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Pollen transport in the Shiyang River drainage, arid China

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Abstract **In order to assess the contribution of the pollen transported by wind and fluvial flows to the pollen spectra in Shiyang River drainage, a typical small endorheic drainage in arid lands of northwest China, preliminary studies on modern pollen rain along two transects with 91 surface soil samples, 8 atmospheric samples, 30 modern fluvial flow samples and 50 riverbed mud samples, were carried out. Results show that dispersal agents (air, flowing water) have dissimilar effects on transport of pollen and the structure of pollen spectra. Fluvial flow has a stronger capacity than wind to transport large quantities of pollen over long distances. Pollen transported by fluvial flow makes a large contribution to the pollen spectra of riverbed alluvial sediments. Paleoenvironmental reconstructions undertaken using pollen spectra from fluvial sediments in arid lands are strongly influenced by pollen transport. Therefore, the sources, the transportation agents and the depositional condition of pollen should be systematically investigated before pollen assemblages are used to derive the environmental significance in such settings.**

Keywords: modern pollen transport, arid regions, Shiyang River drainage.

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The arid lands of central Asia, located in the mid-latitudes of the Eurasia continent, have been extensively studied in recent years due to their significant contribution or sensitive response to global changes[1—7]. In such regions, however, rare geological records can be well preserved due to the erosional environment. Pollen trapped by lake sediments, therefore, provides excellent evidence for past environment, especially for climate-related vegetation change. However, most of the lakes in the Gobi-desert regions are open lakes supplied by rivers originating in high mountains, which pass through multiple vegetation zones within short distances before terminating in desert lakes[8]. Previous research has shown that much of the pollen in the sediments of terminal lakes is transported by fluvial flow[9—11]; under deteriorated climate when the vegetation is degraded and vegetation cover around the lake very sparse, the percentages of pollen from external sources in the pollen spectra from lake sediments are even higher[10]. Similarly, in arid regions, strong winds and flash floods are common: both can carry pollen long distances. As the local vegetation coverage in arid lands is low, resulting in small total amount of local pollen, the pollen assemblage from lake sediments may be dominated by the external pollen[12]. Influenced by both the characteristics of water system of endorheic drainages and geography of arid lands, the interpretation or paleoenvironmental reconstruction of pollen data from lakes in arid lands are more complex than elsewhere. It is essential to assess the pollen sources, the transportation processes, and environmental significances before the pollen assemblages from such lakes are used to reconstruct past environment.

Here we present a systematic analysis of the pollen transported by aeolian and fluvial processes to a typical small endorheic drainage in the Shiyang River drainage of the arid lands of northwest China, together with an evaluation of their transporting capacity.

1 Setting

The Shiyang River drainage (100°57′ E—104°57′ E; 37°02′ N—39°17′ N) lies on the northern side of the Qilian Mountain and extends to the eastern corner of the Hexi Corridor. A flood plain and the Gobi Desert lie between the southern margin of a paleolake and the northern margin of the Qilian Mountains. To the north of the paleolake is an alluvial plain and sandy desert. The climate situation in the southern portion of the drainage is cool temperate and semi-arid, while in the middle and northern portion, temperate and arid climate prevails. The dominant wind direction in winter is northwest as a result of the Mongolian High and the westerlies. In summer, the Asian southeast monsoon extends to Central China, resulting in southeast wind in the drainage area. The distribution of modern vegetation in the drainage is strongly related to elevation: a perennial snow and ice zone (> 4500 m); a cushion-like vegetation zone (4500—3800 m); a meadow zone (3800—3500 m); an alpine shrub zone (3500—3100 m); a *Picea* and *Sabina* forest zone (3100—2500 m); a mountainous grassland zone (2500—2350 m); a desert grass zone (2350—2000 m) and a Gobi-sand desert zone (< 2000 m)[13,14] (Fig. 1). The Shiyang River, the main river supplying the paleolake, originates from the northern side of eastern Qilian Mountains, flowing northward and disappearing between the Tengger and Badain Jaran Deserts in its lower reaches.

