Chinese Science Bulletin 2006 Vol. 51 No. 14 1747—1756

DOI: 10.1007/s11434-006-2029-9

Fluctuation of *Picea* timberline and paleo-environment on the northern slope of Tianshan Mountains during the late Holocene

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Received January 10, 2006; accepted February 20, 2006

Abstract As a good indicator of Holocene climate, the fluctuation of alpine timberline is a synthetical result of impacts of many environmental factors during geological and historical periods and modern times. As the dominant tree species of mountainous conifer forests on the northern slope of Tianshan Mountains in Xinjiang, the distribution of *Picea schrenkiana* and its population size are sensitive to climatic change. The typical natural profile of Huashuwozi and the nearby Xiaoxigou archaeological profile, located in Quanzijie Township, Jimusaer County in Xinjiang, were chosen to analyze and compare the relative high-resolution pollen records, and to measure ^{14}C dating and SEM (scanning electron microscope) microstructure for charcoal fragments contained in Xiaoxigou profile's cultural layers. The results show that in these two profiles, the high percentages of *Picea* (more than 20% and 35%, respectively) appeared in the stratum of the same period (2000—1300 a BP), which corresponds to the charcoal fragment's age of *Picea schrenkiana* contained in Xiaoxigou cultural layers. These results convincingly revealed that during the period of 2000—1300 a BP, the timberline for *Picea schrenkiana* on the northern slope of Tianshan Mountains in Xinjiang declined by about 330m compared with the present.

Keywords: northern slope of Tianshan Mountains, *Picea*, timberline, Holocene.

The fluctuation of alpine timberline, which can serve as a good indicator for Holocene climate, is the synthetically effective results of many environmental factors during geological and historical periods and modern times. In recent years, researches on alpine timberline and treeline have attracted considerable attention in America and Europe[1−4], whereas studies in China mainly focused on Tibet Plateau, Mt. Xiao Wutai, Mt. Wutai, Mt. Taibai, etc[5−10]. Among these studies, various terminologies for the upper limit of forests on high mountains were used, such as timberline, forestline, treeline and forest above treeline[6, 11, 12]. Timberline in this paper is defined as the ecotone between forestline and treeline. According to the published literature, the fluctuation of alpine timberline is influenced by many environmental factors. Besides climate, the impact of human activities can also not be ignored[13]. Pollen, palaeowood and plant macrofossil are important evidence to make research on the dynamic change of alpine timberline[8], therefore, it is essential to perform the researches on timberline fluctuation and climatic change by pollen analysis, dendrochronology and the identification and dating of macrofossils[14].

As one of the dominant tree species in boreal and cold-temperate evergreen coniferous forests, the genus *Picea*, consisting of about 40 species all over the world, is broadly distributed in the subalpine of temperate, cold-temperature and subtropical climate zones in the Northern Hemisphere. Ravazzi[3] reconstructed the late Quaternary history of fossil spruces in Southern Europe (*Picea abies* Karst, *Picea omorika* (Pancic) Purkyne) based on 163 selected pollen, charcoal and macrofossil records. McLeod and MacDonald[15] used the fossil pollen records from the sediments of 13 lakes to reconstruct the postglacial spread and population expansions of *Picea mariana* (Mill.) B.S.P., *Picea glauca* (Moench) Voss in the western interior of Canada. In China, there are 16 spruce species and 9 varieties. In the Pliocene and Early Pleistocene, spruce trees were once widely distributed in the subalpine regions on the Tibet Plateau[16]. In the Quaternary, especially in the last glacial stage, spruce forests were distributed in lowlands and hills as well as a few plains in the eastern, middle, western and southern China[10, 17]. According to pollen assemblage dominated by *Picea* and *Abies*, and many macrofossils of wood, cones, seeds and needles of *Picea wilsonii* in the late Pleistocene strata in Beizhuang Village (490m), Weinan City, Shaanxi, Xu *et al.*[10] thought that during 23 ka BP spruce ever declined to hilly area at an elevation of 490m with the annual mean temperature cooler than today by 7℃. Li[18] and Lu *et al*.[19] discussed the spatial dispersal characteristic of modern surface spruce pollen from Tianshan region, Xinjiang and Tibetan Plateau, which coveres latitudes 25°—45°N and longitudes 75°—106°E at a altitude from 1000m to 5700m respectively. They further studied the relationships between modern spruce pollen and vegetation, elevation, wind velocity and direction as well as the topographic conditions[18, 19].

