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Altitudinal changes of surface pollen and vegetation on the north slope of the Middle Tianshan Mountains, China

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Abstract: To provide information on vegetation patterns and altitudinal distributions of pollen assemblage in surface soil layers, their complicated relationships in a dryland mountain-basin system in northwestern China and a realistic basis for paleovegetational reconstruction, we investigated 86 vegetation quadrats and analyzed 80 soil samples from the surface soil layers along an altitudinal transect on the north slope of the Middle Tianshan Mountains from alpine cushion vegetation at 3,510 m near glacier to desert vegetation at 460 m in the Gurbantunggut Desert. According to surface pollen assemblages and the results of the detrended correspondence analysis, the transect can be divided into six major altitudinal pollen zones as alpine cushion vegetation, alpine and subalpine meadows, montane *Picea* forest, forest-steppe ecotone, *Artemisia* desert and typical desert, which basically reflect the characteristics of the mountainous vegetation patterns on the north slope of the Middle Tianshan Mountains. However, *Picea* pollen also exists outside the spruce forest, Chenopodiaceae and *Artemisia* pollen appeared above the elevation of 1,300 m, indicating that most of them might be introduced from lower elevations by upslope winds. Airborne pollen researches from three regions at different elevations further suggest that a high-frequency northwest anabatic wind has a remarkable influence on the transportation and dispersion of surface pollen in the area.

Keywords: altitudinal transect; vegetation zone; pollen assemblage; *Picea* forest; the Middle Tianshan Mountains

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The relationship between pollen assemblage in surface soil layers and vegetation types can be used to understand the complicated interaction between fossil pollen spectra and past vegetation composition, and to infer past climate changes (Xu et al., 2009; Zhang et al., 2010; Li et al., 2012; Zhang et al., 2015). Pollen archives convey accurate environmental information, such as temperature, precipitation and human disturbances (Herzschuh et al., 2010). Many factors including pollen production, dispersal, deposition and preservation affect surface pollen

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assemblage, which make pollen-vegetation-climate research comparatively complicated (Dai et al., 2011). The complicated interaction between surface pollen and modern vegetation should be widely investigated in different geographical regions to provide reliable results and valuable information for past climate reconstruction and further researches.

Mountain is a typical area for studying the modern pollen-vegetation relationship due to its specific topography and pollen dispersal air transport mechanism (Markgraf, 1980; Solomon and Silkworth, 1986; Fall, 1992a, b; Davies and Fall, 2001; Lu et al., 2011). In mountainous areas, modern pollen rains can be distinguished by their main vegetation zones at different elevations (e.g. Davies and Fall, 2001; Yu et al., 2001), which could provide a measure for the reliability of using fossil pollen spectra to reconstruct past vegetation patterns. For the mountains located in the arid areas with vegetation types from lowland deserts and steppes to mountainous forests and alpine meadows, the pollen-vegetation relationship is particularly important (Solomon and Silkworth, 1986; Fall, 1992a; Davies and Fall, 2001).

In Xinjiang, a number of studies were conducted on modern pollen assemblage and its relationship with vegetations in the past two decades (Yan and Xu, 1989; Pan, 1993; Yan, 1993; Xu et al., 1996; Yan et al., 2004; Luo et al., 2009). However, descriptive or quasi-quantitative studies could not reflect the quantitative relationship between pollen assemblage in surface soil layer and vegetation, especially in the regions around the Middle Tianshan Mountains where have various vegetation types and unique topographies. Therefore, the objective of this study was to explore the complicated relationship between pollen spectra characteristics and modern vegetation using statistical analysis. These results might contribute to the quantitative reconstruction of past vegetation and climate changes in Xinjiang.

1 Materials and methods

1.1 Study area

The study area is located on the north slope of the Middle Tianshan Mountains in Xinjiang (Fig. 1), where the vegetation displays a vertical distribution from 3,900 m at alpine cushion vegetation to 400 m in the Gurbantunggut Desert with a horizontal distance about 80 km from the south to the north. Glacier and perennial snow cover a large area at above 3,900 m. Vertical vegetation belts span elevations below 3,900 m with alpine cushion vegetation at 3,900–3,400 m, alpine and sub-alpine meadow at 3,400–2,600 m, Tianshan spruce (*Picea schrenkiana*) forest at 2,600–1,720 m, forest-steppe ecotone at 1,720–1,300 m, *Artemisia* desert at 1,300–700 m and typical desert at below 700 m (Fig. 2; Comprehensive Investigation Team of Xinjiang and Institute of Botany, Chinese Academy of Sciences, 1978; Editorial Committee for Forests of Xinjiang, 1989).