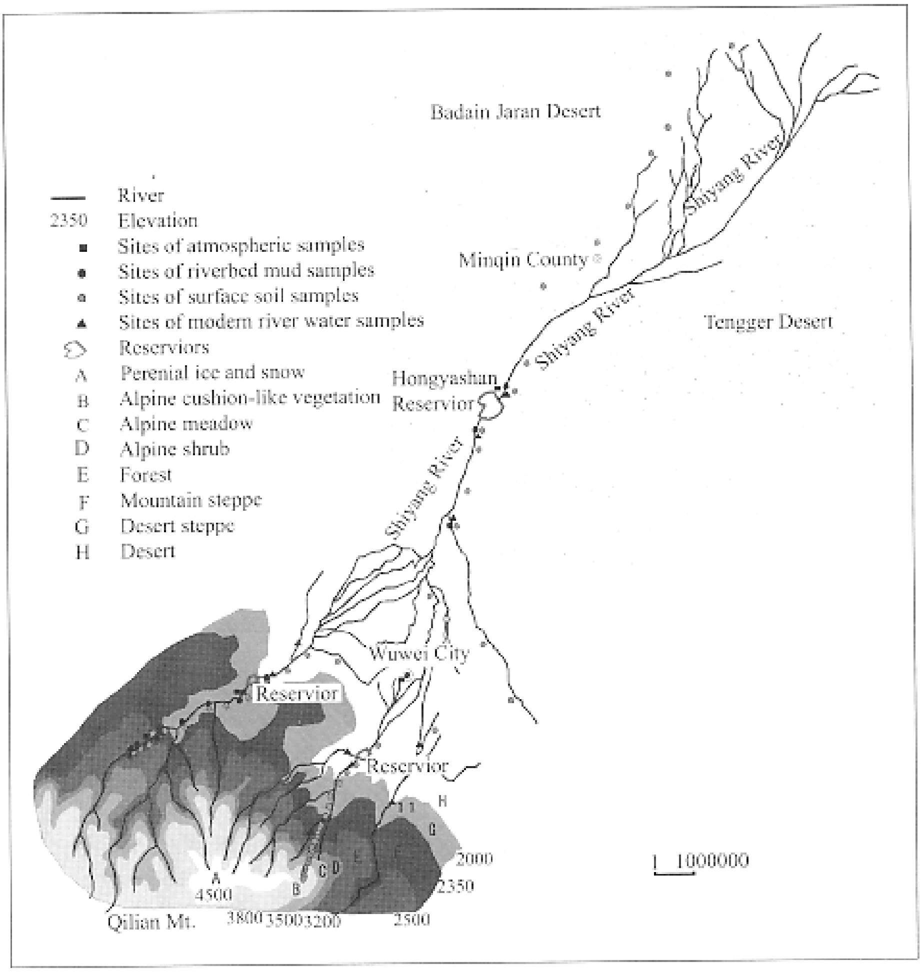

Fig. 1. Modern pollen sampling sites in the Shiyang River drainage.

2 Materials and methods

(ⅰ) Sampling. Four types of modern pollen samples were collected at a number of sites in the catchment, namely atmospheric, surface soil, fluvial flow and riverbed mud (Fig. 1). Along the two transects shown in Fig. 1, 91 surface soil samples were collected in total. This paper only presents the results of the second transect, from forest margin at the upper reaches of the Xiying River to the terminal paleolake in the desert. Eight atmospheric samples were collected at three sites in the middle and lower reaches, Wugou Village, Wuwei City and the outlet of Hongyashan Reservoir. Thirty water samples were collected at 15 sites from the lowest forest limit along the river to the outlet of the reservoir before and after two periods of rainfall. Because the water diminishes rapidly in the lower reaches down to the reservoir, no water samples were collected from this part of the river. Instead, 50 riverbed samples were taken at 32 sites (Fig. 1). Surface soil or sand, in the absence of soil, were sampled directly. Atmospheric samples were collected in the flowering season of *Picea* (June 10—July 30, 2001) because the primary component of pollen assemblages from the lake sediments in Shiyang River drainage is *Picea*[15] and the concentration of pollen in the air is the highest in its flowering season[16]. Two methods were employed to sample the air-borne pollen. The first is filtration with an electric KB-120 TSP (Total suspended particle) collector by pumping airflow in and out of the collector in which a filtration paper is fixed. This method was used in Wugou Village and Wuwei City. The second is adhibition with oil-coated cloth supported by a wooden frame, trapping pollen in the air. This method was used in Wugou Village and the outlet of the Hongyashan Reservoir. With the second method, the concentration of *Picea* in the pollen assemblages should provide information about the maximum capacity of air to transport *Picea* pollen. Riverbed mud samples were taken by collecting the surface sediments under water flow in the river.

