a ^{14}C half-life of 5 568 a. The age of top section of the profile is set to 0 a BP, because the characteristics of pollen assemblage at top section and in surface soil are similar and then the top section is considered to be not denuded. Ages of the remaining samples were interpolated by assuming that the sediment rate is constant between the two dated samples. Then the chronology was established on the basis of these two dating. A total of 52 samples, at a interval of 2 cm each (time resolution is about 38−88 a) were obtained for pollen analysis. At least 300 pollen and spore grains of terrestrial plants (the maximum is 1 284) in each sample were counted, except the deep sample at 102−74 cm with poor pollen (but > 150 grains). At the same time charcoal was analyzed by its size. Pollen diagram was drawn using the TILIA and TILIAGRAPH. Pollen percentage for tree, shrubs, and herbs were calculated upon a pollen sum including aquatic pollen and spores. Mass concentration (grains per gram) was calculated by the method of direct concentration. No *Lycopodium* spore was added.

Proxy environmental indices, such as grain size (determined by Mastersizer 2 000 laser particle distribution analyzer), loss on ignition and susceptibility (determined by MS2 susceptibility analyzer) were also measured for the same samples as pollen identification (by the State Key Laboratory of Western China's Environmental System, Lanzhou University).

2 Results

Thirty-nine genera and families were identified in 52 samples. Among them, main arboreal pollen was *Picea schrenkiana*, together with a fewer pollen of *Pinus*, Cupressaceae, *Larix*, *Betula* and *Salix*. Main meso-xerophytic shrub and herb pollen was *Artemisia*, Chenopodiaceae, *Ephedra*, Leguminosae, Rosaceae, *Nitraria* and *Tamarix*. Main meso-hydrophytes herb pollen was *Thalictrum*, *Polygonum*, Gramineae, *Plantago*, Caryophyllaceae, Umbelliferae, Cyperaceae and Cruciferae. Mesic and aquatic vascular pollen types were *Potamogeton*, *Sparganium* and *Typha*. Freshwater phycophyta spore included *Spirogyra*, *Zygnema*, *Chlamydomonas* and *Diatom*. Fern spore types were Polypodiaceae and *Batrychium*. Lichen and moss spore included *Athalamia*, *Asterella* and *Sphagnum*.

Based on variations in pollen concentration and main pollen percentage, pollen diagram was divided into five zones (Fig.2). *Artemisia* / Chenopodiaceae (A/C) ratio was usually used to indicate the humidity or aridity condition in arid area (Ann, 1990; Huang, 1993). Here *Artemisia* / *Ephedra* (A/E) ratio was also introduced to research of environmental and vegetation change. The high A/E ratio reflects the more humid.

Zone I ca. 3.6−3.2 ka BP (110−102 cm). The sediment consists of brown-black peat with high pollen concentration. The pollen assemblage is dominated by *Picea schrenkiana* and *Artemisia*. Pollen percentage and concentration of *Picea* are high (37% at the depth of 108 cm). A/C and A/E ratios are significantly high.

Zone II ca. 3.2−2.0 ka BP (102−74 cm). Sediment is brown-black peat with clay. More than 150 pollen grains were counted, which is the minimum of the whole profile. The pollen assemblage is still dominated by *P. schrenkiana* (25%−35%), *Artemisia* and *Ephedra*. This zone did not have freshwater *Chlamydomonas* and *Diatom*.

Zone III ca. 2.0−1.4 ka BP (74−60 cm). Sediment composition is the same as zone II, but pollen concentration is higher than Zone II though pollen percentage decreased relatively. The pollen assemble is characterized by *Ephedra* and *Artemisia*. The A/C and A/E ratios are very high.

Zone IV ca. 1.4−0.5 ka BP (60−32 cm). The lowest lithology consists of brown-black peat with clay, the middle is light brown peat, but the upper is light brown clay with peat. Pollen concentration went on increasing and reached a maximum value. Pollen assemblage is dominated by shrub and herb pollen (60%), but *Picea* percentage rose up to 15%, whereas a few exceeded 20%. At the same time *Ephedra* percentage decreased. Concentration of aquatic pollen is the highest and A/C and A/E ratios are slightly high.