1.2 Pollen sampling and vegetation survey

In the summer of 2002, a transect was set up on the north slope of the Middle Tianshan Mountains along an altitudinal gradient from 3,510 to 460 m (Fig. 1) to collect pollen in surface soil layers and to investigate modern vegetation. The transect started at 43°47′34″N, 88°13′26″E and ended at 43°23′56″N, 88°54′17″E. Total 86 vegetation quadrats, 20 m×20 m each, were investigated along the transect (Table 1) with two or three quadrats in each vegetation zone at an elevational interval of 20–100 m. Tree, shrub and herb were investigated if existed in quadrats. In each quadrat, the number of trees, tree species, height, canopy range and diameter at breast height were recorded. Each quadrat was divided into four plots, 10 m×10 m each. Shrub species, the number of shrubs, height and canopy range were counted in each plot. Two subplots, 1m×1 m each, were randomly selected in each plot and herb species, height and coverage were recorded. At the same time, moss polsters (forest only), litter and topsoil (forest and grassland) were taken randomly at each vegetation quadrat and then mixed and sealed into a plastic box as an one-site sample. In total, 80 surface soil samples were collected by this cinquefoil sampling method (Table 1).

1.3 Pollen extracting and counting

We used 50 g soil from each sample for pollen analysis. Pollen was extracted from the soil using

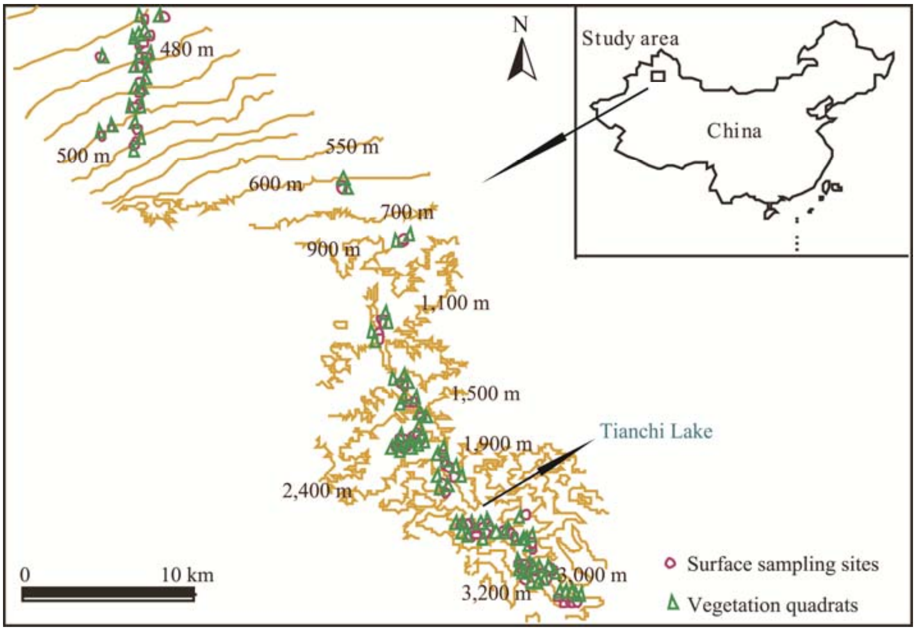

Fig. 1 Sampling locations along an altitudinal gradient on the north slope of the Middle Tianshan Mountains

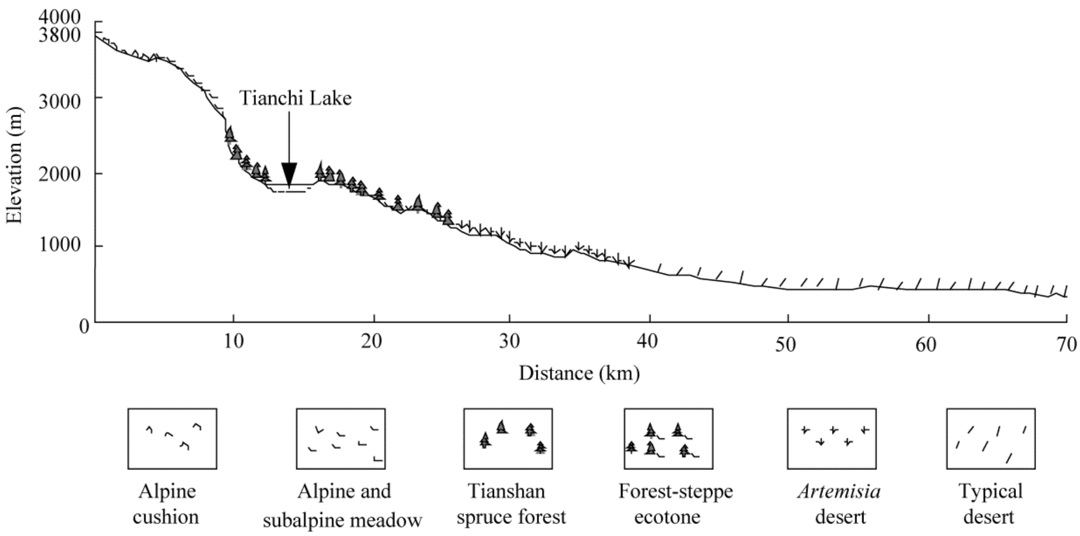

Fig. 2 Vegetation vertical distribution on the north slope of the Middle Tianshan Mountains

classic treatments of K_2CO_3, HCl, HF, concentrated HCl, heavy liquid and acetolysis mixture (Li et al., 1995). Treated pollen samples were placed in glycerin and examined with the Olympus microscope. Two or three slices were examined for each sample and at least 300 terrestrial pollen grains (mean, 406) were counted. Pollen identification was based on information from published books of palynology and pollen morphology (Xi and Ning, 1994; Wang et al., 1995). Unknown and indeterminate pollen grains such as broken, concealed, corroded, crumpled and degraded ones were excluded. We identified 56 pollen families and genera.