(ⅱ) Pretreatment. The samples of surface soils and sediments from the riverbeds are weighed after they are dried at a low temperature (50℃). Tablets of *Lycopodium* L. spores (12524 grains/tablet) were added to each sample. The following procedures are identical to ref. [16]. For the atmospheric samples collected by TSP collector, the filtration paper with pollen absorbed was put into distilled water. After the pollen is washed in the water, the filtration paper was removed. The water was then filtered through a 6-μm mesh in an ultrasonic cleaner. The remains above the filtration cloth were purified with HF and glycerin. The atmospheric samples collected with oil-coated cloth were dissolved in an alkaline liquid. Tablets of *Lycopodium* L. spores were also added before filtration of the samples in the ultrasonic cleaner. HCl and HF were used to process the residues on the filtration cloth. Fluvial flow samples were processed according to ref. [17].

More than 500 and 300 pollen grains are identified under the microscope for the surface soil samples and the riverbed mud samples, respectively. For the flow samples, if the pollen concentration was high, more than 300 grains were counted, whereas all the grains collected were counted in low concentration samples.

3 Results

Over 60 taxa were identified from all the samples. According to relationship between the pollen assemblages and the distribution of modern vegetation in the whole drainage, all pollen taxa can be divided into four ecological groups. The first group is extra-regional pollen, such as *Cedrus*, with very low percentage, probably transported by long distances by strong winds. This group can be ignored when interpreting the pollen assemblages. The second group comprises the pollen taxa from upland vegetation, especially from the forest zones, represented by *Sabina*, *Juniperus*, *Picea*, *Betula*, *Corylus*, *Ulmus*, *Quercus*, *Salix*, *Acer*, *Selaginella*, *Polypodium*, Caprifoliaceae, Ericaceae, amongst others. The third group contains the pollen taxa from lower reaches of the drainage, the desert vegetation zones, and includes *Nitraria*, *Calligonum*, *Ephedra*, *Zygoghyllum*, *Tribilus*, Plumbaginaceae, Tama- ricaceae and Elaeagnaceae. Finally, the fourth group is the regional vegetation taxa, represented by Rosaceae, Leguminosae, Rhamnaceae, Gramineae, Compositae, Chenopodiaceae, Cyperaceae, *Artemisia* and *Polygonum*. They are from plants growing widely in the drainage and it is hard to judge their exact sources, whether from uplands or lowlands. As *Pinus* pollen is from a mixed source of natural vegetation in the upland and artificially planted vegetation throughout the drainage, it is classified in the fourth group. The results of surface soil and riverbed mud samples analyzed are presented by percentage spectra in the order of upland vegetation to lowland vegetation (Figs. 2 and 3). The results of flow samples are listed in ref. [18] and those of the atmospheric samples are shown in Table 1. Because of the extremely low content of aquatic plant pollen, the pollen percentage was calculated according to the total number of pollen grains.

According to Fig. 2, two types of pollen assemblage can be distinguished from the surface soil pollen spectra. Above the steppe desert vegetation zone, the pollen assemblages are dominated by *Picea* pollen, and so cannot reflect the nature of local vegetation except in forest zone. Below the steppe desert vegetation zone, the pollen assemblage still has a percentage of the pollen of the second group, but because the amount of the pollen of local vegetation is increased, it can provide an approximation for the local vegetation. The characteristic of atmospheric pollen assemblage (Table 1) is similar to that of surface samples; it is dominated by *Picea* pollen above the steppe desert vegetation zone, and thus cannot reflect the local vegetation. The pollen assemblages in the middle and lower reaches are equivalent to the local vegetation at the sampling site. The pollen assemblages of flow samples in natural condition consist primarily of two kinds of pollen and spores: one kind is derived from the uplands and includes the second and the fourth pollen groups, the other is from the local vegetation and includes the third and the fourth pollen groups. Furthermore, upland pollen is a primary component. So the pollen assemblages of the flow samples cannot reflect local vegetation. The pollen assemblages of riverbed mud samples do not reflect local vegetation, because the pollen assemblages of all the samples are similar (Fig. 3), being dominated by upland pollen.

In all, within a range of 50 km distance from the tree line, the pollen assemblages of atmospheric samples and surface soil samples, which are influenced by pollen of forest zones are mostly dominated by *Picea* pollen, and do not reflect nature of local vegetation. Beyond this range, the pollen assemblages and the pattern of local vegetation are basically in agreement. The pollen assemblages of riverbed mud samples and flow samples, which represent nature of flow transport, have a very high upland pollen content and therefore do not reflect the local vegetation, either.