Zone V ca. 0.5−0 ka BP (32−0 cm). The lowest sediment is light sandy clay, but the upper is brown clay. Pollen concentration decreased, but average concentration is still high. *Picea* percentage decreased gradually, but it is not

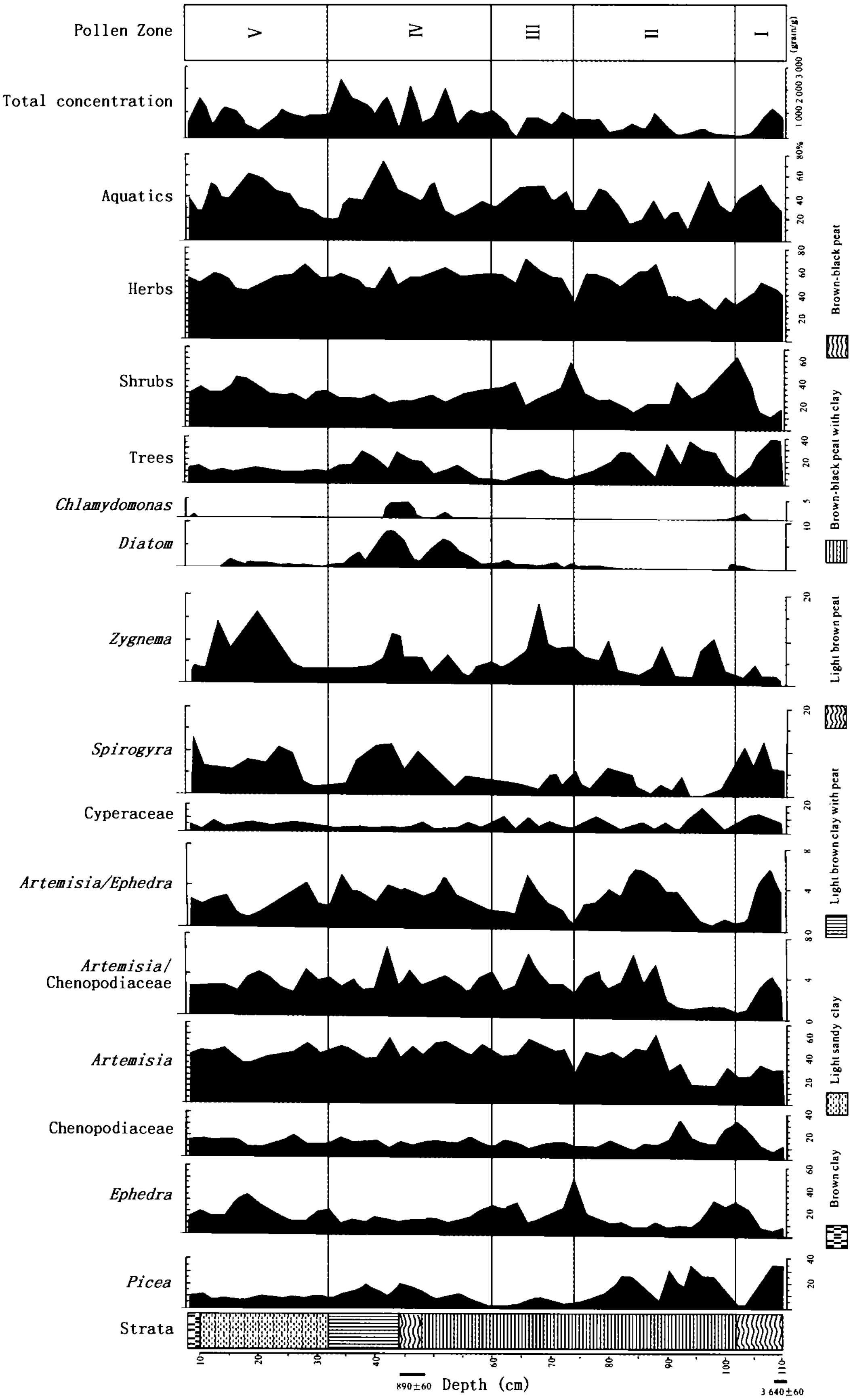

Fig.2. Pollen diagram of the Daxigou profile.

less than 10%, while *Ephedra* increased. *Ephedra* and *Artemisia* are two important components of this zone. A/C and A/E ratios decreased gradually and aquatic vegetation decreased, too.

Accordingly, pollen percentage curve of *Picea* contents changed from peak value at the bottom of Zone Ⅰ, to low value in Zone Ⅰ, peak value in Zone Ⅱ, low value in Zone Ⅱ and Ⅲ, and peak value in Zone Ⅳ and decreased in Zone Ⅴ (Fig.2). By contrast, *Ephedra* and Chenopodiaceae had the opposite trends with the change of *Picea*, while aquatic vegetations and A/C and A/E ratios are the same as *Picea*.

A few hygrophytes and aquatic pollen were counted from bottom to top of the profile. Among these plants, contents of Cyperaceae, *Spirogyra*, *Zygnema*, *Diatom* and *Chlamydomonas* are very high. It is remarkable that the minimum value of total pollen concentration of the Daxigou profile occurs in Zone Ⅱ, whereas the peak of *Picea* occurs in Zones Ⅰ and Ⅳ.