1.4 Data analysis

Pollen taxa with percentage composition up to 0.5% were chosen for data analysis. About 17 taxa were used for detrended correspondence analysis (DCA) (ter Braak et al., 2002), including *Picea*, *Betula*, *Salix*, *Ephedra*, *Tamarix*, *Nitraria*, Chenopodiaceae, Compositae, *Artemisia*, Ranunculaceae, *Thalictrum*, Caryophyllaceae, Cyperaceae, Rosaceae, Gramineae, Leguminosae and Umbelliferae. Temperature and precipitation data from 1951 to 2006 were collected from 6 weather stations (Fukang, Qitai, Urumqi, Tianchi, Xiaoquzi, Daxigou) on the north slope of the Middle Tianshan Mountains. These data were used to calculate correlation coefficients with pollen data and to analyze the monthly wind direction frequencies from 2001 to 2006 in these areas.

Table 1 Characteristics of vegetation and pollen assemblage of surface soil layer along the altitudinal transect on the north slope of the Middle Tianshan Mountains

Vegetation zone	No. of quadrat	Elevation (m)	Dominant species (coverage (%))	Pollen zone	No. of pollen samples	Dominant pollen taxa (percentage (%))
1, alpine cushion	Nill	>3,500	*Thylacospermum caespitosum*, *Potentilla biflora* (total coverage 25–60)	I	1	Tree pollen (20.6): *Picea* (11.4), *Salix* (8.7), *Betula* (0.5); Shrub pollen (14.3): *Ephedra* (11.4), *Nitraria* (7.4); Herb pollen (65.1), *Artemisia* (37.3), Chenopodiaceae (16.2), Compositae, *Thalictrum*, Ranunculaceae, Caryophyllaceae, Gramineae (1.2–2.7)
2, alpine and subalpine meadow	1–17	3,390–2,600	*Poa* 3.3 (0–13.5), *Festuca* 10.2 (0–30), *Carex* 16.2 (0–38.4), *Thalictrum* 4.0 (0–15), *Polygonum viviparum* 8.8 (1.3–21.6)	II	2–20	Tree pollen (20.6–43.8): *Picea* 29.8 (11.4–40.0), *Salix* 5.1 (2.5–9.4); Shrub pollen (1.3–13.8): *Ephedra* 8.5 (0–11.4), Tamaricaceae 1.4 (0–4.9), *Nitraria* 0.6 (0–2.4); Herb pollen (43.6–65.6): Chenopodiaceae 20.4 (12.7–24.7), *Artemisia* 18.3 (11.6–37.3), Compositae 0.9 (0–2.7), Gramineae 0.9 (0–2.2), *Thalictrum* 3.5 (1.9–6), Caryophyllaceae 4.4 (0.9–21.7), Ranunculaceae 1.5 (0.8–2.5)
3, Tianshan spruce forest	18–37	2,600–1,800	*Aegopodium alpestre* 12.9 (0–32.5), *Calamagrostis arundinacea* 1.9 (0–9.6), *Cicerbita azurea* 7.7 (0–25.4), *Picea schrenkiana* 59.2 (27.3–84.4), *Poa* 1.0 (0–2.5), *Thalictrum* 0.8 (0–3.8)	III	21–47	Tree pollen 66.2 (22.6–94.0): *Picea* 62.4 (10.4–93.3), *Salix* 3.2 (0.7–11.5); Shrub pollen 7.1 (1.4–24.6): *Ephedra* 4.1 (0.7–10.8), Tamaricaceae 2.8 (0–13.9); Herb pollen 26.7 (4.6–52.8): Chenopodiaceae 12.7 (1.8–25.4), *Artemisia* 6.7 (0.7–12.4)
4, forest–steppe ecotone	38–50	1,720–1,300	*Aegopodium alpestre* 7.4 (0–30.6), *Calamagrostis arundinacea* 6.1 (0–19.2), *Artemisia* 4.9 (0.1–32.5) *Carex* 8.9 (0–33.8), *Cotoneaster* 12.9 (0–39.8), *Fragaria viridis* 4.7 (0–41.3), *Galium boreale* 2.7 (0–13.6), *Geranium pratense* 2.1 (0–5.4), *Lonicera* 4.6 (0–16.1), *Poa* 2.9 (0–13.8), *Rosa* 16.9 (0.1–56.8), *Sorbus tianschanica* 3.5 (0–22.9), *Salix* 2.9 (0–22.7), *Picea schrenkiana* 17.5 (0–86.5), *Senecio nemorensis* 3.5 (0–15.3), *Spiraea* 2.8 (0–16.4), *Thalictrum* 1.7 (0–4.3)	IV		Tree pollen 23.2 (20–27.6): *Picea* 14.7 (10–23.4), *Salix* 7.1 (3.2–11.3); Shrub pollen 21.1 (16.9–23.5): *Ephedra* 11.1 (7.7–15), Tamaricaceae 9.4 (6.8–15.3); Herb pollen 55.7 (50–63.1): Chenopodiaceae 27.1 (23.7–29.6), *Artemisia* 15.4 (11.6–22), *Thalictrum* 3.7 (1–9.6)
5, *Artemisia* desert	51–63	1,230–700	*Artemisia rupestris* 14.5 (0.3–54.4), *Festuca* 2.8 (0–10.1), *Gleiditsia* 16.5 (0–38.7), *Carex* 5.4 (0–33.8)	V	48–59	Tree pollen 11.1 (7.9–16): *Picea* 3.7 (0.7–9.3), *Salix* 6.2 (3.7–11.2)； Shrub pollen 12.6 (9.1–19.2): *Ephedra* 5.6 (2.4–12.5), Tamaricaceae 6.7 (4–10); Herb pollen 76.3 (64.7–81.8): Chenopodiaceae 18 (9.5–28), *Artemisia* 53 (31.2–61.5)
6, typical desert	64–86	620–460	*Artemisia rupestris* 7.6 (0–64.6), *Haloxylon ammodendron* 3.5 (0–41.2), *Petrosimonia sibirica* 4.8 (0–32.6), *Salsola* 4.5 (0–65), *Suaeda physophora* 2.9 (0–26.3), *Reaumuria* 6.9 (0–20), *Tamarix hispida* 3.3 (0–27)	VI	60–80	Tree pollen 16.6 (8.2–27.6): *Picea* 1.7 (0.6–4.2), *Salix* 4.5 (0.9–6.9), *Ulmus* 10 (2.5–20.2); Shrub pollen 11.6 (4.7–28.1): *Ephedra* 4.2 (1.4–10.3), Tamaricaceae 6.6 (3.2–17.2); Herb pollen 71.8 (51.7–84): Chenopodiaceae 49.3 (25.4–72.4), *Artemisia* 17 (5.4–40.1), *Thalictrum* 1.5 (0.3–3.6)

