Relationship Between Surface Soil Pollen and Spores and Vegetation in the Qaidam Basin (Postprint)

Authors: Zhao Nannan, Yang Zhenjing, Ning Kai, Yang Qinghua, Bi Zhiwei, Wang Pan

Date: 2020-06-09T00:00:00+00:00

Abstract

Through surface soil pollen analysis and vegetation quadrat surveys at 124 sample sites in the Qaidam Basin, this study investigated the correspondence between surface soil pollen and vegetation. The results indicate that surface soil pollen assemblages in the Qaidam Basin can effectively reflect local vegetation characteristics, though differences exist in specific family and genus composition. Pollen R-values for Chenopodiaceae, Artemisia, and Ephedra exceed 1, exhibiting over-representation; those for Tamarix and Asteraceae are less than 1, showing under-representation but possessing certain indicative significance for vegetation. Poaceae and Nitraria pollen demonstrate under-representation at most sample sites, yet Poaceae pollen exhibits moderate representation at constructive species sites, while Nitraria pollen shows moderate representation in saline-alkali areas. The percentages of major family and genus pollen correlate with vegetation coverage, with Poaceae, Cyperaceae, Asteraceae, and Tamarix showing relatively high correlations, enabling the establishment of corresponding functional relationships. Vegetation-free areas in the western basin still contain substantial pollen, primarily over-represented types from Chenopodiaceae, Artemisia, Ephedra, and Pinus. The Artemisia to Chenopodiaceae pollen ratio (A/C) demonstrates a decreasing southeast-to-northwest trend, corresponding well to the basin’ s gradually arid environmental characteristics from southeast to northwest. Principal component analysis of major herb and shrub surface soil pollen data reveals that pollen assemblages in this region are primarily controlled by hydrological conditions and soil salinity-alkalinity.

Full Text

Preamble

Relationship between Surface Pollen and Vegetation in the Qaidam Basin

ZHAO Nan-nan, YANG Zhen-jing, NING Kai, YANG Qing-hua, BI Zhi-wei, WANG Pan

Institute of Hydrogeology and Environmental Geology, Chinese Academy of Geological Sciences, Shijiazhuang 0500061, Hebei, China

Abstract: In order to investigate the relationship between surface pollen and modern vegetation, in total 124 surface pollen samples collected from Qaidam basin have been analyzed. The result shows that the corresponding relationship between pollen assemblages of surface samples and main vegetation types is significant, however, pollen assemblages of surface samples cannot fully reflect the composition of families and genera. R values of Chenopodiaceae, Artemisia and Ephedra are greater than 1, indicating these three pollen types are super representative. R values of Tamarix and Compositae are less than 1, showing these two pollen taxa having low representativeness for their coverages. Further, Gramineae and Nitratia has low representation in most samples. But Gramineae has better representativeness in areas where it' s the constructive or dominant species in plant communities, and Nitraria in alkali region has moderate representativeness. There is a certain correlation between the pollen percentage of main families and vegetation coverage, and higher correlations can be established for Gramineae, Cyperaceae, Compositae, and Tamarix. Pollen in the non-vegetation regions is mainly composed of Chenopodiaceae, Artemisia and Ephedra. Ratio of Artemisia to Chenopodiaceae (A/C) shows a decreasing trend from southeast to northwest, corresponding well to the environmental characteristics of the basin that is changing gradually drier from southeast to northwest. Principal component analysis of the main herbaceous and shrub pollen shows that the pollen distribution in this area is mainly controlled by hydrological condition and soil pH value.

Key words: pollen representation; R values; pollen percentages; vegetation coverage; ratio of Artemisia to Chenopodiaceae; principal component analysis; Qaidam basin

The Qaidam Basin is rich in natural resources and known as the "Treasure Basin," playing an important role in China' s "Western Development Strategy" and serving as one of the first national-level circular economy experimental industrial parks [1-2]. However, in recent years the basin has faced problems such as vegetation degradation, expanding desertification, and deteriorating natural environment [3]. To balance economic development and environmental protection, it is essential to understand past environmental evolution patterns, modern environmental characteristics, and future environmental trends. One of the primary and fundamental tasks is investigating the distribution of surface pollen and its correspondence with modern vegetation [4-5]. Located on the northern edge of the Tibetan Plateau, the basin lies in the transition zone between monsoon and non-monsoon regions, with a dry and cold climate and sparse human activity, making its vegetation sensitive to environmental changes [6-7]—an ideal area for investigating relationships among pollen, vegetation, and environment. Wang [8] studied the representativeness of major pollen types in different communities in the northeastern basin; Zhao et al. [9] found through comparison of surface pollen and lake sediment pollen that surface pollen better reflects local vegetation, while lake sediment pollen mainly reflects pollen sources; Zhang et al. [10] discovered through analysis of modern surface pollen in the eastern basin that precipitation is the main factor affecting vegetation distribution and pollen grain size. Previous studies on surface pollen in the Qaidam Basin have focused on local areas [8-11], failing to summarize overall variation characteristics of basin pollen and their causes, with quantitative relationships between pollen and vegetation being somewhat insufficient. Building on this foundation, this study covers the entire Qaidam Basin with a large scope, numerous sampling points, and comprehensively investigates distribution characteristics and influencing factors of surface pollen. Simultaneously, multiple parameters are used to analyze pollen representativeness and quantitative relationships with vegetation, aiming to provide references for paleovegetation and paleoenvironment reconstruction in the Qaidam Basin.