Although the difference in climate, soil, vegetation, population and geologic historical condition in Xinjiang are remarkable, spruce is the dominant or sole constructive species of mountain conifer in Xinjiang[20]. The snow ridge spruce (*Picea schrenkiana* Fischer & C. A. Meyer are equal to Tianshan spruce: *P. schrenkiana* var. *tianshaniea*), mainly distributed on the southern and northern slopes of the Tianshan Mountains, the Siberian spruce (*Picea obovata* Ledebour), mainly distributed on the southwestern slope of the Altay Mountains, are two spruce species dominating in Xinjiang region[21]. As the major tree species of mountain forests of Xinjiang, the distribution range and population size of *Picea schrenkiana* during prehistoric and historic period are very sensitive to climate[22]. Yan *et al.*[22] discussed the timberline change according to the pollen record of Huashuwozi profile. However, in this study, Xiaoxigou archaeological site, only 200m away from Huashuwozi profile, was selected as the typical research profile. Charcoal samples in cultural layers of Xiaoxigou profile were collected for dating and SEM (scanning electron microscope) analysis. By comparing these data with the dating results and pollen assemblage of Huashuwozi profile, the fluctuation of spruce timberline on the northern slope of Tianshan Mountains during the Late Holocene can be estimated. At the same time, the response mechanism of timberline fluctuation to climate change is also discussed.

1 Investigated area and methods

Picea schrenkiana forest, distributed from 1500—1600 m to 2700—2800 m on the northern slopes of the Tianshan Mountains, forms a forest zone at the altitude of 1200 m[20, 21]. The study area is located at low mountains and hilly region (1200—1600 m), being horizontally 10km to the north of the lower limit of modern spruce forest on the northern slopes of the Tianshan Mountains. The climate in this region is dry, with annual mean precipitation of about 300mm and annual mean temperature of 5℃. Besides *Triticum aestivum* and *Zea mays*, the climate is favorable for the growth of *Solanum tuberosum* and *Allium sativum*. The natural vegetation is desert steppe, dominated by *Artemisia* sp., *Stipa glareosa*, *Ceratoides lateens*, *Ceratocarpus arenarium*, *Peganum harmala*, *Cirsium japonicum*, *Caragana leucophloea*, etc. Plants such as *Carex*, *Iris* and *Trifolium* grow in the gullies with rivulet between ridges due to higher water table. Scattered *Populus davidiana* and *Ulmus* sp. were planted at the sides of gullies[22]. Local inhabitants narrated that many birch trees once grew there, hence it was named Huashuwozi Village.

Xiaoxigou archaeological site (43°48.1′N, 89°7.3′E, 1360 m) is located at the west ridge of Huashuwozi Village (1410 m), Quanzijie Township, Jimusaer County in Xinjiang[23]. The section consists, from the bottom to the top, of 7 layers: khaki clay, greyish black lower cultural layer, khaki loess, greyish black upper cultural layer, khaki loess, gray, greyish yellow loess and khaki loess [22]. Some relics with the characteristics of Neolithic and Han Dynasty, such as ancient painted pottery, stoneware, irony sword and lamp, were excavated[24]. The section can be divided into two cultural layers. The upper one is scattered with little charcoal at the depth of 180—140 cm, whereas the lower one contains a lot of charcoal at the depth of 120—104 cm. By collecting charcoal samples for dating and SEM analysis, the fluctuation of spruce timberline can be confirmed[13, 14].

Pollen records from archaeological sites are inevitably disturbed by human activities, therefore, it is disadvantageous to reconstruct paleovegetation and to study timberline fluctuation. In order to get pollen record which is undisturbed by human activity, a natural profile (i.e. Huashuwozi profile, 43°48.3′N, 89°8′E, 1320 m), 200 m away from the archaeological site, was selected as the contrast profile as the time calibration of the archaeological profile. These two profiles are located at the outlying hill on the northern slopes of the Tianshan Mountains. The total depth of Huashuwozi profile is 110 m, which consists of greyish black clay with a little gravel, brown-black clay, greyish clay with light yellow clay, dark-gray clay, light brown clay and brown clay.

We took 38 samples with an interval of 5cm for Xiaoxigou profile and 52 samples with an interval of

2 cm for Huashuwozi profile (2—3 m interval at the bottom). All pollen samples were treated with heavy liquid acetolysis. 39 pollen taxa for Xiaoxigou profile and 42 for Huashuwozi profile were counted and identified for each sample under 10×40 magnification Olympus microscope. Of the 90 samples analyzed, more than 10000 pollen grains were recorded. Averagely, 150 pollen grains contained in each sample were identified with a few exceptions. Then, the Tilia/ Tilia-Graph software was used for the calculation of percentages and for the drawing of the pollen diagrams.