4 Discussion and conclusion

(i) In the Shiyang River drainage, the capacity of wind to transport pollen is relatively strong. The research into wind transportation of *Picea* pollen by Li[18] shows that the percentage of *Picea* pollen from surface soil samples is over 50%, with a maximum of 84.2%, in the pure *Picea* forest. 500 m away from the *Picea* forest, however, the percentage of *Picea* pollen falls to 1%: this is in agreement with previous studies[19—21]. However, the range of influence of *Picea* pollen transported by wind in the Shiyang River drainage is wider than in other regions. The absolute concentration of *Picea* pollen decreases with distance from *Picea* forest; however, within 50 km, the absolute amount of *Picea* pollen is still high. In addition,

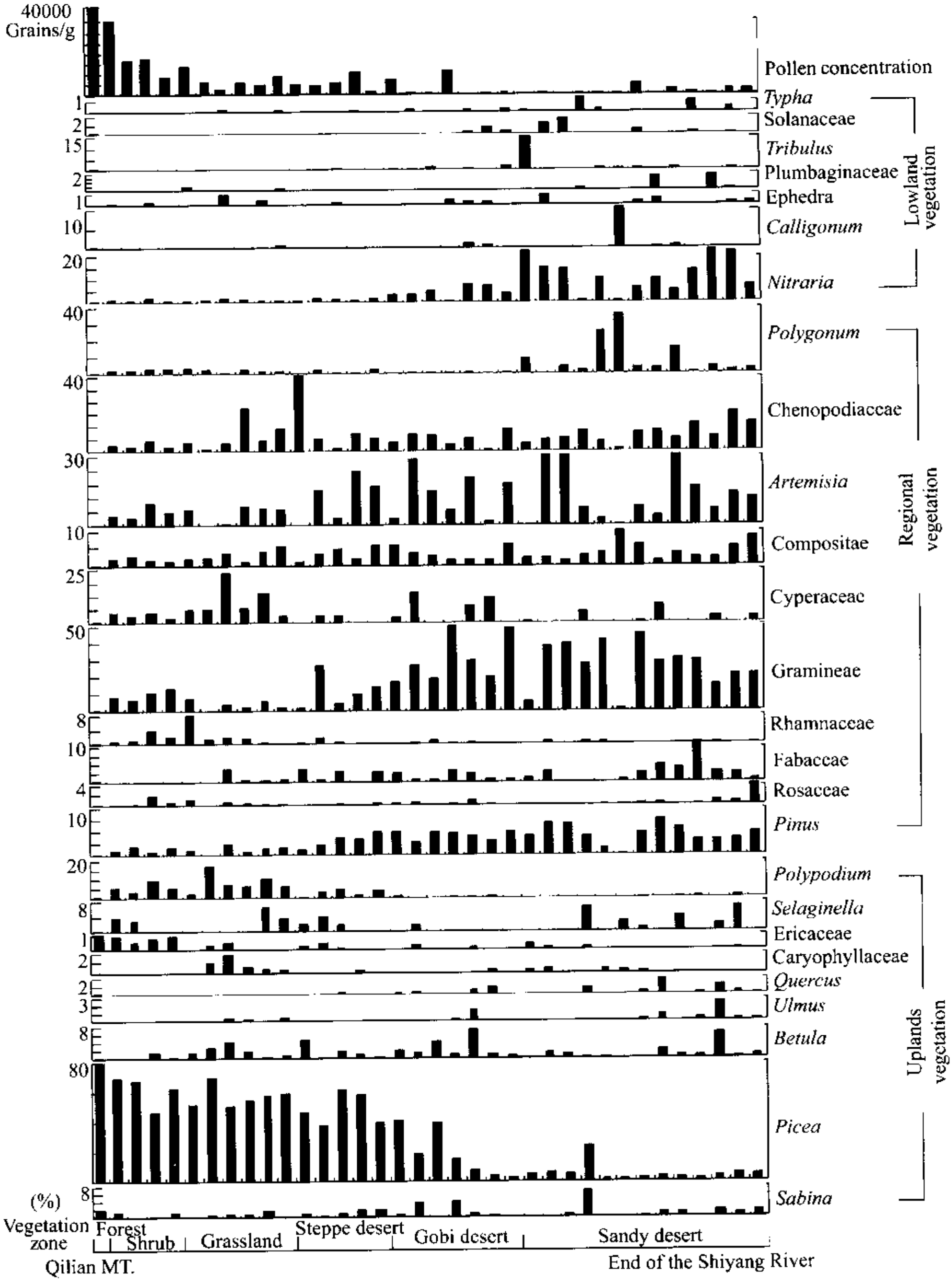

Fig. 2. Pollen spectrum of surface soil samples along the Xiying River and the Shiyang River (percentage values).

whereas the amount of local pollen in arid lands is small, because the local vegetation is so barren, the percentage of *Picea* pollen is very high in the pollen spectra. Hence there is a poor relationship between the pollen assemblage of surface soil and atmospheric samples and the pattern of vegetation, and both types of pollen spectra provide a poor reflection of local vegetation. However, the effective range of the wind is narrow, so the wind contribution to pollen spectra diminishes rapidly beyond 50 km from the forest, and the pollen spectra reflect the local vegetation.