1 Materials and Methods

1.1 Study Area Natural Overview

The Qaidam Basin is located at 34°45 ~39°20 N, 87°49 ~99°17 E, with an elevation of 2650~3350 m, representing China’ s highest-altitude inland basin and desert distribution area [12]. The basin is surrounded by mountains, with the Elashan, Kunlun, Altun, and Qilian mountains to its east, south, northwest, and northeast respectively. Situated in the transition zone between monsoon and westerly wind regions, the basin is highly sensitive to climate and environmental changes [13-14]. The climate is characterized as inland arid and alpine, with precipitation concentrated in summer. Annual precipitation is 300 mm in the southeast, 20 mm in the northwest, and less than 5 mm in desert areas, showing an overall decreasing trend from southeast to northwest and from periphery to center [15]. The mean annual temperature is 3.5°C, with January averaging approximately -12°C and July approximately 16°C, increasing from surrounding mountains to the central desert area [16]. The basin experiences abundant sunshine and strong evaporation, dominated by Gobi wind-sand landforms, with large saline-alkali areas distributed in the central and northwestern regions. These climatic and environmental characteristics result in sparse vegetation, consisting only of a few drought-tolerant species. Vegetation coverage generally decreases from southeast to northwest, with desert steppe in the southeast, shrubs predominating in the center, and non-vegetated areas in the northwest [17].

1.2 Sample Collection and Identification

Sampling was conducted along transects around the Qaidam Basin and in typical central areas. The principle was to select one sampling point every 20 km of horizontal distance in natural vegetation areas without human disturbance, simultaneously conducting surface soil collection and vegetation surveys (Figure 1 [Figure 1: see original paper]). Vegetation quadrat survey methods included 1 m$\times$1 m herb layer surveys, 5 m$\times$5 m shrub surveys, and 10 m$\times$10 m tree surveys depending on actual conditions, recording plant coverage, richness, species composition, and other characteristics. GPS positioning was used to accurately record longitude, latitude, and elevation of each quadrat. Surface soil samples (primarily the top 0.5 cm) were collected using the "plum blossom sampling method" within each quadrat. Vegetation quadrats and surface soil samples were numbered according to collection sequence, yielding 124 surface pollen samples with corresponding vegetation surveys (Figure 1 [Figure 1: see original paper]).

During laboratory analysis, 50~150 g was taken from each sample based on lithology and vegetation survey conditions, with 300 g taken from coarse sandy gravel samples from the western and central basin. Conventional acid-alkali treatment and sieving methods were used for pollen extraction. Pollen identification and counting were performed using an Olympus optical microscope at 40$\times$10 magnification, with most samples containing over 400 pollen grains. Pollen analysis results were calculated as percentages based on the total sum of terrestrial plant pollen for major pollen types in the Qaidam Basin.

1.3 Data Processing

Pollen percentage diagrams and vegetation coverage diagrams were drawn using Tilia 1.7.16. Canoco 4.5 was used for principal component analysis (PCA) of logarithms of major family pollen percentages, and PCA factor relationship diagrams were drawn. Pollen representativeness was discussed using R values of typical families and genera [18], where the Rik value of species k at site i [19] can be expressed as: $R_{ik} = P_{ik}/V_{ik}$; that is, the ratio between pollen proportion (Pik) and plant proportion (Vik) of species k at site i. R values for n sampling points were estimated using arithmetic averaging: $R_k = \sum(P_{ik}/V_{ik})$. The relationship between pollen percentage and vegetation coverage was shown using scatter plots (with pollen percentage on the vertical axis and vegetation coverage on the horizontal axis), with specific functional relationships provided for families showing significant correlations.