2 Results

2.1 Pollen assemblages in surface soil layer

More than 32,502 pollen-spore grains were counted; families and genera were identified as 24 and 31, respectively. The altitudinal pollen spectra can be divided into 6 pollen zones (Fig. 3) according to modern vegetation survey and the characteristics of pollen spectra.

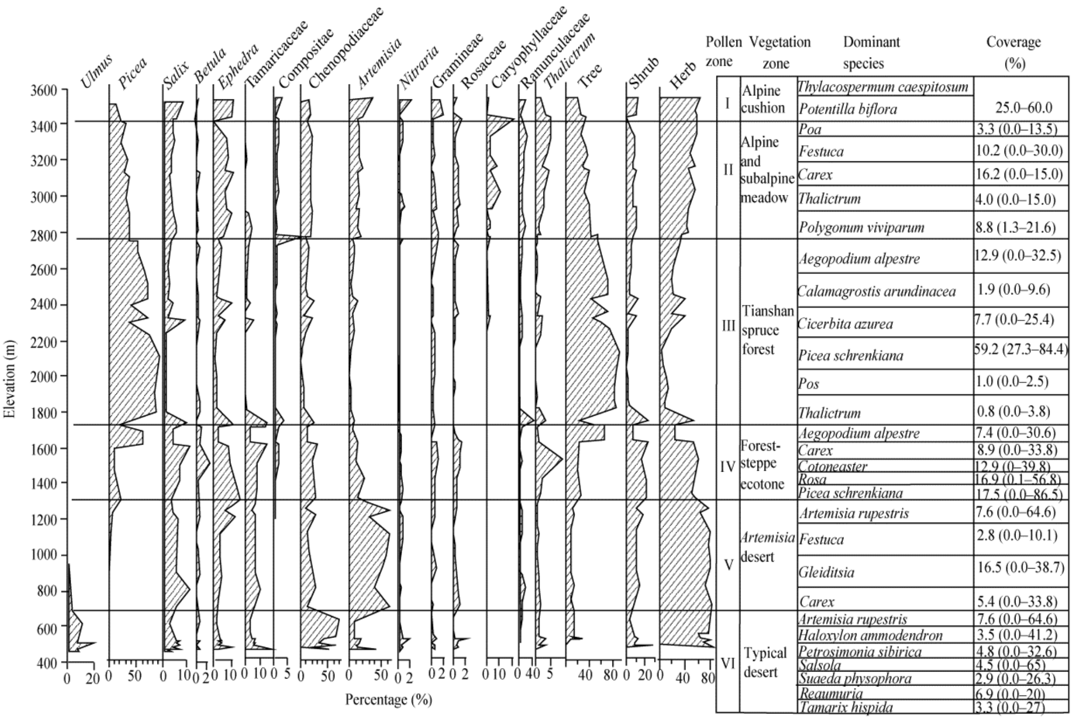

Fig. 3 Pollen assemblages in surface soil layers (percentage) along the altitudinal transect on the north slope of the Middle Tianshan Mountains