(ii) The pollen-transporting power of water is much greater than that of wind. According to Fig. 4, the percentage of the second pollen group transported by wind in surface soil and atmospheric samples falls quickly from the upper to the lower reaches, while the amplitude of changes of the second pollen group from fluvial flow and

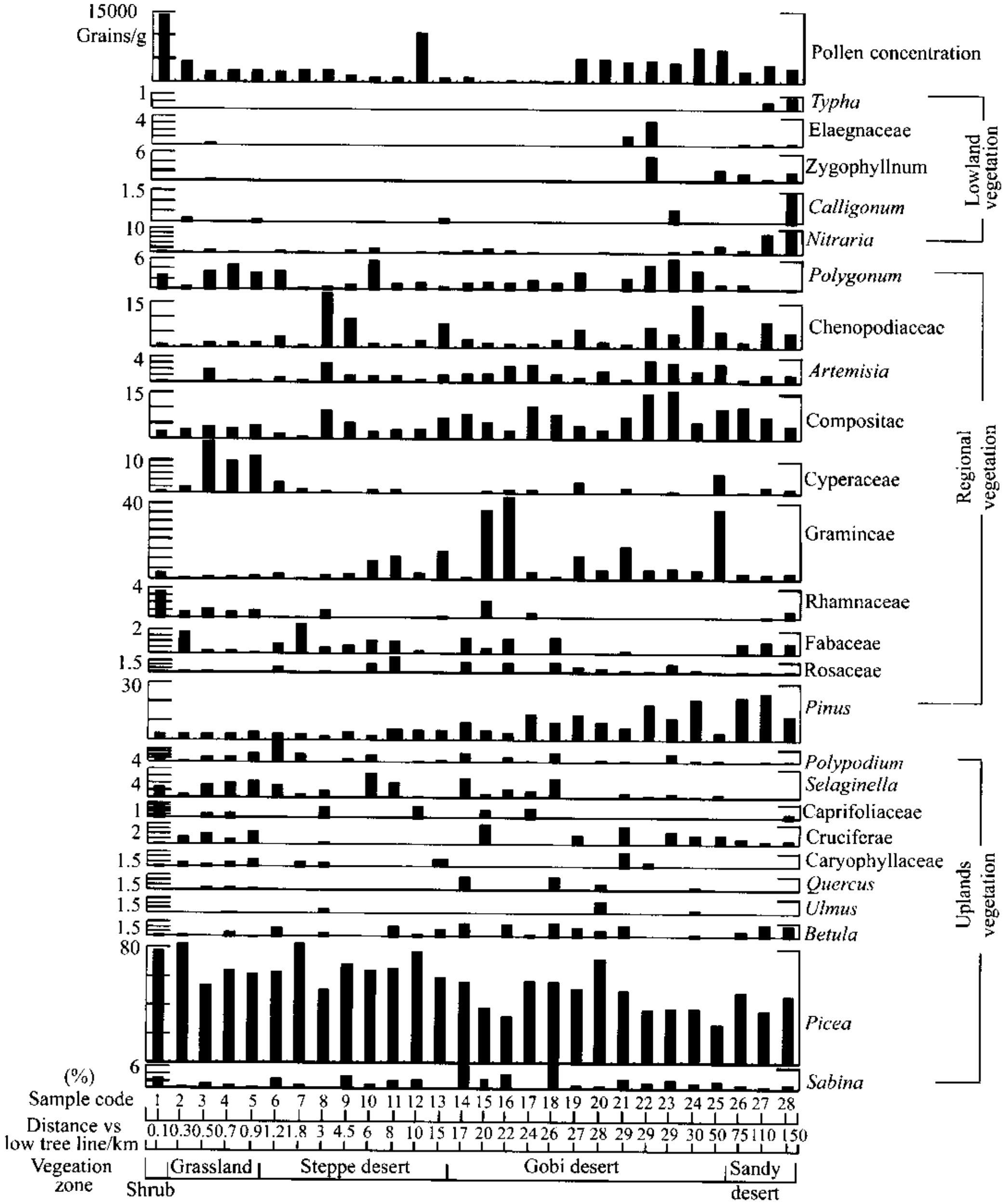

Fig. 3. Pollen spectrum of fluvial sediment samples (percentage values). Samples 1—14 are located at the river bed of the Xiying River. Samples 15—18 are from the outlet of the Xiying reservoir where most of the pollen from the upper reaches of the river is deposited. Pollen concentrations are low at this site. Samples 19—24 are from the bed of the Zamu River. Samples 22—24 are from 5, 25 and 50 cm, respectively, from the same sample site. Samples 25 and 26 are from the bed of the Hongshui River; samples 27 and 28 are from the bed of the Shiyang River.

riverbed mud samples is comparatively small. Further, in the middle and lower reaches of the drainage, the percentage of upland pollen in samples transported by flow is much higher than that of the samples transported by wind.

(iii) Pollen transported by fluvial flow has a large contribution to the pollen spectra in the alluvial sediments in lower reaches of the catchment. Pollen assemblages in river-bed mud samples represent the accumulation of pollen transported by flow over a relatively long time, whereas the samples from river flow represent pollen transport at a single point in time. Theoretically, the upland pollen in riverbed mud and water flowsamples can be transported by both wind and flow to the sampling site. Thus in flow and river mud samples, the contribution of flow equals the percentage of upland pollen minus that of surface soil or atmospheric samples. Based on this, in the

Table 1 Main pollen taxa and their percentage in atmospheric samples