2 Results

2.1 Characteristics of Surface Pollen in Typical Vegetation Types

Based on vegetation quadrat survey results in the Qaidam Basin, coverage of major families and genera was statistically analyzed (Figure 2 [Figure 2: see original paper]). Trees consisted only of Haloxylon ammodendron appearing at individual sites (mean coverage 0.7%). Shrubs were relatively common (mean coverage 5.54%), mainly including Ceratoides, Ephedra, Tamarix, and Nitraria. Herbs were most abundant (mean coverage 14.2%), including Gramineae, Compositae, Artemisia, Chenopodiaceae, Cyperaceae, and Cruciferae. A total of 56,397 pollen grains were identified from 124 samples (average 454 grains/sample), belonging to 37 families and genera, all extant species in the Qaidam Basin and adjacent areas. Tree pollen accounted for only 3.75%, mainly Pinus. Shrub pollen accounted for 13.56%, mainly Ephedra, Nitraria, and small amounts of Hippophae, Elaeagnus, Tamarix, Ceratoides, and Lonicera. Herbaceous pollen averaged 82.5%, with Chenopodiaceae being most abundant (51.1%), followed by Artemisia (17.6%), plus Gramineae, Cyperaceae, Compositae, Ranunculaceae, Cruciferae, Polygonum, and Typha. Based on surface pollen characteristics and modern vegetation surveys, the Qaidam Basin was divided into five vegetation zones (Figure 3 [Figure 3: see original paper]), with major pollen families and genera generally corresponding to surveyed vegetation.

Zone I (Desert Steppe Zone): 13 samples, mainly from the southeastern basin (Figure 1 [Figure 1: see original paper]). This zone primarily grows herbaceous plants (mean coverage 46.5%), with vegetation composition of Gramineae (15.6%)–Chenopodiaceae (12.7%)–Artemisia (6%)–Leguminosae (4.8%)–Cyperaceae (3.2%). Corresponding pollen assemblage is Chenopodiaceae (50.7%)–Artemisia (20.6%)–Nitraria (10.8%)–Gramineae (4.2%)–Ephedra (3.6%). Tamarix (1.7%), Nitraria (1.7%), and Ceratoides (1.2%) pollen were rarely counted. Leguminosae and Cyperaceae pollen contents were below 1%. Additionally, the pollen assemblage contained Pinus (4.5%) and small amounts of Typha, Polygonum, and Cruciferae, though no corresponding plants were found.

Zone II (Shrub Desert Zone): 28 samples (Figure 1 [Figure 1: see original paper]), mainly from around Golmud in the southern basin, with surface soil salinization appearing at multiple sites to the west. Mean vegetation coverage was 25%, with main composition of Gramineae (5.1%)–Chenopodiaceae (5.1%)–Compositae (1.7%)–Leguminosae (1.6%)–Ephedra (1.25%)–Nerium (1.1%)–Calligonum (0.9%). Pollen assemblage was Chenopodiaceae (43.8%)–Artemisia (15.3%)–Ephedra (11.1%)–Gramineae (9.1%)–Nitraria (7.4%)–Pinus (2.1%). Artemisia and small amounts of Cyperaceae, Ranunculaceae, and Cruciferae pollen in the assemblage were not found in vegetation surveys. Nerium (1.1%), Calligonum (0.9%), Ceratoides (0.9%), and Lycium ruthenicum showed no corresponding pollen. Tree vegetation (0.9%) was mainly Haloxylon ammodendron, appearing only at individual sites east of Golmud.

Zone III (Saline Desert Zone): Multiple sites showed salt crust crystallization, divided into two subzones (III and III). Subzone III from southwestern basin contained 19 samples (Figure 1 [Figure 1: see original paper]) with severe soil salinization, vegetation coverage of only 12.7%, and few species. Main vegetation families were Gramineae (salt-tolerant Phragmites, 7.9%)–Nitraria

(1.3%)–Ceratoides (1.3%)–Tamarix (0.9%). Corresponding pollen assemblage was Chenopodiaceae (60.4%)–Artemisia (10.3%)–Gramineae (7.4%)–Nitraria (6.1%)–Ephedra (3.3%)–Pinus (2.6%). However, Chenopodiaceae, Artemisia, and Ephedra plants were not found in vegetation surveys; Tamarix and Ceratoides pollen contents were below 0.5%.

Subzone III from central basin (Figure 1 [Figure 1: see original paper]) contained 6 samples corresponding to major saline-alkali industrial bases. Vegetation species were scarce with coverage of only 8.5%, mainly Gramineae (salt-tolerant Phragmites, 5.3%) plus scattered Nitraria, Ceratoides, Tamarix, and Calligonum. Corresponding pollen assemblage was Chenopodiaceae (57.1%)–Artemisia (18.1%)–Ephedra (9.1%)–Gramineae (4.5%)–Nitraria (2.9%). Chenopodiaceae, Artemisia, and exotic Pinus (1.9%) and Picea (0.5%) that comprised substantial proportions were absent from vegetation surveys, while pollen contents of Ceratoides, Tamarix, Nitraria, and Calligonum remained low.