2.1.1 Pollen zone I: Alpine cushion vegetation

This zone is between 3,510 to 3,420 m, herb pollen accounts for a large proportion (65.1%) and dominated by *Artemisia* (37.3%) and Chenopodiaceae (16.2%). A small amount of Compositae, *Thalictrum*, Ranunculaceae, Caryophyphyllaceae and Gramineae are identified (1.2%–2.7%). Tree pollen accounts for 20.6% and is dominated by *Picea* (11.4%) and *Salix* (8.7%) with sparse *Betula* pollen (0.5%). Shrub pollen accounts for 14.3% and is dominated by *Ephedra* (11.4%) and *Nitraria* (7.4%).

2.1.2 Pollen zone II: Alpine and subalpine meadow

This pollen zone is well defined by the high content of herb pollen (43.6%–65.6%). Chenopodiaceae (12.7%–24.7%) and *Artemisia* (11.6%–37.3%) are dominant pollen, but they are found in the modern vegetation between 3,420 to 2,755 m. Similarly, tree pollen such as *Picea*, *Salix* and *Betula*, shrub pollen such as *Ephedra* and *Nitraria* also account for a relative high proportion, but they cannot be found in modern vegetation as well. The dominant pollen taxa such as *Poa*, *Festuca*, *Carex*, *Thalictrum* and *Polygonum viviparum* do exist in modern vegetation.

2.1.3 Pollen zone III: Montane *Picea* forest

This zone has the highest content of *Picea* pollen (10.4%–93.3%) with the lowest content of shrub and herb pollen. Between the elevations of 2,755–1,720 m within the *Picea* forest, mean *Picea* pollen content is 62.4% and the mean coverage of *Picea* forest is 52.5%. *Picea* pollen content reaches the highest amount of 93.3% at the elevation of 2,100 m.

2.1.4 Pollen zone IV: Forest-steppe ecotone

This zone is between 1,720–1,230 m and characterized by high content of herb pollen (50.0%–63.1%) and shrub pollen (16.9%–23.5%). *Picea* pollen content abruptly declines to 10%–20%. The percentage of tree pollen, such as *Salix* and *Betula*, increases. Shrub pollen percentage such as *Ephedra* and Tamaricaceae is also higher than that in zone III. Herb pollen occupies the largest proportion in this zone, dominated by *Artemisia*, Chenopodiaceae, *Thalictrum*, Compositae and Ranunculaceae. These shrub and herb pollen come from shrub species of *Rosa platyacantha Schrenk*, *Rosa albertii*, *Cotoneaster melanocarpus*, *Caragana pleiophylla* and *Lonicera hispida* (accounting for 47.4% of shrub layer), and herb species of *Calamagrostis arundinacea*, *Agropyron cristatum*, *Elymus dahuricus*, *Poa annua*, *Calamagrostis epigeios*, *Festuca ovina*, *Aegopodium alpestre*, *Carex*, *Artemisia*, *Senecio nemorensis* and *Heteropappus altaicus* (accounting for 84.8% of herb layer).

2.1.5 Pollen zone V: *Artemisia* desert

Relatively high content of *Artemisia* pollen (31.2%–61.5%), low content of arboreal, shrub and other herb pollen distinguish the vegetation belt in 1,230–620 m. *Picea* pollen only occupies 1%–5% of tree pollen. However, the percentages of *Salix* and *Ulmus* pollen increase, whereas shrub pollen of *Ephedra*, Tamaricaceae and *Nitraria* decrease compared to those in zone III. Herb pollen is dominated by *Artemisia* and Chenopodiaceae.

2.1.6 Pollen zone VI: Typical desert

Chenopodiaceae pollen (25.4%–72.4%) absolutely dominated the area below 620 m, reflecting the typical desert vegetation is dominated by herb and shrub species of Chenopodiaceae, such as *Petrosimonia sibirica* (0–32.6%), *Suaeda physophora* (0–26.3%), *Reaumuria* (0–26.3%), *Tamarix hispida* (0–27.0%) and *Haloxylon ammodendron* (0–41.2%).

2.2 Pollen ratio

As shown in Fig. 4, Chenopodiaceae/*Artemisia* (C/A value) is the lowest in the *Artemisia* desert, showing that the percentage of *Artemisia* pollen is greatly higher than that of Chenopodiaceae. In addition, the value reaches the maximum in the typical desert, making it clear that Chenopodiaceae has the greatest value in this pollen zone. Most of C/A values are greater than 1 at the elevation of above 1,300 m. Between 1,300–700 m in the *Artemisia* desert, C/A values are smaller than 1. C/A value suddenly increases below 700 m and reaches 13.5 at 620 m. Chenopodiaceae dominated desert vegetation in this region where the annual precipitation is 100–300 mm (Zhou, 1995). Montane spruce forest zone has the highest content of arboreal pollen. Besides this zone, arboreal pollen/non-arboreal pollen (AP/NAP) values are all extremely low.