Three samples (110—88, 50—48 and 17—14 cm) of Huashuwozi profile and a sample from Xiaoxigou profile (155—145 cm) were selected for ^{14}C dating. ^{14}C dating analyses were also made for the minor charcoal fragment samples contained in ash pits at the bottom and the middle of the upper cultural layers of Xiaoxigou profile. Among them, middle ash pit's charcoal fragment samples were measured by the Laboratory of Technological Archaeology and Cultural Relics Preservation, Peking University, whereas other samples were dated by the ^{14}C laboratory of Institute of Geology, China Earthquake Administration. ^{14}C dating results are listed as follows. Three ^{14}C ages of Huashuwozi profile were dated to 2170±185 a BP (cal. 2150±225 a BP), 1050±50 a BP (cal. 950±60 a BP), 450±55 a BP (cal. 510±30 a BP) and 3240±60 a BP (cal.3470±85 a BP), respectively. Charcoal fragment samples at the bottom and the middle of ash pits of the upper cultural layer were dated at 1930±65 a BP(cal. 1875±65 a BP) and 1755±75 a BP (cal. 195 AD), respectively. At the same time, 7 bigger charcoals were selected from the bottom ash pit and 5 charcoals from the middle ash pit by the flotation method. After pretreatment, these samples were collected for SEM analysis and identified based on their microstructure[1)]. In addition, grain size and loss on ignition were also measured for 52 samples of Huashuowozi profile by the National Key Laboratory of Ministry of Education, Lanzhou University.

2 Results and interpretations

2.1 Charcoal chronology and microstructure

The identification of charcoal in archaeological sites began in last century. Santa[25] primarily used it in paleoecological research in North Africa. Since then, it has become an important research method for Quaternary Science and paleoecology. In China, Cui *et al*.[26,27] identified a palaeo-spruce timber in the Hunshandak sandy land and charcoals from two sites of Bronze Age in the Chifeng area. Results showed that palaeo-timber was *Picea jezoensis* in the Hunshandak sandy land, whereas charcoals in the Chifeng area were *Quercus monogolia*. According to these results, vegetation and climate in these study areas were reconstructed.

The anatomical characteristics of charcoals (^{14}C 1930±65 a BP) collected in the bottom ash pit of the upper cultural layer in Xiaoxigou archaeological site are similar to modern *Picea schrenkiana* (Fig. 1). However, charcoals (^{14}C 1755±75 a BP) collected in the middle ash pit were identified as *Picea schrenkiana* (Fig. 1), *Salix xerophila* and *Prunus padus*, which cannot grow there at present. The reason may be that these tree species were cut and moved in the vicinity or from the Tianshan Mountains by the forefathers.

2.2 Comparisons with pollen data

Tinner *et al.*[13] and Wick *et al.*[28] thought that human activity was the important factor in influencing timberline fluctuations when they used pollen and plant macrofossils record to study Holocene vegetation change. In our case, however, further evidence should be searched to investigate the relationship between timberline fluctuation and human activity.

5 pollen-assemblage zones were distinguished based on the lithology, main pollen percentage, pollen concentration and AP/NAP (arboreal pollen/not-arboreal pollen) value[29] for Xiaoxigou profile (Fig. 2).

(i) Zone I (190—180 cm). The lithology consisted of clay layer with a little pollens (about 5 families and 11 genera). The pollen assemblage was dominated by shrub and herb types (mean 95.4%), in which Chenopodiaceae and *Tamarix* amount to 23.3% and 21.0%, respectively, but arboreal pollen was only 2.2%—7.0%, average percentage of *Picea* was only 2.4%, and pollen concentration was very low (441—572 grain/g). The AP/NAP ratio was also at low value, but the pollen Simpson index was relatively high (mean 8.61), indicating that regional vegetation was desert-steppe, which was dominated by xerophytic with a little super-xerophytic desert plants.

(ii) Zone II (180—140 cm). 7 families and 17 genera were identified, more than in Zone I. The pollen