Zone IV (Non-vegetated Zone): 24 samples from the central-western basin (Figure 1 [Figure 1: see original paper]) with no plant growth, but still containing considerable pollen. Main pollen assemblage was Chenopodiaceae (43.2%)–Artemisia (23%)–Ephedra (10.1%)–Nitraria (4.2%)–Pinus (5.4%).

Zone V (Shrub Desert Zone): 35 samples from northern basin (Figure 1 [Figure 1: see original paper]) with vegetation coverage of 23.2%. Main plants were Chenopodiaceae (10.7%)–Gramineae (5.4%)–Ceratoides (3.9%)–Tamarix (2.5%). Pollen assemblage was Chenopodiaceae (56.3%)–Artemisia (18.3%)–Nitraria (6.7%)–Gramineae (4.3%)–Ephedra (3.0%). Artemisia and Ephedra absent from vegetation surveys showed pollen contents below 1% for Nitraria, Ephedra, Calligonum, and Lycium. Tree vegetation was mainly Haloxylon ammodendron (1.8%), with Pinus (1.7%) as the main tree pollen.

2.2 Relationship Between Major Pollen and Vegetation

Herbaceous pollen dominates surface samples in the Qaidam Basin, with Chenopodiaceae, Artemisia, and Gramineae being most widespread and abundant. Chenopodiaceae pollen occupies substantial proportions (20%-80%) at almost every site, with R values generally greater than 1 (Table 1), even exceeding 40 in zones where non-Chenopodiaceae species dominate, showing obvious over-representation. No Chenopodiaceae plants grew near 41.9% of sampling sites, yet considerable proportions (10.2%~55%) of Chenopodiaceae pollen were present. The relationship between vegetation coverage and pollen percentage for Chenopodiaceae was not close in this study area (Figure 4a [Figure 4: see original paper]), with a coefficient of determination (R^2) of 0.14496.

Artemisia pollen occurs at almost every site (10%~30%), with R values basically greater than 1 (Table 1), showing over-representation. However, only 26.8% of sites had Artemisia plants, mainly concentrated in eastern Zones I and

V, while the highest Artemisia pollen content (23%) occurred in the northern non-vegetated Zone IV. Artemisia showed the lowest correlation between pollen percentage and vegetation coverage among all families (Figure 4b [Figure 4: see original paper]), with R^2 of only 0.01194.

Gramineae plants are dominant species throughout the Qaidam Basin, but their pollen representativeness is relative. Gramineae pollen R values in northeastern and central basin were far less than 1 (Table 1 , Zones III and V), showing low representation. However, at sites where Gramineae was dominant in southeastern Zones I and II, R values were near 1 (Table 1), showing better representativeness. No Gramineae plants occurred at 46.8% of sites, with pollen proportions generally below 5%. Overall, Gramineae pollen percentage showed certain positive correlation with vegetation coverage (Figure 4c [Figure 4: see original paper]), with coefficient of determination (R^2) of 0.60869 and established correlation function: $y = 1.35323 + 0.84475x$.

Cyperaceae and Compositae are dominant species in alpine meadows [20-21], but in the Qaidam Basin they appear only in relatively higher eastern and northeastern areas (above 3,200 m) and are not constructive species, with R values far less than 1 (Table 1), showing low representation. Only 8.1% of sites had Cyperaceae plants with coverage not exceeding 20%, and corresponding Cyperaceae pollen content was less than 10%. Cyperaceae vegetation coverage showed some correlation with pollen proportion (Figure 4d [Figure 4: see original paper]), with R^2 of 0.49895 and correlation function: $y = 1.18683 + 0.41083x$.

The relationship between Compositae pollen content and vegetation coverage is shown in Figure 4e [Figure 4: see original paper], with R^2 of 0.46005 and correlation function: $y = 1.60961 + 0.88345x$. Compositae plants occurred at 22.6% of sites, with corresponding Compositae pollen proportions all exceeding 3%; other sites showed Compositae pollen below 3%. Therefore, Compositae pollen content reaching 3% in this study area may indicate nearby Compositae plant growth.

The main woody plants in the Qaidam Basin are shrubs, with Tamarix being most widespread. However, Tamarix pollen R values are far less than 1, with some sites showing R = 0 (Table 1), indicating particularly low representation. Tamarix pollen appeared at 6.5% of sites with percentages below 2%, but Tamarix shrub communities with coverage $ 8^{2}$ of 0.62573 and correlation function: $y = 0.05114x - 0.04164$.