3 Discussion

3.1 Palaeoclimate and palaeoenvironment reconstruction since 3.6 ka BP

From ca. 3.6 to 3.2 ka BP, slightly higher percentage and concentration of *Picea* indicated that its biomass was high at that time. High A/C and A/E ratios, low percentage of *Artemisia* and high pollen concentration of aquatic plants (Fig.3) reflected that climate was warmer and more humid than present and *Picea* treeline shifted upwards. In addition, Fig.3 shows that average granularity and LOI value are slightly high. This might indicate that climate was more humid and vegetation coverage was high, but coarser particle could be easily transported because of high precipitation and runoff.

From ca. 3.2 to 2.0 ka BP, relatively higher *Picea* percentage but lower pollen concentration (Fig.3) could not suggest that *Picea* forest appeared there or treeline moved upwards. Low LOI value, A/C and A/E ratios and aquatic vegetation reflected that at that time vegetation coverage was low and the climate became relative drier and cooler than before.

From ca. 2.0 to 1.4 ka BP, *Picea* percentage and pollen concentration were very low, whereas total concentration and aquatic pollen began to increase (Fig.3), indicating that climate became warmer and more humid and vegetation coverage increased.

From ca. 1.4 to 0.5 ka BP (550−1 350 a AD), *Picea* percentage and concentration rose rapidly. It is also worth notice that LOI value reached a maximum and average granularity increased (Fig.3), which indicated that coarser particle could be easily transported due to high precipitation and much melt water from glacier and snow. In particular the obvious peak of concentrations of total pollen and arboreal, shrub, aquatic and herb pollen in this zone could represent the Climatic Optimum stage in the Daxigou section during 1.4−0.5 ka BP. At that time *Picea* forest-line moved upwards again. Susceptibility decreased greatly from Zone Ⅳ because oxidized ferromagnetic particles were changed into hydrate by stronger soil gleization in the long-term reductive condition (Sun *et al.*, 1995).

From ca. 0.5 ka BP to the present, the percentage and concentration of *Picea* decreased obviously (Fig.3). This implied that vegetation coverage was still high and the climate was warmer and more humid than present but less than Zone Ⅳ, because concentration of total pollen, *Artemisia*, Chenopodiaceae, and *Ephedra* were high.

3.2 *Picea*'s indicative significance of environments

Another profile of a thaw channel was obtained with low time resolution at the elevation of 3.5 km in the same study area several years ago (provided by Liu Gennian in Peking University). Two dating data were measured at the depth of 110 cm ((2 015 ± 80) a BP) and 134 cm ((3 640 ± 70) a BP), respectively. Pollen identification (by Kong Zhaochen and Du Naiqiu in Institute of Botany, The Chinese Academy of Sciences) and pollen diagram (Fig.4) showed that *Picea* content also varied obviously through this profile with three remarkable peaks of *Picea* since 3.6 ka BP. It is not incidental that there is the same fluctuation of *Picea* curve at the same period for those two similar profiles. To give a rational explanation it is essential to synthetically analyze the ecological characteristics and pollen transport of genus *Picea*.

3.2.1 Transport of *Picea* pollen in North Xinjiang Experimental studies on *Picea* pollen rain showed that the transport capacity of *Picea* pollen is lower than *Pinus* (Janssen, 1966; Li, 1991). However, *Picea* amount changes obviously when it is influenced by strong updraft and valley wind. For example, the Chaiwopu Basin of North Xinjiang is the windy belt and wind speed is up to 5 m/s. Around the period of *Picea* florescence from April to June it is the season with the highest wind speed in a year. Contents of *Picea* pollen in surface soils of this basin increase generally during this season, but *Picea* pollen in desert soil away from the spruce forest reduces to 2%−5%. In the alpine meadow above the *Picea* forest belt of the Nanshan Mountain, however, *Picea* pollen content of the surface soil is still 7.1% although here the altitude is 0.5−0.8 km higher than the upper limit of *Picea* forest. In the alpine