Sites	Wugou Village				Wuwei	Hongyashan Reservoir		
Distance from lower tree line	30 km				50 km	140 km		
(%) Code	KQ-	KQ-1	KQ-5	KQ-6	KQ-Ⅱ	KQ-2	KQ-3	KQ-4
Sabina	2.59	1.33	1.75	1.24	1.69	1.18	1.63	0.66
Picea	2.41	14.22	31.07	9.91	1.69	3.62	2.91	3.01
Pinus	1.03	2.00	1.75	2.79	0.85	10.94	4.71	4.63
Betula	1.55	0.00	0.00	0.31	0.85	1.02	1.20	2.16
Quercus	0.00	0.22	0.00	0.00	0.00	0.31	0.17	0.30
Populus	8.79	1.11	0.00	0.00	4.24	0.16	0.00	0.00
Ranunculaceae	1.90	0.00	0.00	0.00	6.78	0.00	0.00	0.30
Humulus	1.03	0.00	0.22	0.00	0.00	0.94	0.43	0.12
Thalictrum	0.69	0.00	0.00	0.62	0.00	0.16	0.17	0.54
Cruciferae	1.72	0.00	0.00	0.31	0.85	0.08	00.17	0.54
Plantago	0.34	0.00	0.00	0.31	0.00	0.08	0.00	0.18
Caryophyllaceae	2.41	0.22	0.00	0.00	1.69	0.00	0.09	0.60
Corylus	4.14	0.67	1.31	1.24	15.25	0.08	0.43	1.02
Fern	0.00	0.22	0.88	0.31	0.00	0.08	0.00	0.18
Rosaceae	2.41	0.22	0.44	1.24	0.00	2.52	0.09	2.22
Leguminosae	4.66	0.67	0.88	0.62	0.85	1.26	0.60	2.53
Rhamnaceae	0.52	0.00	0.00	0.62	0.00	0.16	0.51	0.24
Cyperaceae	6.03	0.67	0.66	0.00	5.08	5.66	1.03	4.09
Gramineae	22.24	21.11	35.01	40.25	15.25	12.04	16.44	13.59
Compositae	1.38	1.78	1.75	4.64	0.85	4.80	5.65	4.39
Artemisia	6.21	9.33	2.84	11.76	11.02	0.71	2.57	0.66
Chenopodiaceae	10.86	22.67	9.63	11.46	12.71	4.56	7.11	4.09
Polygonum	0.34	1.33	0.66	0.93	0.00	1.81	1.97	1.02
Elaeagnaceae	0.34	0.44	0.44	0.00	0.85	2.75	3.68	2.35
Tamaricaceae	1.21	0.44	0.00	0.00	0.85	0.00	0.00	0.00
Nitraria	4.14	15.11	7.66	8.98	3.39	34.07	30.39	32.96
Calligonum	1.72	0.00	0.00	0.93	0.00	6.06	11.30	11.12
Ephedra	0.86	1.11	0.88	0.62	6.78	1.26	0.86	2.95
Tribilus	0.00	0.44	0.44	0.00	0.85	0.16	0.17	0.06
Zygoghyllum	6.21	0.00	0.00	0.00	1.69	0.00	0.00	0.06
Typha	0.00	0.67	0.44	0.00	0.00	2.68	3.17	2.65
Pollen sum	580	450	457	323	142	1271	1168	1663
Concentration/grains g^{-1}		4545	3609	13968		46752	11732	13703
Concentration/grains cm^{-2}		1.8	1.44	5.6		18.7	4.6	5.4