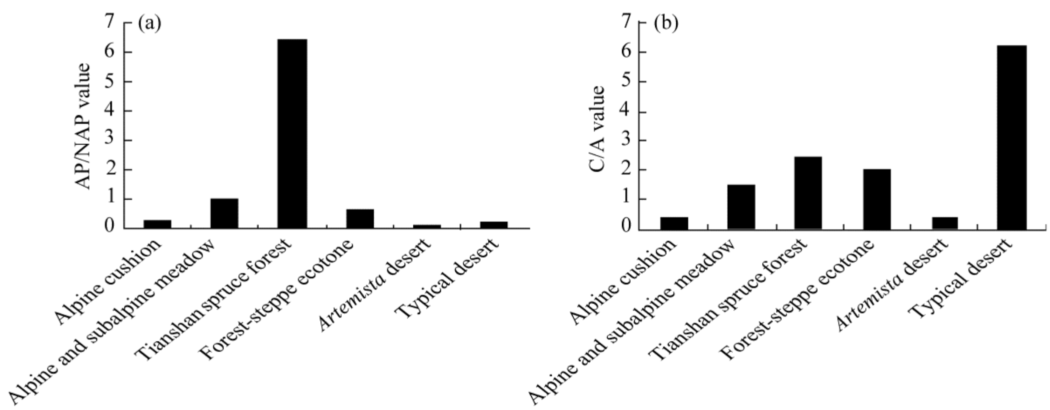

Fig. 4 Arboreal pollen/non-arboreal pollen (AP/NAP value; a) and Chenopodiaceae/*Artemisia* (C/A value; b) ratio along the altitudinal transect on the north slope of the Middle Tianshan Mountains

2.3 Pollen assemblages and environmental variables

DCA was used to analyze the relationships between the pollen assemblages and environmental variables using CANOCO 4.5. DCA results (Fig. 5) revealed that the first two axes captured 57.1% of the variance in the pollen data (axis 1, 46.8%; axis 2, 10.3%). The eigenvalues of the first two axes are obviously higher than those of the second two axes, indicating that pollen data are controlled by two environmental factors represented by axis 1 and axis 2. Figure 5 shows that pollen zones I, V and VI are distinct from the other pollen zones. There are correspondences between the zone I and Rosaceae; the zone II and Compositae; the zone III and *Picea*; the zone IV and *Ephedra* and Cyperaceae; the zone V and *Artemisia*; and the zone VI and Chenopodiaceae. With respect to pollen taxa, *Picea* shows lower scores on axis 1, whereas typical desert vegetation types such as Chenopodiaceae and *Artemisia* have a higher value, showing that Axis 1 represents the changes of humidity. In axis 2, *Artemisia* has the lowest value and Chenopodiaceae has the highest value. Moreover, a distribution mode of one center (humid region vegetation type, all kinds of meadow and *Picea schrenkiana* forest) and two apices (two drought poles, the *Artemisia* desert and typical desert) were shown in Fig. 5, reflecting the humidity changes on the north slope of the Middle Tianshan Mountains.

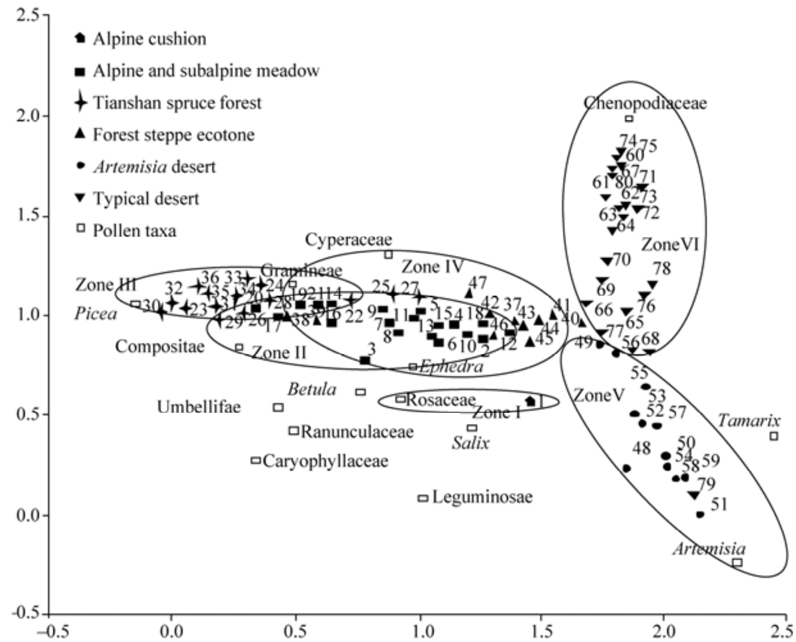

Fig. 5 Detrended correspondence analysis results of pollen assemblages of the surface soil sampling sites and pollen taxa