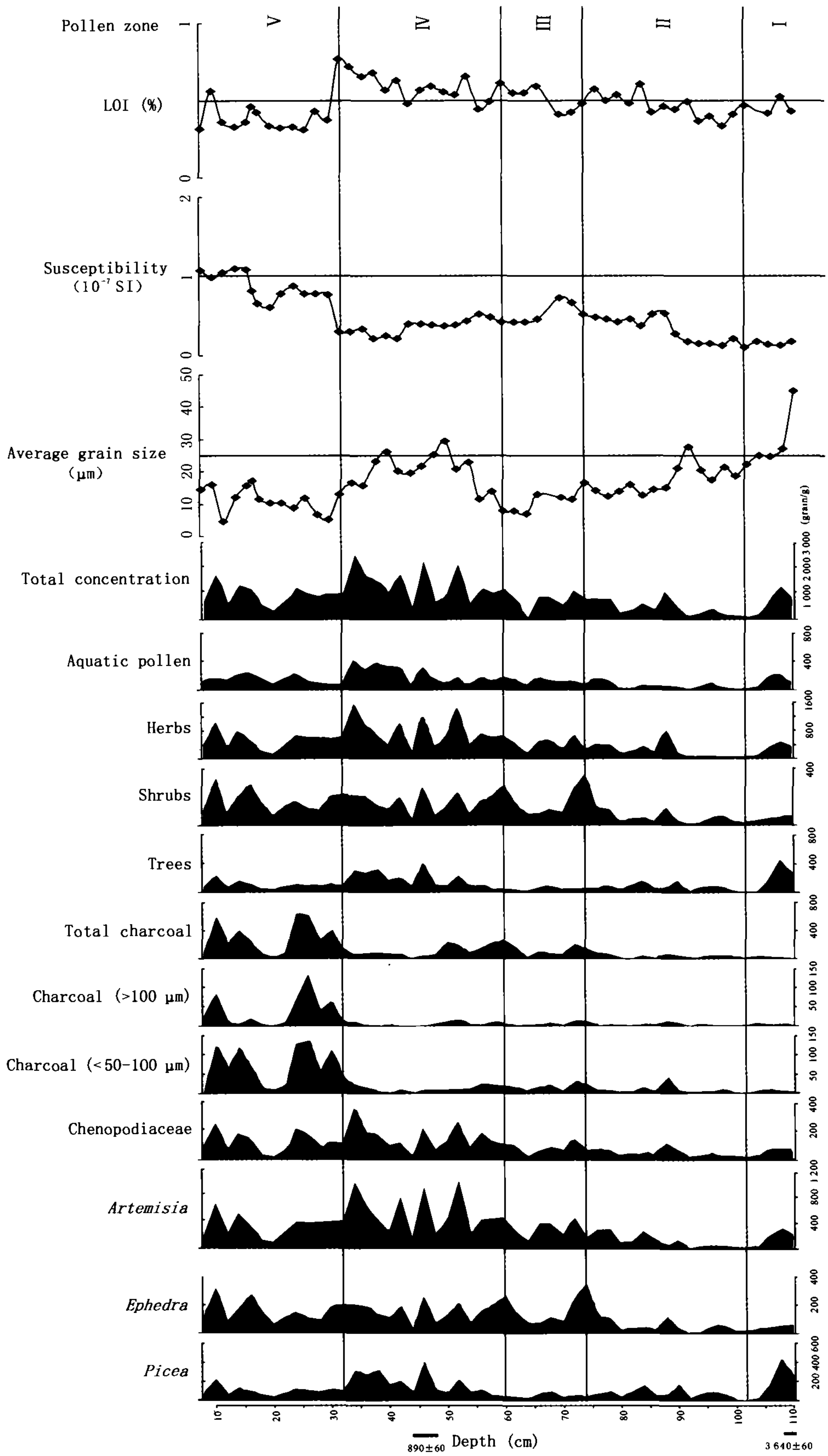

Fig.3. Pollen concentration (grain/g), grain size, susceptibility and loss of iqnition (LOI) of the Daxigou profile.