percentage pollen spectra of flow transporting samples in two sampling sites of the middle and lower reaches, we calculate the mean contribution and the instantaneous contribution of fluvial flow. The mean contribution is represented by the difference between the percentage of riverbed mud samples and that of surface soil samples, and the instantaneous contribution is presented by the difference between the percentage of fluvial flow samples and that of surface soil samples (Table 2). According to the results, the contribution of the pollen transported by fluvial flow in the percentage pollen assemblage of flow and riverbed mud samples is extremely large. The absolute concentration of flow contribution can also be calculated in the sampling site mentioned above by the same principle.

(ⅳ) In the Shiyang River drainage, the difference between the four types of modern pollen spectrum at one site is very large. This difference has great significance for paleoenvironmental reconstruction with pollen records. Firstly, dispersal agents cause the different representation of pollen assemblage. For example, in the lower reaches of the catchment, the pollen assemblage from surface soil and atmospheric samples reflect local vegetation, whereas those from river flow and riverbed mud samples do not, since they contain large amounts of upland pollen. Thus the effect of dispersal agents among pollen assemblages must be considered when using pollen records to reconstruct paleoenvironment in arid lands. Secondly, the geographic environment features of the research area cause the different representation of pollen assemblage in different sampling sites for the same agent. For example, due to the larger productivity of *Picea* pollen and the stronger wind in arid lands, the pollen assemblage of surface soil samples from the steppe desert to the tree line do not reflect local vegetation patterns. However, pollen assemblages of surface soil samples below the desert vegetation zone may represent local vegetation. Therefore, in arid lands, the differential contributions from various