Nitraria is one of the dominant shrubs in the Qaidam Basin, mainly growing in the eastern and northeastern basin. Nitraria showed low representation at most sites, with R values less than 1 (Table 1). However, in desert saline-alkali areas, Nitraria pollen R values exceeded 1, showing over-representation. No Nitraria occurred at 82.3% of sites, yet Nitraria pollen (1%~13%) was present at all sites. The correlation between pollen percentage and vegetation coverage was very low (Figure 4g [Figure 4: see original paper]), with R^2 of 0.0422.

Ephedra vegetation is mainly distributed near Golmud in the southern basin, occurring at approximately 16.3% of sites, while its pollen occurs throughout the Qaidam Basin. Ephedra pollen R values exceed 1 (Table 1), showing obvious over-representation. The correlation between Ephedra pollen proportion and vegetation coverage was not significant, with R^2 of 0.09828. Calligonum vegetation occurred at approximately 16.3% of sites (coverage 10%~20%), mainly concentrated east of Golmud and northwest of Da Qaidam, but its pollen percentage was very low with R values far less than 1, showing low representation. The correlation between pollen and vegetation coverage was also very low (Figure 4i [Figure 4: see original paper]), with R^2 of 0.09681.

2.3 Characteristic Pollen Ratio Studies

The Artemisia/Chenopodiaceae (A/C) ratio is commonly used as an indicator of moisture conditions in arid and semi-arid regions [22-23], with lower A/C values indicating drier conditions. $A/C > 1$ indicates steppe areas, while $A/C < 0.5$ indicates desert zones [20,24]. It is generally believed that only when Artemisia and Chenopodiaceae pollen combined exceed 50% do they have indicative significance for local environmental moisture [25-26]. Among the Qaidam Basin surface pollen samples, 99 samples had Artemisia and Chenopodiaceae pollen combined exceeding 50% (Figure 5 [Figure 5: see original paper]), with most sites showing A/C between 0 and 1. Sites with higher A/C values were basically concentrated in the eastern basin, while central and western areas showed A/C values basically less than 0.5.

Notably, in non-vegetated Zone IV with 0% vegetation coverage and the driest environment, A/C values were abnormally high (mean 0.62), lacking environmental indicative significance (reasons for abnormal Artemisia pollen percentage increase are detailed in Section 3.1). Overall, A/C values show a decreasing trend from southeast to northwest, corresponding well to the gradually drying environmental characteristics from southeast to northwest. Therefore, when using A/C for paleoenvironmental reconstruction, comprehensive consideration of geographical location, climatic characteristics, and pollen concentration is necessary.

Some scholars use the Ephedra/Chenopodiaceae (Ep/C) ratio as a basis for further drought classification, with higher Ep/C values indicating drier environments [27]. In this study area, Ep/C values did not increase with drought intensity, possibly due to strong winds, widespread desert Gobi, saline-alkali lands, and non-vegetated areas in the Qaidam Basin. Therefore, the particularity of the study area should be considered when using Ep/C.

2.4 Relationship Between Pollen Concentration and Vegetation Coverage

Vegetation distribution in the Qaidam Basin is relatively obvious, decreasing from southeast to northwest with coverage reducing from 89% to 0% (Figure 6a [Figure 6: see original paper]). This vegetation pattern caused significant variation in sample pollen concentrations (Figure 6b [Figure 6: see original paper]), with maximum concentrations reaching 28,199 grains • g^{-1} and minimum only 12 grains • g^{-1}. Overall, pollen concentration distribution corresponded well with vegetation coverage—also showing a gradual decreasing trend from southeast to northwest. Vegetation coverage and pollen concentrations from high to low for each zone were: southeastern Zone I (desert steppe) with 40%~80% coverage and mean pollen concentration of 7,930 grains • g^{-1}; south-central Zone II (shrub desert) with 20%~50% coverage and mean concentration of 5,646 grains • g^{-1}; northern Zone V (Gobi desert) with 10%~40% coverage and mean concentration of 4,007 grains • g^{-1}; southwestern Zone III (saline desert) with 5%~20% coverage and mean concentration of 1,249 grains • g^{-1}; and northwestern Zone IV (non-vegetated) with 0% coverage and mean concentration of 584 grains • g^{-1}. Pollen concentrations differed significantly between different vegetation zones, particularly being 13.5 times higher in desert steppe than in non-vegetated areas, indicating that pollen concentration can serve as an important indicator for reconstructing plant communities and growth environments in arid and semi-arid regions like the Qaidam Basin.

However, within the same vegetation zone, pollen concentration sometimes showed no obvious correlation with vegetation coverage at different sites, a finding also demonstrated in previous studies [22-23,27], possibly related to specific pollen production and dispersal.