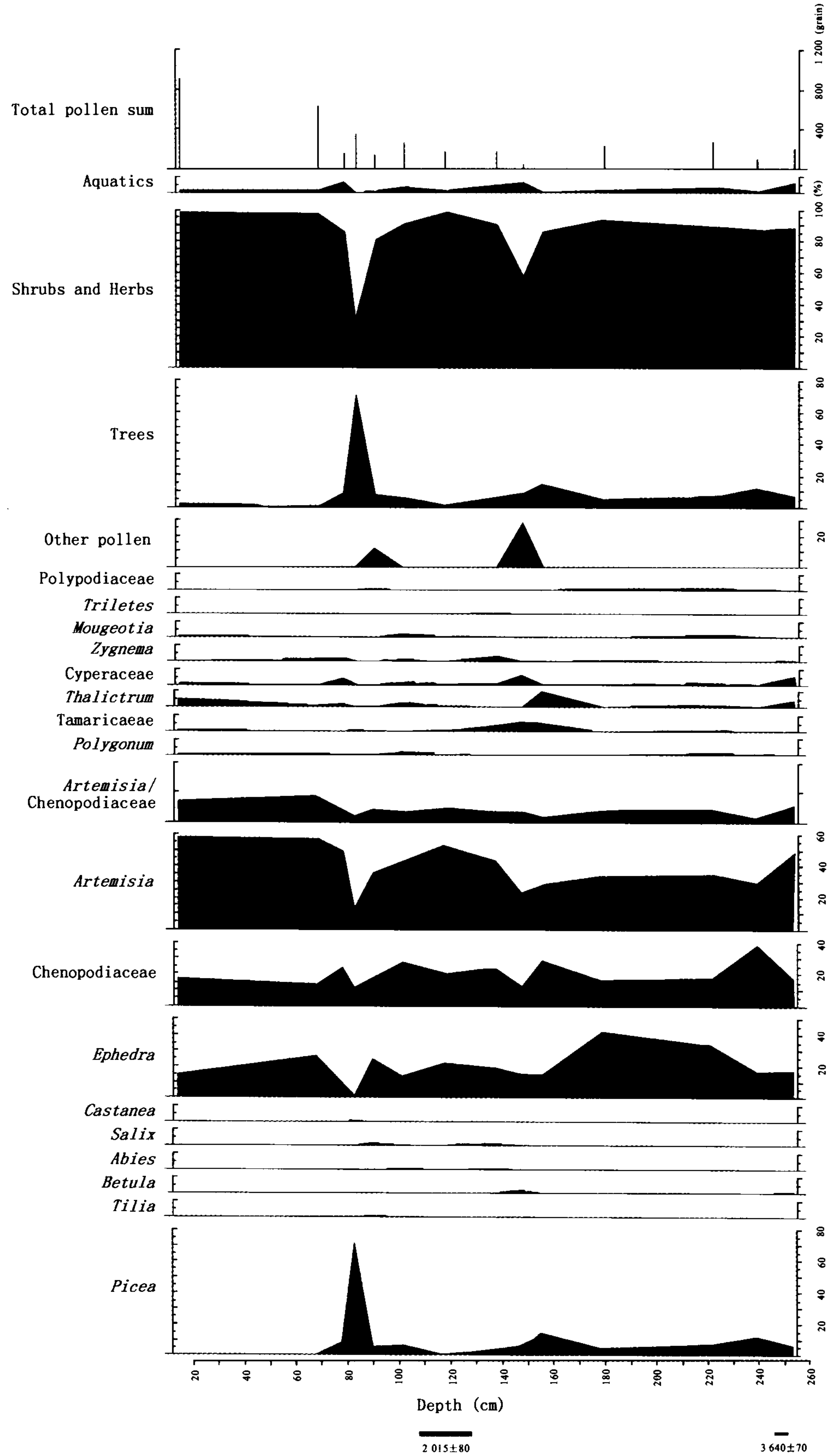

Fig.4. Pollen percentage diagram of a thaw channel profile at the Daxigou weather station in the Head Area of the Urumqi River, central Tianshan Mountains.

meadow pollen is obviously transported by updraft, which is much more than those in desert transported by downdraft. Such phenomenon that updraft moves a great deal of pollen exists in common in the mountainous areas of West China (Li, 1988). Hence it is an universal phenomenon of pollen transport. Statistics of *Picea* pollen contents in surface soils from the Tianshan Mountains, Altay Mountains, Kunlun Mountains, Tarim Basin and Junggar Basin also showed that those samples that *Picea* contents exceed 30% were collected at 1.3–2.8 km, and those samples that *Picea* contents exceed 20% were collected at 1.3–3.3 km. The former altitude range is basically the same as the distribution range of *Picea* forest, but the latter obviously exceeds its upper limit. Therefore, *Picea* pollen in surface soils at 0.5 km above upper limit of forest is more than 20%, which is likely to be influenced by valley wind (Yan *et al.*, submitted).

In addition, other 28 surface pollen samples (Fig.5) collected from the same study area but with altitudes (3 880 m) down to the Chaiwopu Basin (1.1 km) indicated that, in the alpine rocky vegetation belt (3 880 m) spruce pollen occupied 9.6% of total pollen content and 15.9% in the alpine meadow (3.5 km), but it was only 2.2% in Chaiwopu (1.1 km) under the lower limit of spruce forest (Fig.5). This might be due to that valley wind at the Daxigou area exists all the year and the wind speed here is 1 m/s higher than the vicinal hillside (Editorial Committee of Land Resource in Xinjiang, 1993).

3.2.2 Treeline movement of Picea forest and its response to climatic change Fossil pollen analysis also indicated that cold temperate forests consisting of *Abies* and *Picea* were distributed widely in mountains and plains in mainland of southwestern, northwestern, northern and eastern China and Taiwan during the Quaternary Glacial Stage (Xu *et al.*, 1980; Chen, 1988; Fang, 1996; Editorial Committee of Forests in China, 1997), which suggested that coniferous forest of cold temperate zone had larger distribution area than today. Vegetation zone has horizontal and vertical shifts along with the frontier and retreat of the glacier. Generally speaking, snowline and treeline shifted down when glacier expanded, while cold temperate coniferous forest retreated gradually along with the mountain glacier melting in the interglacial periods when temperature increased.