1) SEM analysis was done by Mr. Yao Xishen of Chinese Academy of Forestry

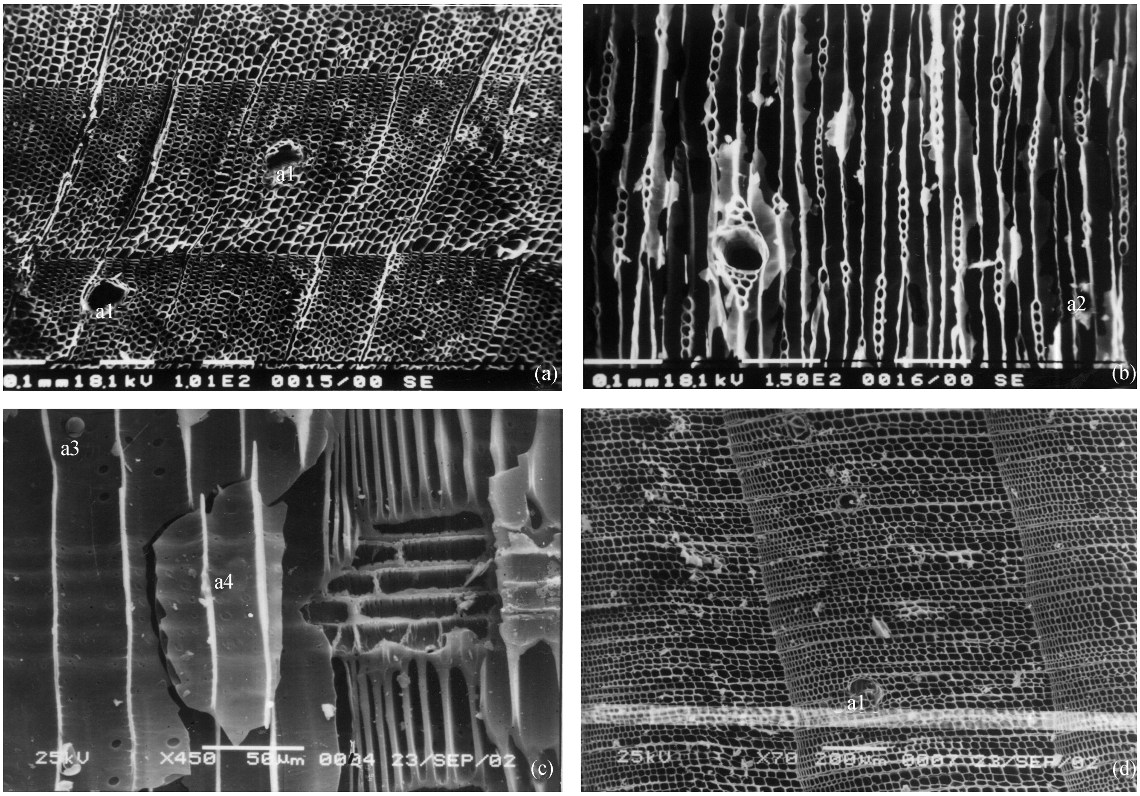

Fig. 1. The microstructure of charcoals of *Picea schrenkiana*. (a) Cross section (^{14}C age 1755±75 aBP); (b) tangential section (^{14}C age 1755±75 aBP); (c) radial section (^{14}C age 1755±75 aBP); (d) cross section (^{14}C age 1930±65 aBP). a1, Resin canal; a2, uniseriate ray; a3, tracheid; a4, cross-field.

assemblage was still characterized by shrub and herb pollens (mean 93.4%), notably the percentage of *Artemisia* increased considerably (mean 21.0%). A/C (*Artemisia*/Chenopodiaceae) value was higher than in Zone I (0.58－2.1). But *Tamarix* (mean 7%) and *Ephedra* (mean 5.7%) percentage decreased greatly. Pollen concentration began to increase and reached its maximum value (604－5152 grain/g), and AP/NAP value and pollen Simpson index were also higher than those of Zone I, reflecting a more humid climate than Zone I.

(iii) Zone III (140－120 cm). This zone included 7 families and 11 genera of pollen, less than Zone II. Shrub and herb pollen increased and reached the maximum of this profile (100%), especially Chenopodiaceae percentage (mean 34.6%) increased rapidly. *Artemisia* (mean 22.7%) and *Ephedra* (mean 6.9%) percentages were slightly higher than Zone II, and A/C value decreased to 0.26, but *Tamarix* percentage reduced to 4.4%. During this period, arboreal pollen percentage and total pollen concentration (13 grain/g) were at their lowest values and the pollen Simpson index and AP/NAP ratio were lower than Zone II, implying a relatively dry climate compared with Zone II.

(iv) Zone IV (120－104 cm). In this zone, 26 pollen taxa were identified, more than that of Zone III. The percentage of arboreal pollen increased rapidly to 15.7%, whereas those of shrub and herb pollen decreased to 84.3%. Percentages of Chenopodiaceae (mean 24.3%), *Artemisia* (mean 10.8%), *Tamarix* (mean 2.9%) and *Ephedra* (mean 3.4%) reduced considerably, whereas that of *Picea* increased rapidly to 35.5%. AP/NAP value and pollen Simpson index were at their highest levels and pollen concentration (230－1078 grain/g) was higher, reflecting that the climate became more humid than Zone III.

(v) Zone V (104－0 cm). Percentages of arboreal pollen (mean 3.6%) began to decrease again, whereas those of shrub and herb pollen (mean 96.4%) increased once again. Percentages of Chenopodiaceae (mean 38.8%), *Artemisia* (mean 12.0%), *Ephedra* (mean 12.6%) and *Tamarix* (mean 5.5%) were higher than Zone IV with low A/C value of 0.11－0.51. In this zone, pollen concentration began to increase (1881