2.5 Pollen Principal Component Analysis

Principal component analysis was performed on logarithms of 13 dominant shrub and herb pollen types from 124 sites (Figure 7 [Figure 7: see original paper]). Eigenvalues for PCA axes 1 and 2 were 0.568 and 0.173 respectively, while axes 3 and 4 were 0.104 and 0.098 respectively. The cumulative variance contribution of the first two axes was 74.1%, indicating that samples were mainly controlled by environmental factors represented by axis 1, with axis 2 factors being secondary. The lowest axis 1 score was Chenopodiaceae, while the highest were moisture-preferring species such as Cyperaceae and Cruciferae, suggesting axis 1 mainly reflects hydrological factors in desert areas. Previous studies also indicate that hydrological factors are most important for plant growth in arid and semi-arid regions [8,17,28]. The lowest axis 2 score was Artemisia, while the highest were saline-alkali tolerant Nitraria and Gramineae (mainly Phragmites), suggesting axis 2 may mainly reflect soil salinity, pH, and other latent environmental factors. Based on different positions of pollen types on the ordination axes, pollen types could be basically divided into three groups: Group 1 includes Chenopodiaceae, Artemisia, Ephedra, and Polygonaceae, representing dominant species in arid desert environments; Group 2 includes Compositae, Ranunculaceae, Leguminosae, Typhaceae, Rosaceae, Cyperaceae, and Cruciferae, possibly representing non-dominant species preferring steppe; Group 3 includes Nitraria and Gramineae (mainly Phragmites) as dominant species in arid saline-alkali areas of the basin.

3 Discussion

3.1 Influence of Exotic Pollen and Pollen Migration in Non-vegetated Areas

Large non-vegetated areas exist in the western and northwestern basin (near Mangya), yet these areas contain considerable pollen content, mainly recognized over-represented pollen types such as Chenopodiaceae, Artemisia, Ephedra, and Pinus. In surface pollen analysis, pollen types whose parent plants are not found locally are considered exotic pollen, which can be divided into short-distance and long-distance migrated pollen [29].

Chenopodiaceae and Ephedra pollen can find corresponding dominant plants in other vegetation zones of the basin, belonging to short-distance migrated pollen. Such pollen may be brought by local air currents and all indicate arid environments. Short-distance migrated pollen remains relatively close to parent plants, reflecting similar climatic environments, thus having little impact on pollen spectrum interpretation.

In non-vegetated zones, Pinus (5.4%) and Artemisia (23%) pollen contents are much higher than in other vegetation zones. Pinus pollen may originate from the Qilian Mountains to the north [30], as its bisaccate structure facilitates long-distance dispersal [31-32]. Artemisia pollen may partially come from short-distance dispersal within the basin, but mainly from the Altun Mountains to the west and Qilian Mountains to the north [30,33]. The basin experiences prevailing northwest-southeast winds year-round with high wind speeds. The "valley effect" in canyons between the Altun and Qilian mountains easily creates strong winds, such as frequent high-wind events in Mangya in the northwestern basin [13,34]. Such winds and air currents may carry large amounts of Pinus and Artemisia pollen from nearby mountains to adjacent non-vegetated areas for deposition, while pollen concentrations in this zone are much lower than in other zones, resulting in relatively increased percentages of Pinus and Artemisia pollen. This type of pollen belongs to long-distance migrated pollen and may cause misinterpretation of local pollen spectra.

When interpreting stratigraphic pollen, comprehensive judgment should be made based on pollen concentration and specific assemblages. If pollen consists mainly of recognized high-production, easily dispersed over-represented families (such as the Chenopodiaceae-Artemisia-Ephedra-Pinus combination in this region) with almost no other pollen types, and pollen concentration is significantly lower than adjacent areas, the area can be identified as non-vegetated.

3.2 Representativeness of Major Pollen Taxa

The above analysis shows that pollen assemblages in the Qaidam Basin can be divided into five zones that roughly reflect local vegetation characteristics, with dominant pollen types in the assemblages basically being dominant plant species in each zone. Major dominant pollen types include Chenopodiaceae, Gramineae, Artemisia, Ephedra, Nitraria, Cyperaceae, and Compositae, consistent with stratigraphic pollen types in this region [35-36], providing good basic material for regional stratigraphic pollen research and paleoclimate reconstruction. However, representativeness differs among pollen types: Chenopodiaceae, Artemisia, and Ephedra pollen show obvious over-representation, confirmed in multiple studies [24,31], possibly due to high pollen production [37]. Low representation of Compositae, Cyperaceae, Tamarix, and Calligonum pollen has also been confirmed [21,37]. Gramineae shows low representation in most areas of the basin, confirmed by previous studies as possibly resulting from low pollen production and poor preservation [38]; however, Gramineae pollen representativeness is better at saline-alkali sites, possibly because Phragmites is the constructive species in many saline-alkali sites, and sampling during July-August coincides with the flowering period, allowing better preservation of Gramineae (Phragmites) pollen. Among shrubs, Nitraria also shows low representation at most sites but better representativeness in saline-alkali sites, possibly because Nitraria is a dominant species in saline-alkali areas with relatively increased pollen content.