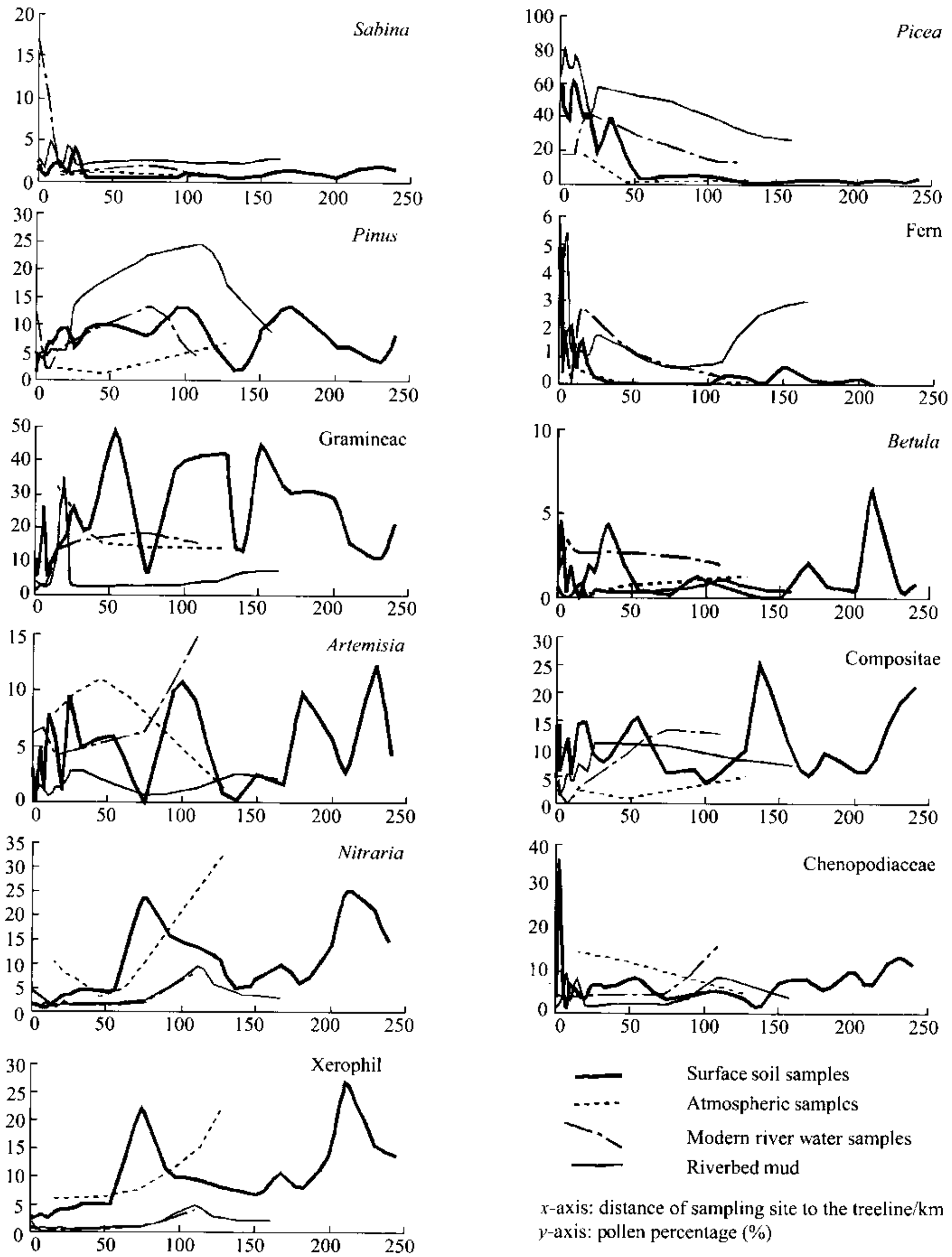

Fig. 4. Variation of primary taxa from modern pollen samples in the Shiyang River drainage.

geographical areas must be considered when using pollen records to reconstruct paleoenvironment. Thirdly, due to the effect of pollen transported by flow, the structure of pollen spectra and its environmental significance may become more complex depending on the sediment type studied. Pollen records used to reconstruct paleoenviroment related to fluvial sediments are mostly from lakes, oceans, deltas and rivers. Especially in arid lands, the sediments used to reconstruct paleoenviroment are almost all related to sediments transported by fluvial current except sands that are transported by wind. Results of pollen transport in the Shiyang River drainage show that fluvial flow has a stronger capacity than wind to transport large quantities of pollen over long distances. Furthermore, in

Table 2 Contribution of water-borne pollen in pollen assemblages from fluvial sediments and fluvial flow samples in the middle and lower reaches of the Shiyang River drainage

Sample sites	Distance from lower tree line		Percentage (%)				Concentration/grains g^{-1}			
			Picea	*Pinus*	*Sabina*	*Betula*	*Picea*	*Pinus*	*Sabina*	*Betula*
Chongxing town		Fluvial flow	9	4.1	1	2.1				
(38°21′30″)		Fluvial sediments	37.1	24.7	0.8	1.26	1328	885	44	45
	110 km	Surface soil	1.3	2.6	0.4	1	156	53	28	2
(102°48′54″)		Average contribution	35.8	21.9	0.4	0.26	1172	832	16	43
		Instantaneous contribution	7.7	1.5	0.6	1.1				
Hongshui		Fluvial flow	21.4	13.4	2.2	2.7				
River bridge		Fluvial sediments	49.5	22.3	1.1	0.6	1240	560	59	14
(38°12′06″)	75 km	Surface soil	5.1	8.1	0.3	0.1	38	61	27	1
(102°46′20″)		Average contribution	44.5	14.2	0.8	0.5	1202	499	32	13
		Instantaneous contribution	16.3	5.3	1.8	2.6				

the arid lands of the research area, the Shiyang River passes through multiple vegetation zones over a short distance and transports large amount of upland pollen to the lowlands, where either the local vegetation coverage or total pollen productivity is so low that local pollen assemblages are overwhelmed by allochthonous pollen from uplands. This is also proved by our result that in the four types of modern pollen spectra, those from the river-bed mud samples exhibit the most obvious difference to the local vegetation composition. Thus the pollen transported by flow is extremely likely to be the primary component of pollen spectra from lake sediments in the lower reaches. Conclusively, in arid regions like the Shiyang River drainage, caution must be paid when pollen records from sediments related to fluvial flow are used to reconstruct paleoenvironment. The sources of pollen, the transportation agents and the depositional condition of the study site should be well understood in order to derive the environmental significance of the pollen assemblages before we can use the pollen data in reconstruction.

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