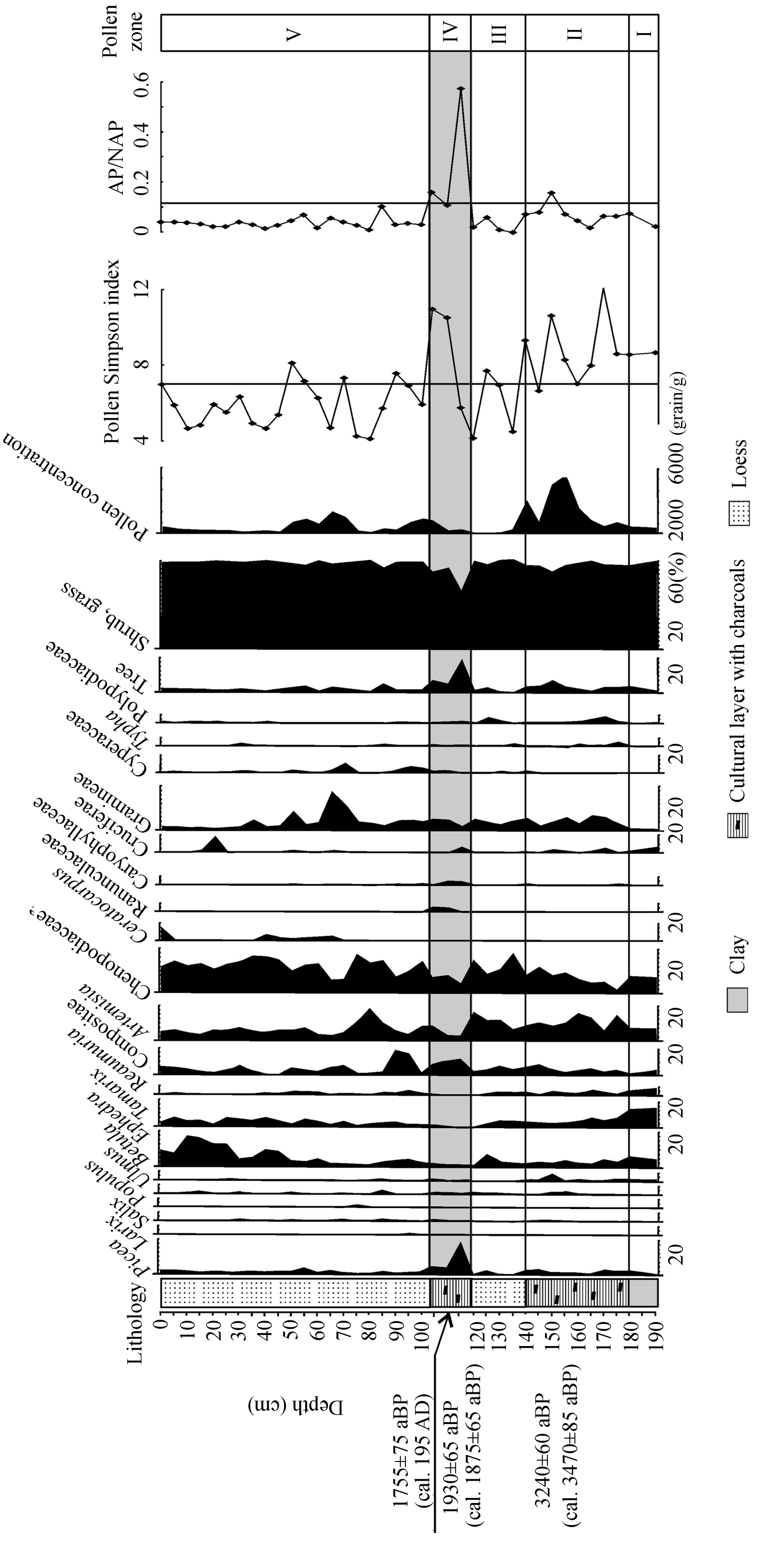

Fig. 2. Pollen diagram of Xiaoxigou profile.

grain/g), and then decreased to 81 grain/g. The pollen Simpson index and AP/NAP value were lower than Zone IV, indicating that the climate was drier than Zone IV.

According to the vertical change of main pollen percentage[22] and pollen Simpson index[29] of Huashuwozi profile, 4 pollen-assemblage zones can be distinguished (Fig. 3).

(i) Zone I (110—88cm, 2150—2000 a BP). This zone was characterized by a relatively low percentage of arboreal pollen (mean 4.9%) and high percentage of xerophytic and super-xerophytic pollen (mean 95.0%). At the bottom of the zone, Chenopodiaceae percentage (mean 44.7%) was higher, and then decreased to 21.0% in the upper part. Relatively low total pollen concentration (140 grain/g), pollen Simpson index (mean 8.1), LOI and AP/NAP value reflected that regional vegetation was desert-steppe dominated by xerophytic Chenopodiaceae, *Ephedra*, *Tamarix*, *Reaumuria*, *Peganum* and *Zygophyllum*.

(ii) Zone II (88—58 cm, about 2000—1300 a BP). The pollen assemblage was still dominated by shrub and herb pollen (mean percentage 90.8%), but the mean percentage of arboreal pollen increases to 9.2%, notably that of *Picea* reached the maximum (mean 8%), with 21.5% at the depth of 72—66 cm. Percentages of xerophytic and super-xerophytic pollen decreased, especially Chenopodiaceae percentage (mean 23.3%) reduced to its lowest value, whereas those of *Artemisia*, Gramineae, Compositae, Ranuculaceae, Leguminosae, Caryophyllaceae, Labiatae, Umbeliferae, Cruciferae, Liliaceae, *Allium* and Cyperaceae increased. Pollen concentration (309 grain/g), pollen Simpson index and LOI value were higher, and AP/NAP value reached its highest value. The pollen assemblage suggests a steppe vegetation with some trees.