3.3 Relationship Between Pollen Percentages and Vegetation Coverage

Due to the special climate and geographical location of the Qaidam Basin, pollen percentages of major families show certain correlations with parent plant coverage, though slightly lower than results from northern China [37,39]. Chenopodiaceae, Artemisia, Nitraria, and Ephedra are dominant vegetation in the basin, their pollen appears in almost every sample with considerable proportions, but shows no obvious correlation between pollen percentage and vegetation coverage. However, these pollen types can reflect overall environmental characteristics of the study area—relative aridity. Artemisia pollen percentage shows a decreasing trend from southeast to northwest with precipitation reduction, possessing certain ecological indicative significance, possibly because Artemisia prefers more humid conditions. Gramineae, Cyperaceae, Compositae, and Tamarix pollen percentages show good correlations with vegetation coverage, effectively indicating vegetation near sampling sites and warranting attention in stratigraphic pollen studies. Relationships between major families and vegetation coverage in this study area differ from conclusions in other regions, such as good correlations between Nitraria pollen percentage and vegetation coverage and unclear relationships for Gramineae in other northern China regions [37,39]. These differences may result from frequent high-wind events and obvious pollen migration disturbance in the basin. Additionally, extensive bare ground, strong sunlight, and saline-alkali environments may affect pollen preservation, requiring verification through comparison with pollen flux studies. Therefore, region-specific approaches should be adopted when reconstructing stratigraphic pollen, rather than mechanically applying conclusions from other study areas.

3.4 Relationship Between Pollen-Vegetation and Environmental Gradients

The most important environmental factor affecting plant growth and distribution in arid and semi-arid regions is moisture conditions [40]. As soil moisture decreases from southeast to northwest across the basin, vegetation coverage, abundance, pollen concentration, and species diversity gradually decrease. Plant and pollen species composition also changes, with moisture-preferring Compositae, Cyperaceae, Artemisia, and Ranunculaceae decreasing in coverage and pollen percentage while A/C ratio increases; drought-tolerant Chenopodiaceae and Ephedra increase in coverage and pollen percentage. In saline-alkali areas, only Nitraria and Gramineae (Phragmites) grow, with pollen assemblages dominated by Chenopodiaceae-Artemisia-Gramineae-Nitraria.

4 Conclusions

(1) Pollen concentration in non-vegetated areas is far lower than in other zones, with pollen assemblages dominated by over-represented pollen such as Chenopodiaceae-Artemisia-Ephedra-Pinus. This conclusion can be applied to identify non-vegetated areas in stratigraphic pollen analysis.

(2) In this study area, Artemisia, Ephedra, and Chenopodiaceae pollen show over-representation; Compositae, Cyperaceae, Tamarix, and Calligonum show low representation; Gramineae and Nitraria show low representation at most sites, but Gramineae pollen shows moderate representativeness at constructive species sites, and Nitraria pollen shows moderate representativeness in saline-alkali areas.

(3) Correlation relationships can be established between pollen percentages of Gramineae, Cyperaceae, Compositae, and Tamarix and vegetation coverage, with these pollen types effectively indicating vegetation near sampling sites. Correlations for Chenopodiaceae, Artemisia, Ephedra, and Nitraria are not high, but they can effectively indicate overall environmental conditions of the study area.

(4) Vegetation and pollen distribution in the basin are mainly controlled by hydrological factors, with soil salinity and other latent factors playing secondary roles.

[1] Chen Yan, Lei Tao, Zhang Guoqing, et al. The geological conditions, resource potential and exploration direction of oil in Qaidam basin[J]. Marine Origin Petroleum Geology, 2019, 24(2): 64-74.

[2] Feng Qiao, Fu Suotang, Zhang Xiaoli, et al. Restoration of jurassic prototype basins in Qaidam basin and its adjacent areas and prospects for oil and gas exploration[J]. Earth Science Frontiers, 2019, 26(1): 44-58.

[3] Shi Xiuyun, Chen Hongsong, Liu Chengfeng, et al. Sandstorm weather analysis in Golmud in recent 5 years [J]. Qinghai Meteorology, 2019, 6(1): 11-15.

[4] Yang Zhenjing, Xu Jianming. Advances in studies on relationship among pollen, vegetation and climate[J]. Acta Phytoecologica Sinica, 2002, 26(Suppl.1): 73-81.