3 Discussion

3.1 The relationship between surface pollen and modern vegetation

DCA results revealed that the indicative taxa of pollen zone I is Rosaceae and the coverage of *Potentilla biflora* is relatively high in this zone. The indicative taxa of zone II is Compositae and the mean vegetation cover of the species is also very high in this zone. *Picea* percentage in surface soils is 40%–90% at the elevation of 2,800–1,800 m in the distributional range of *Picea* forest vegetation zone, but it has a higher content only below the lower limit of *Picea* forest (<1,800 m). Deciduous tree pollen of *Salix* and *Betula* appear in all pollen zones with very low contents of ca. 5% and 1%, respectively. *Ulmus* pollen only appears at the elevation below 1,600 m while *Ephedra* pollen was found at all elevations with higher contents in non-forest elevations (ca. 6%–8%) than in forest elevations (2%–6%). Compositae pollen appears at all elevations with higher percentage at high (3,500–2,800 m) and middle (1,800–1,400 m) elevations. Other herb pollen such as Graminaceae, *Thalictrum*, Ranunculaceae and Rosaceae appear in all elevations with low contents. Pollen of Caryophyllaceae only appears in high elevation of 3,500–2,800 m. *Nitraria* pollen mostly appears in non-forest elevations. Pollen of Chenopodiaceae and *Artemisia* occur in all of elevation with high contents of ca. 10%–70% and 10%–60%, respectively, but their contents at forest elevations are higher than those at non-forest elevations. The highest content appears in the low elevations, especially in the desert zone.

Surface pollen assemblages basically reflect the characteristics of modern vegetation. Among all pollen, considerable amount of pollen comes from vegetation in original places. For example, *Picea* pollen is more than 50% in *Picea* forest stand and less than 5% in desert. Mean content of *Artemisia* pollen is 53% in *Artemisia* desert and Chenopodiaceae pollen is 49% in typical desert.

However, pollen assemblages of surface soil layer don't well reflect the modern vegetation in some places. For example, at 3,400 to 2,700 m in the area of meadow vegetation, pollen assemblage is dominated by *Picea* within the range of 11%–40%. The elevation of 2,600–2,700 m is the upper limit for modern *Picea* forest. Therefore, *Picea* pollen in the meadow vegetation above 2,700 m might be introduced from spruce forest stand below 2,700 m. Similarly, spruce tree is absent in the desert zone, but its pollen percentage is more than 1%.

3.2 Typical arboreal pollen and vegetation

Airborne pollen is produced by the flowering plants. Therefore, airborne pollen amount during the period of peak florescence can reflect the characteristics of modern vegetation within a radius of about 50 km in this area. During the period of July 2001 to July 2006, airborne pollen rain samples were collected from Tianchi Meteorological Station (43°53′58.38″N, 88°07′15.75″E; 1,942.5 m asl), Fukang Desert Ecosystem Observation and Experiment Station (44°17′27.41"N, 87°55′52.65″E; 477 m asl) and Beishawo Grass Peat Experimental Field Station (44°22′40.74″N, 87°55′9.74″E; 443 m asl) through three sets of airborne pollen trap on the north slope of Tianshan Mountains (Yang, 2004; Mao, 2008; Pan et al., 2011).The results indicate that the percentage and volume concentration of *Picea* pollen obviously change along the altitudinal gradient, reaching its peak value in the Tianchi area (*Picea* forest), with an average of 21.2%. About 50% of the spruce pollen grains were collected at the beginning of June, and the pollen concentration decreased to 1.8% in Fukang and Beishawo areas at lower elevations (Table 2), which is in accordance with surface pollen assemblage characteristics.

Table 2 Pollen percentages of main taxa from atmosphere and surface soil and local vegetation covers (Yang, 2004; Mao, 2008)

Pollen type	Tianchi area (*Picea* forest zone)					Beishawo, Fukang (average)		
	Airborne pollen (%)			Surface soil pollen (%)	Vegetation coverage (%)	Airborne pollen (%)		
	Summer	Autumn	Average of 5 years			Summer	Autumn	Average of 5 years
Picea	33.0	2.4	21.2	62.4	53.7	1.8	0.3	1.1
Chenopodiaceae	20.9	18.1	12.4	12.7	0.0	60.6	33.7	57.2
Artemisia	24.2	64.0	49.1	6.7	<0.1	10.4	48.9	22.1

The content of *Picea* in Zone III reaches 62.4%, which is corresponding with its vegetation coverage (53.7%). In Zone I and II, surface pollen assemblages are also dominated by *Picea* (11%–40%), but the elevation is higher than the upper limit of modern *Picea* forest. This phenomenon is likely caused by anabatic wind. Air current in the valley contributes mostly to such pollen transportation, which has been confirmed by previous studies (Li, 1991; Yan et al., 2004). As the edificator of coniferous forest in the northern Xinjiang, the dispersal and transportation of *Picea* pollen are quite distinct (Rousseau et al., 2003). According to the meteorological data at Tianchi from 2001 to 2006, the wind directions in this area were dominated by northwest or southeast winds. The frequency of southeast mountain wind is low from June to August while the northwest valley wind reaches the highest value in the transition of spring and summer due to the special mountain and valley topography and has a remarkable influence on the transport and dispersion of pollen. The peak concentration of *Picea* pollen appears in early summer. As a result, *Picea* pollen percentage above the upper limit of *Picea* forest is higher than that below the lower limit of *Picea* forest stand. Studies in the California Inyo Mountains (Solomon and Silkworth, 1986), the Colorado Rocky Mountains (Fall, 1992b), the Niederhorn mountain/valley system (Markgraf, 1980) and in the central Jordan Rift (Davies and Fall, 2001) also demonstrated the conclusions (Fig. 3).