For this profile, from ca. 3.6 to 3.2 ka BP, high pollen concentration and percentage of *Picea* might suggest that at that time the climate was warmer and more humid than today. *Picea* forest zone expanded and treeline moved upwards. A great deal of *Picea* pollen was transported from the forest area to the place of profile. The stage looked like a "small interglacial stage". From ca. 3.2 to 2.0 ka BP, *Picea* percentage was still very high, but pollen concentration, LOI and susceptibility were low, indicating a drier and colder "ice age" climate. Furthermore, pollen percentages of samples from the fourth to eleventh excluding the eighth at Zone II were very low. In contrast, a previous study indicated that there was high pollen content of *Picea* in

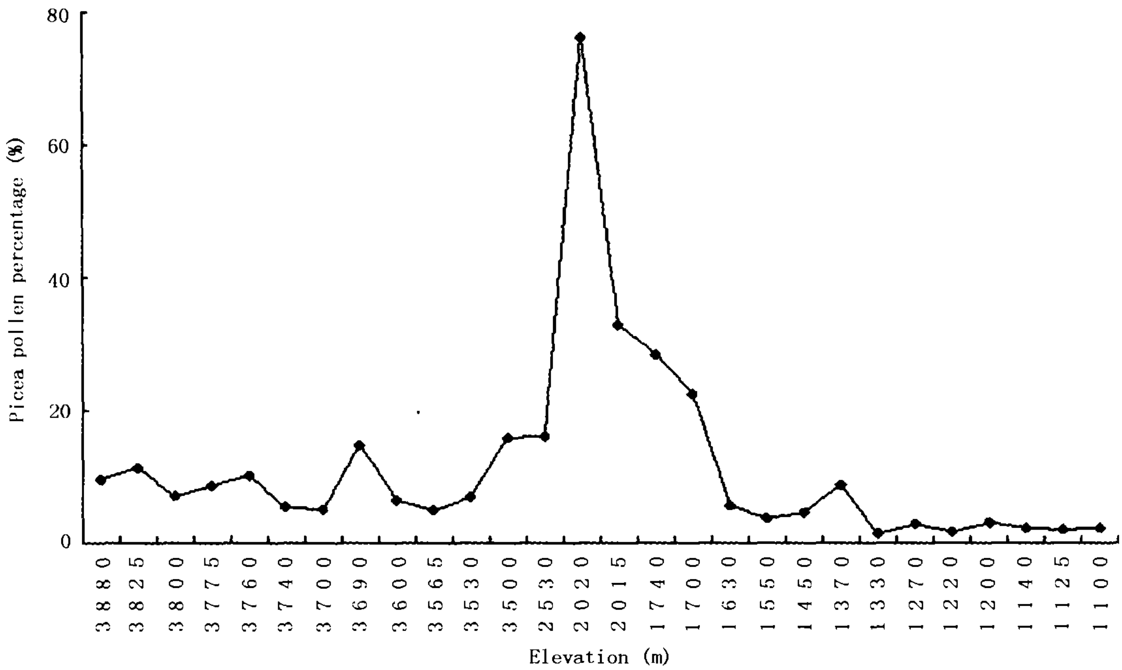

Fig.5. Relationship between spruce pollen percentage and elevation in the northern slope of the Tianshan Mountains.

surface soils of the First Glacier in the source area of the Urumqi River (Zhou *et al.*, 1981), which might be due to the transportation of valley updraft wind. On the other hand, when identifying pollen samples of Zone Ⅱ, we found that pollen grains in this zone were not only small but also fragmentized mostly. It is possible that after they were blown into the glacier by valley updraft *Picea* pollen grains were crashed by the friction of glacier. Then they deposited to the lowland by glacial melt water. A glacier frontier in the head area of the Urumqi River occurred in 2.8 ka BP (lichen dating) since the New Ice Age and the moraine ridge of Shanbei group Ⅲ formed. This "S" type of moraine ridge is located 250−300 m east away from the Second Glacier in the head area of the Urumqi River and is mainly composed of eyeball gneiss, schist, granitic diorite and dolerite (Chen, 1988). So there is an obvious relationship between *Picea* content and the advance and retreat of glacier. The Zone Ⅳ also suggested that from ca. 550 to 1 350 a AD not only the percentage and concentration of *Picea* pollen increased again, but also the pollen concentration of shrubs, herbs and aquatics increased. At the same time there were high LOI and grain size and low susceptibility, which reflected that climate became warmer and more humid again, as coincided with Zhao *et al.* (1983).