(iii) Zone III (58—16 cm, about 1300—450 a BP). The predominant taxa in this zone were still shrub and herb pollens (mean percentage 96.6%), while xerophytic and super-xerophytic pollen increased. The percentage of Chenopodiaceae was higher than in Zone II (mean 30.5%), whereas that of *Picea* decreased (mean 2.6%). Pollen concentration (76.8 grain/g), pollen Simpson index, AP/NAP and LOI values were at their lowest values, indicating a desert-steppe vegetation landscape, which was dominated by xerophytic Chenopodiaceae, *Artemisia*, Compositae and Gramineae.

(iv) Zone IV (16—0 cm, since 450 aBP). As compared with Zone III, percentages of xerophytic and super-xerophytic pollen in this zone were lower. Among them, Chenopodiaceae bear a percentage of 17.2%, *Picea* 4.2%, but *Betula* reached its highest value (13.2%), implying that a lot of birches grew there at that time; therefore, after which the Huashuwozi Village was named. Higher pollen Simpson index and AP/NAP value, highest pollen concentration (mean 949 grain/g) indicated a regional vegetation of desert and steppe-steppe. Percentages of Leguminosae, Umbeliferae, Cruciferae, Liliaceae, and *Allium* were higher than in Zone III and those of Gramineae and Cyperaceae began to increase.

As seen in Fig. 2, *Picea* displays an average percentage of 3.75% in Xiaoxigou profile, with its peak value of 35.1% appearing at the depth of 115 cm. At the same time, pollen concentration and AP/NAP value were also at their highest values. If *Picea* charcoals were the burnt firewoods transported by forefathers from long distance, high *Picea* percentage should not appear in Xiaoxigou profile. Furthermore, Yan *et al*.[30] collected 131 pollen samples in surface soils in the Tianchi area, the Altay area, the Kunlun Mountains area, the Chaiwopu area and the Taklimakan Desert area of Xinjiang. According to their statistical results, the most important factor affecting spruce pollen percentage is the distance of sampling from the spruce forest stand. Spruce pollen concentration is basically less than 5% when this distance is more than 10 km. Within the spruce forest stand, spruce pollen had concentration of 50%—60%. Generally, more than 30% spruce pollen concentration in a site could represent the existence of spruce forest stand in this area[30]. In addition, a total of 80 surface pollen samples were sampled along an altitudinal transect by Yang Zhenjing, ranging from 460 to 3510m on the northern slope of the central Tianshan Mountains. The analyzed results showed that *Picea* percentage of mountain spruce forest ranged from 10.4% to 93.5%, and the average value was 62.4%[1)]. Therefore, the appearance of peak value of *Picea* pollen percentage in the Xiaoxigou profile, 10 km away from the lower limit of spruce forest, suggested that spruce forest grew in the nearby region at that time. Here it should be noted that the average

1) Yang Z J. A Study on Modern Palynology in the Northern Slope of Mid-Tianshan Mt., Xinjiang. Postdoctoral Report, Institute of Botany, Chinese Academy of Sciences, 2004