In addition, according to the results of correlation coefficient between airborne pollen concentration and wind velocity, the correlation coefficient of *Picea* is 0.394 with a significant correlation level at 0.05. In the study area, wind velocity is getting higher from April to June during the full-bloom stage of *Picea* and the pollen grains are easily carried upwards, which leads to the high content of *Picea* pollen above the upper limit of modern *Picea* forest. While in other seasons, the wind direction turns from northwest to southeast and the production of *Picea* is relatively low. As a consequence, there is a small amount of pollen carried from high elevation to the lower areas.

3.3 Typical herb pollen and vegetation

Chenopodiaceae and *Artemisia* are dominant species in the desert communities with high pollen percentage. The relationship between Chenopodiaceae, *Artemisia* and the amount of their pollen explains the connection of surface pollen assemblage and desert vegetation. Previous investigations in Xinjiang showed that when the vegetation coverage of some dominant species reaches 30%, their pollen content is equal to their coverage. But if a low coverage and a high pollen content appear together, it likely results from a large production of pollen grains. However, it is easy to understand the relationship between their plants and pollen of Chenopodiaceae and *Artemisia* because their pollen grains mostly fall around the plant. In the *Artemisia* desert along the transect, *Artemisia* pollen content is 31.2%–64.0% and the coverage of *Artemisia* species is 0.3%–33.4%; in typical desert, Chenopodiaceae pollen content is 25.4%–72.4% and their plant coverage is 5.6%–56.3%. Therefore, when pollen assemblage is dominated by Chenopodiaceae and *Artemisia*, their pollen amounts reflect the modern vegetation characteristics. High amounts of *Artemisia* pollen spectra represent *Artemisia* desert vegetation landscape. In contrast, the desert at lower elevations is characterized by the great amount of Chenopodiaceae pollen. Airborne pollen from the north slope of the Tianshan Mountains (Yang, 2004; Mao, 2008) showed that Chenopodiaceae and *Artemisia* are over-represented in Tianchi area. But in Beishawo area, Chenopodiaceae is well-represented, just as the *Artemisia* in Fukang area, which was demonstrated by Li et al. (2005). Species of Chenopodiaceae and *Artemisia* in modern vegetation above 1,230 m don't appear frequently but their pollen amounts are not low in pollen assemblages (Fig. 3). The researches of airborne pollen in the Tianchi area proved that the major portion of Chenopodiaceae and *Artemisia* pollen are brought from *Artemisia* desert and typical desert by updraft (Yang, 2004).

4 Conclusions

This research demonstrated a strong relationship between vegetation and surface pollen spectra along the transect from 3,510 to 460 m on the north slope of the Middle Tianshan Mountains.

Pollen assemblages in the surface soil layers basically reflect the characteristics of the mountainous vegetation patterns on the north slope of the Middle Tianshan Mountains. Among all pollen, considerable amount of surface pollen come from vegetation in original places. However, there are some differences between surface pollen spectra and vegetation zones. Some boundaries of pollen assemblage and modern vegetation zone are different, for example, the elevational span of *Picea* pollen zone is higher than that of *Picea* forest. Percentages of *Picea*, Chenopodiaceae and *Artemisia* pollen are much higher than their relative coverage in modern vegetation. They have over-representation. Moreover, *Picea* pollen exists outside the *Picea* forest, and Chenopodiaceae and *Artemisia* pollen are distributed above 1,300 m elevation, indicating that most of them are foreign pollen carried by updraft.

When pollen assemblage is dominated by Chenopodiaceae and *Artemisia*, their pollen amount can be used to define modern vegetation characteristics. In this case, the pollen percentages and taxa coverage in modern vegetation are basically equivalent. Therefore, the ratio of Chenopodiaceae to *Artemisia* in pollen assemblage can reflect arid characteristics of modern vegetation in arid area.

Most pollen and spore are dispersed by the highly-frequent northwester wind on the north slope of the Tianshan Mountains. It is proved by the results of airborne pollen research in three different elevation regions on the north slope of the Middle Tianshan Mountains. The *Picea* pollen of spruce forest and eremophytes pollen at lower elevations are usually transported to higher elevations. It is difficult to recognize vegetation patterns on the basis of surface pollen assemblage in the high elevation zones. Therefore, the modern vegetation and long distance wind transport must be taken into account for the interpretation of surface pollen in the Quaternary sediment analysis.

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