Besides the influence of valley wind and glacier movement, *Picea* percentage could reflect the historical treeline changes. Treeline is more sensitive to climate change, which has become one of the hotspots of global change study (Liu, 2002). At present the lower limit of *Picea* distribution is 1.7 km and the upper limit is 2.7 km, with a maximum of 1.0 km *Picea* forest belt. The snowline is at 4.2−4.5 km. The altitude difference between the upper limit of forest and the snowline is 1.5−1.8 km (Editorial Committee of Xinjiang Forest, 1989). Altitude of the treeline depends mainly on temperature, but the altitude of snowline relies mainly on precipitation. Studies suggested that averaged air temperature of the warmest month is the most important thermal control of the development of zonal dark coniferous forests (Li and Zhou, 1979; Wu, 1983; Liu *et al.*, 2002). The mean temperature of the warmest month at the upper limit of this forest is generally about 10−14 °C. Pollen analysis of the Daxigou profile also indicated that the upper limit of spruce forest is mainly controlled by temperature because precipitation is enough to the survival of spruce trees. The impact of moisture condition on the distribution of dark coniferous forests is also presented to some extent by the impact of moisture condition on thermal condition.

Based on long-term (1950−2000) meteorological records of Daxigou (3 539 m), Xiaoquzi (2 160 m), Tianchi (1 938 m), Jimsar (735 m) and Fukang (547 m) weather stations and using a linear regression, the mean annual temperature and mean annual precipitation along elevations were roughly interpolated (Fig.6). The mean annual temperature at the upper limit of spruce forest is −1.4 °C and the mean annual precipitation is 490 mm. At the lower limit of spruce forest

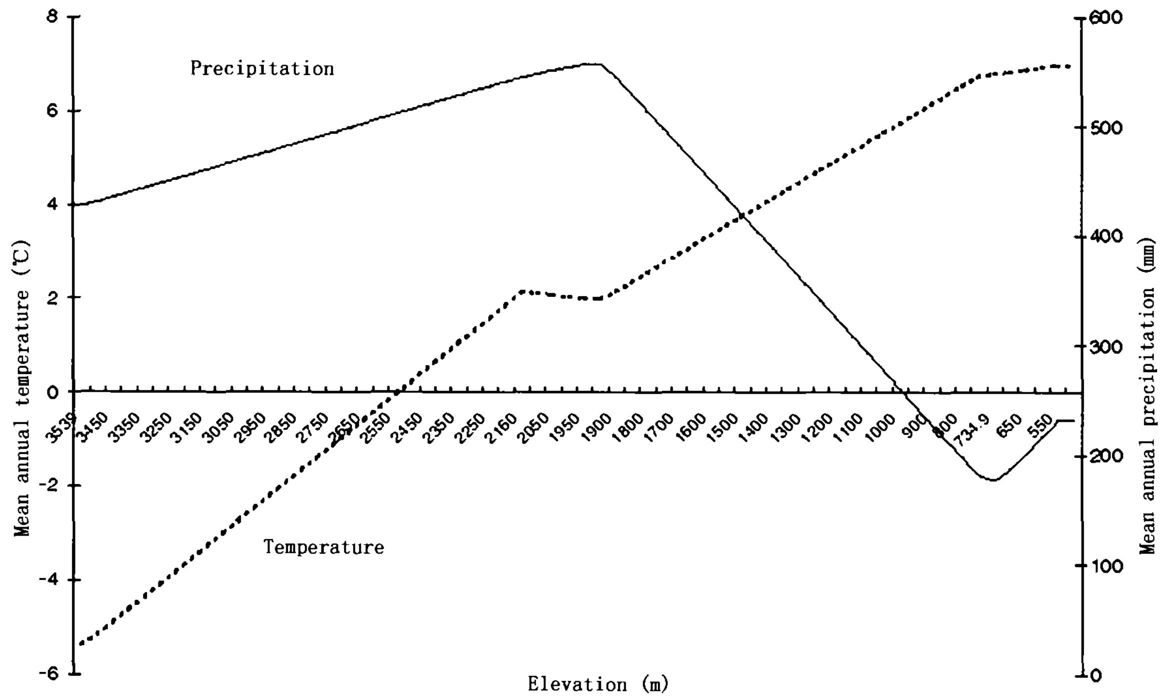

Fig.6. Changes of mean annual temperature and mean annual precipitation along with the increasing elevation in Tianshan Mountains.

the temperature and precipitation are 3.3 °C and 450 mm, respectively (Fig.6). According to pollen analysis at ca. 3.6–3.3 ka BP, spruce pollen occupied 40% of total pollen (excluding aquatic pollen), indicating that the upper limit of spruce forest moved upward by ca. 0.6 km. Then, the mean annual temperature at that time is ca. 3 °C and annual precipitation is ca. 50 mm higher than today.