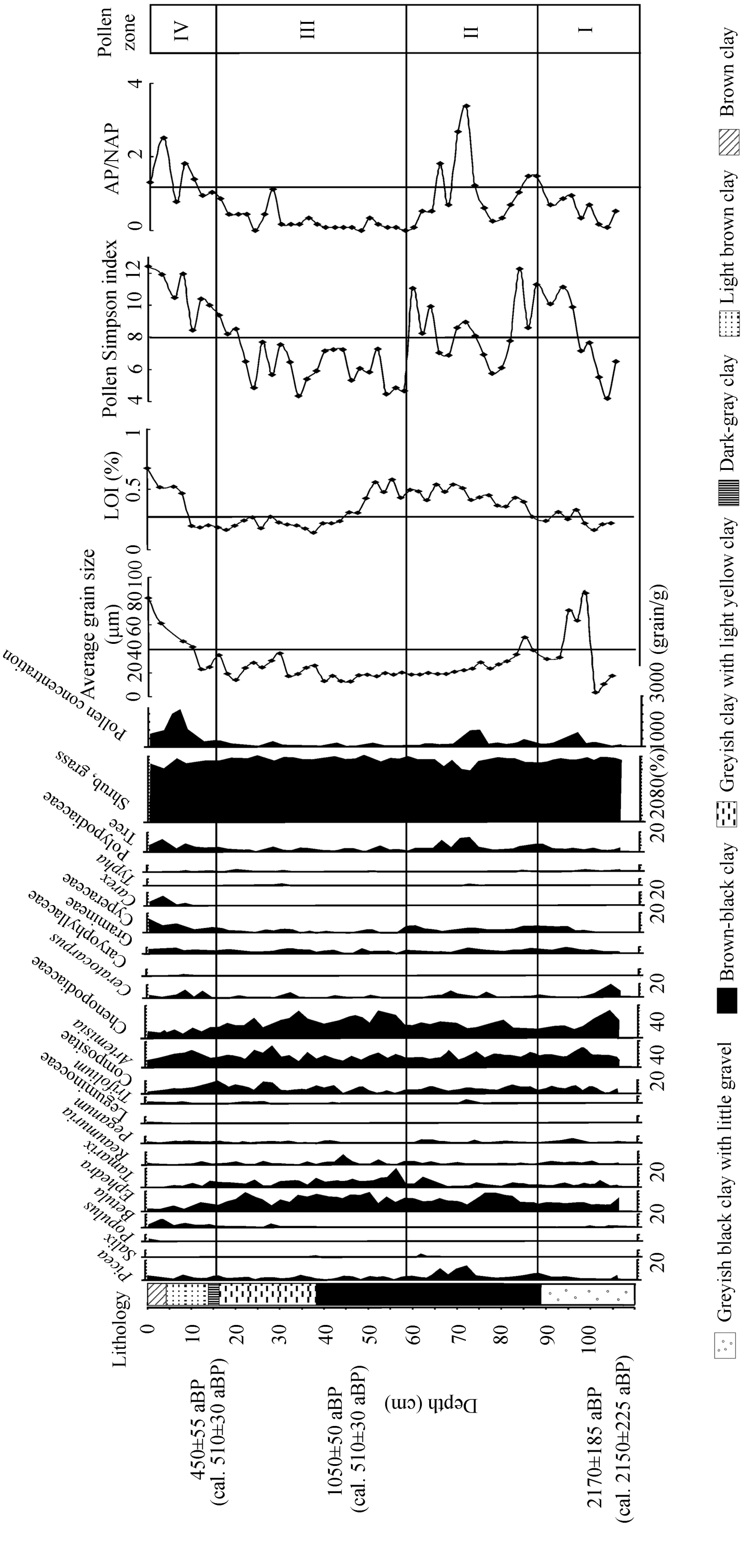

Fig. 3. Pollen diagram, grain size and LOI of Huashuwozi profile.

Picea pollen percentage of Huashuwozi profile, 200 m away from Xiaoxigou profile, was 4.33%, but its peak value (16.7%—21.5 %) appeared at the depth of 72 cm, 70 cm and 66 cm, respectively. At the same time, total pollen concentration, LOI and pollen Simpson index and AP/NAP value were all at their peak values, as shown in Fig. 3. ^{14}C ages of samples at the depth of 110—88 cm, 50—48 cm and 17—14 cm were 2170±185 a BP (cal. 2150±225 a BP), 1050±50 a BP (cal. 950±60 a BP) and 450±55 a BP (cal. 510±30 a BP), respectively. Interpolated with these dating ages and sedimentation rates, ^{14}C ages at depths of 72—66 cm were estimated to date to 1700—1400 a BP. It corresponded to the charcoal fragment's age of *Picea schrenkiana* contained in Xiaoxigou cultural layers with the peak value of *Picea* pollen percentage. Accordingly, the appearance of high percentage of *Picea* in the two profiles in the equivalent horizon (2000—1300 a BP) indicated that charcoals were collected from a not much distance at that time.

3 Discussion

The fluctuation in spruce was qualitatively discussed as above according to the charcoal and pollen data. We also primarily analyzed the climate factors of spruce timberline fluctuation from Daxigou profile on the northern slope of central Tianshan Mountains[31]. However, it is necessary to further analyze the water-thermal climate factors of spruce fluctuation. Therefore, based on the current climate data from 8 weather stations in the study area that provide the average climate data for 50 years (1951– 2000) (from China Meteorological Administration) and other correlative literatures[32, 33], the eco-climate index of modern spruce and contemporary climatic index such as annual average warmth index and mositure index can be calculated (Table 1).

Warmth Index (WI) proposed by Xu[33] and Moisture Index (MI) suggested by Li[32] are two important indices to describe the water-temperature distribution relationship. Calculation methods of these two indices are described as follows:

$$\mathrm{WI} = \Sigma(t_i - 5), \quad (1)$$

$$\mathrm{MI} = \Sigma(p_i/2 - t_i), \quad (2)$$

where, t_i is the monthly average temperature when $t_i >$ 5℃, and p_i is the monthly precipitation when the monthly average temperature >5℃.