In a nutshell, we could conclude that the *Picea* abundance might be related to climatic change, valley wind, the advance and retreat of glacier and treeline moving upward. However to further understand which factor is the most important, more pollen and multi-proxy data are needed in future study.

3.3 Charcoal distribution, vegetation change and human activity

Fire is one of the major disturbances in forest and grassland ecosystems. Charcoal, often called "fossil of fire", is the product by plants after incomplete burning. Small size of charcoals can be transported by air and water from the origin place to deposit site, but airflow only transports about 2% of total charcoals and water can transport most of charcoals. However, large charcoals bigger than 100 μm cannot be transported easily and they deposit mostly in their origin site. Therefore, the number of charcoal particles and their existing section in deposits can be taken as indicators of regional fire occurrence and frequency (Swain, 1973; Singh *et al*., 1981; Patterson *et al*., 1987; Clark, 1988; Chen, 1990; Sander and Gee, 1990; MacDonald *et al*., 1991; Huang *et al*., 1996; Zhang *et al*., 1997; Sun *et al*., 2000).

Figure 3 shows that a small peak of charcoal content existed at depth of ca. 28 cm and the charcoal particles at different sizes ≥100 μm, 50–100 μm and ≤50 μm had the same peaks at the same time. We could not distinguish whether they were woody charcoal or herb charcoal and whether the fire was natural or man-made, but very low pollen contents of *Picea, Ephedra*, Cyperaceae, *Spirogyra* and *Zygnema* and a small peak value (26%) of *Picea* pollen before charcoal peak (Figs.2, 3), indicated that at that time climate was relatively dry and forest fire might occur frequently. The peak *Picea* pollen before charcoal peak also showed that *Picea* forest grew well at that time and forest biomass, shrubs and herbs as well as litters increased that contributed to more occurrences and higher frequency of fires. Therefore charcoal content was abruptly increased.

It is worth mentioning that many peak values of charcoal occurred in Zone Ⅴ. Compared it with susceptibility curve, it can be found that abundance of charcoal particles corresponded very well with high value of susceptibility. Generally, more magnetic oxides lead to combustion within the soil; accordingly the susceptibility increases (Thompson and Oldfield, 1995). Therefore to some extent high charcoal numbers can be correlated with fire. Additionally, biomass should be high if natural fire occurred. But Fig.3 shows that LOI is very lower, indicating biomass was not high. So the likelihood of natural fire can be eliminated. It might be related to the increase of use of fire by increased human activity in recent hundred years, but dry climate increased the possibility of occurrence of fire.

4 Conclusions

Based on pollen concentration, pollen percentage and the analysis of average granularity, susceptibility and LOI, we concluded that the climatic conditions since 3.6 ka BP can be divided into five stages: there was a warm-humid period between ca. 3.6 to 3.3 ka BP, with temperature was higher than today. Then climate deteriorated between ca. 3.2 to 2.0 ka BP. From ca. 2.0 to 1.4 ka BP climate became warmer and more humid again, and the period of Climatic Optimum since 3.6 ka BP prevailed between ca. 1.4 and 0.5 ka BP (550–1 350 a AD). Since ca. 0.5 ka BP, climate became drier.

Based on the synthetically analysis of ecological and transport characteristics, *Picea* pollen abundance is related to valley wind, treeline moving upward and glacier retreating, which reflects the correlation between vegetation dynamic change and environment evolution.

Many peaks of total number of charcoal particles were recorded in Zone Ⅴ. Furthermore, abundance of charcoal concentration corresponded very well with high susceptibility by contrasting it with susceptibility and LOI curve. Since 0.5 ka BP increased human population and human activities as well as dry climate caused the possibility of fires.

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天山乌鲁木齐河源区3.6 ka BP以来的植被变化和环境变迁：以大西沟剖面为例

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摘要： 天山乌鲁木齐河源区大西沟剖面孢粉鉴定结果表明：在3.6~3.2 ka BP,该区气候较今温暖湿润；在3.2~2.0 ka BP,气候变为寒冷干燥，这一时期乌鲁木齐河源地区曾出现一次冰进；在2.0~1.4 ka BP,气候又转为暖湿；在1.4~0.5 ka BP,出现了3.6 ka BP以来气候最适宜的时期。整个剖面自下而上都有一定量的淡水水生植物出现，这反映了该剖面3 ka BP以来一直处于淡水沼泽的环境中。通过对云杉属生态习性、传播特性等综合分析，认为剖面中的云杉丰值可能与林线上移、山谷风搬运以及冰川退缩等有一定的相关性。通过对孢粉样品中炭屑浓度统计以及磁化率测试结果的综合研究，提出在0.5 ka BP左右，该地区可能出现过多次火灾；炭屑的峰值可能与人类活动有关。

关键词： 天山；植被变化；气候变化；孢粉记录；炭屑；多代用数据

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