By simulating, we found that there were linear relationships between elevation, WI and MI values of 8 current weather stations, which can be expressed as

$$\mathrm{WI} = -0.03E + 103.45 \qquad R^2 = 0.9434\,, \quad (3)$$

where WI and E are the simulated WI and elevation, respectively; R^2 is the determination coefficient of multiple correlation coefficient for WI,

$$\mathrm{MI} = -6.51\cdot 10^{-5}E^2 + 0.30E - 208.75 \qquad R^2 = 0.9294\,, \quad (4)$$

where MI and E are the simulated MI and elevation, respectively. The analyses results showed that WI decreases linearly with the increasing of elevation, and precipitation also increases gradually. At an elevation of about 2200 m, precipitation reaches the highest value, and then decreases with the rising in elevation.

According to the above two equations, the WI and MI can be calculated with the value of 22.7—52.6℃·month and of 117.5—142.9 mm·(℃·month)$^{-1}$ for *Picea schrenkiana*, respectively. WI is basically in accordance with Fang *et al.*'s results, which were 11.0—76.0 ℃·month for *Picea purpurea* and 11.0—66.0℃·month for *Picea likiangensis*[34].

Comparing the contemporary eco-climate index between Huashuwozi and Xiaoxigou profile (WI: 62.7℃·month, MI: 82.3 mm·(℃·month)$^{-1}$), we can conclude that during the period of 2000—1300 a BP,

Table 1 Meteorological data and hydro-thermal index from 8 weather stations on the northern slope of Tianshan Mountains in Xinjiang

Observatory	N. latitude(°)	E. longitude(°)	Altitude (m)	Annual mean temperature (℃)	Annual precipitation (m)	WI(℃·month)	MI/mm·(℃·month)$^{-1}$	Year
Caijiahu	44.12	87.32	441.0	5.9	136.4	90.8	–75.3	1961—1998
Fukang	44.10	87.55	547.0	6.9	238.9	92.0	–29.5	1971—2000
Qitai	44.01	89.34	793.5	4.9	185.3	78.3	–40.2	1952—1998
Ürümqi	43.47	87.37	917.9	6.6	256.8	85.4	–24.8	1951—1990
Zhaosu	43.09	81.08	1848.6	3.1	494.3	39.7	139.8	1961—1998
Tianchi	43.53	88.07	1942.5	1.9	581.5	34.8	154.0	1958—1980
Xiaoquzi	43.34	87.06	2160.0	2.1	525.3	34.1	137.3	1956—1990
Daxigou	43.06	86.50	3539.0	–5.3	431.4	7.50	42.2	1958—1990

WI was lower than present by about 10.1℃·month. At that time, the spruce forest was distributed nearby. Accordingly, the lower limit timberline for *Picea schrenkiana* on the northern slope of Tianshan Mountains in Xinjiang declined by about 337m, compared with present. Provided that the future climate in northwest China might incline to become warmer and more humid[35], the upper or lower limit of spruce timberline will shift remarkably, too.

Tranquillini[36] and Fall[4] thought that the upper limit of forest was controlled by low temperature, whereas the lower limit was influenced by rainfall. For spruce, temperature and rainfall are two important climate factors in restricting its growth, but the influences of slope, slope-direction and slope-type cannot be neglected. In total, the climate mechanism in influencing the timberline fluctuation is so complicated that more meteorological data, especially at high elevation (more than 3539 m), are needed and vegetation, landform, and climate change should be considered synthetically to discuss the timberline fluctuation and climate response.

4 Conclusions

Pollen record of Huashuwozi profile showed that regional vegetation was desert steppe before 2000 a BP, but it changed into steppe with a few spruce forests distributed nearby during 2000—1300 a BP. In addition, LOI, pollen concentration, pollen Simpson index and AP/NAP value are higher and the strata are mainly composed of thin sediments, indicating that the climate was more humid than present with much precipitation, a condition favorable for the growth of spruce. During the same period, pollen data, high AP/NAP value and pollen Simpson index of Xiaoxigou profile also reflect a more humid climate.

High percentage of *Picea* (over 20% and 35%, respectively) appeared in the same period (2000—1300 a BP), which corresponds to the charcoal fragment's dating age of *Picea schrenkiana* contained in Xiaoxigou cultural layers. In addition, combined with the analyzed results of hydro-thermal climatic factors of *Picea schrenkiana*, it is convincingly revealed that during the period of 2000—1300 a BP, the timberline for *Picea schrenkiana* on the northern slope of Tianshan Mountains in Xinjiang declined by about 330m compared with the present.

Acknowledgements Discussion with Prof. Liu Hongyan greatly improved the paper. Special thanks are also given to reviewers for their valuable comments, which considerably improved an earlier version of the manuscript. This work was jointly supported by the National Natural Science Foundation of China (Grant No. 90102009), the Scientific Research Foundation for the Returned Overseas Chinese Scholars, State Education Ministry, the Innovation Project of the Chinese Academy of Sciences (Grant No. KZCX1-10-05) and 973 project (Grant No. G1999043502).

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