[5] Yang Qinghua, Yang Zhenjing, Zhang Yun, et al. Relationship between surface sporepollen and modern vegetation in Xarxili Nature Reserve of Xinjiang[J]. Arid Land Geography, 2019, 42(5): 986-997.

[6] You Yonggang, Yang Qinghua, Wang Pan, et al. Investigation on the vegetations in Qaidam basin[J]. Journal of Arid Land Resources and Environment, 2019, 33(2): 183-188.

[7] Liu Xuemei, Gao Xiaohong, Ma Yuancang. Spatio-temporal evolution of vegetation coverage in Qinghai Province, China during the periods from 2002 to 2015[J]. Arid Zone Research. 2017, 34(6): 1345-1352.

[8] Wang Zhiying. Study on the Relationship Between Surface Pollen Assemblage and Vegetable in Qaidam basin[D]. Guangzhou: Guangzhou University, 2008.

[9] Zhao Y, Xu Q H, Huang X Z, et al. Differences of modern pollen assemblages from lake sediments and surface soils in arid and semi-arid China and their significance for pollen-based quantitative climate reconstruction[J]. Review of Palaeobotany and Palynology, 2009, 156(3): 519-524.

[10] Zhang S R, Xu Q H, Nielsen A, et al. Pollen assemblages and their environmental implications in the Qaidam basin, NW China[J]. Boreas, 2012, 41(4): 602-613.

[11] Lu Jingfang, Song Bowen, Chen Ruiming, et al. Palynological assemblage of Eocene-Oligocene pollen and their biostratigraphic correlation in Dahonggou, Daqaidam Area, Qaidam basin[J]. Earth Science, 2010, 35(5): 839-848.

[12] Shen Yuancun, Wang Xiuhong, Cheng Weiming, et al. Integrated physical regionalization of stony deserts in China[J]. Progress in Geography, 2016, 35(1): 57-66.

[13] Xu Wantong, Zeng Biao, Li Bo, et al. Regional differentiation of climate changes in Qaidam basin and its influencing factors[J]. Journal of Lanzhou University (Natural Sciences), 2019, 55(3): 357-364.

[14] Fu Y, Chen H, Niu H H, et al. Spatial and temporal variation of vegetation phenology and its response to climate changes in Qaidam basin from 2000 to 2015[J]. Journal of Geographical Sciences, 2018, 28(4): 400-414.

[15] Yin Wenjie, Zhang Menglin, Hu Litang. Spatiotemporal variation of drought in the Qaidam basin[J]. Arid Zone Research, 2018, 35(2): 387-394.

[16] Zhang Wangxiong, Liu Puxing. Surface humid situation and its affecting factors in the Qaidam basin from 1961 to 2017[J]. Arid Zone Research. 2019, 36(6): 1391-1400.

[17] Zhu Wenbin, Lyu Aifeng, Jia Shaofeng. Study on spatial distribution of vegetation coverage and its affecting factors in the Qaidam basin based on NDVI[J]. Arid Zone Research, 2010, 27(5): 691-698.

[18] Davis M. On the theory of pollen analysis[J]. American Journal of Science, 1963, 261(10): 897-912.

[19] Li Yiyin, Zhang Xinshi, Zhou Guangsheng, et al. Relationship between surface pollen and vegetation in some communities of Northern China[J]. Chinese Science Bulletin, 2000, 45(7): 761-765.

[20] Yang Zhenjing, Kong Zhaochen, Yan Shun, et al. Pollen distribution in topsoil along the Daxigou Valley in the headwaters of the Urumqi River, the central Tianshan Mountains[J]. Arid Land Geography, 2004, 27(4): 543-547.

[21] Wei Haicheng, Zheng Zhuo, Ma Haizhou, et al. Pollen distribution patterns of surfuce soil sample in Qinghai of China and their relationship with vegetation[J]. Arid Land Geography, 2009, 32(6): 932-940.

[22] Li Y M, Zhang Y, Tong G B, et al. Pollen assemblages and anthropogenic influences in the central and western regions of Yunnan Province[J]. The Science of the Total Environment, 2018, 646: 368-376.

[23] Li Yuecong, Xu Qinghai, Yang Xiaolan, et al. Pollen assemblages of major steppe communities in China[J]. Acta Ecologica Sinica, 2005, 25 (3): 555-564.

[24] Luo Chuanxiu, Zheng Zhuo, Pan Anding, et al. Spatial distribution of modern pollen in Xinjiang region[J]. Scientia Geographica Sinica, 2008, 28(2): 272-275.

[25] Chang J, Hui Z C, Pan B T, et al. Characteristics of the modern pollen assemblages from different sedimentary environments of the middle reaches of the arid Heihe region of Asia[J]. Quaternary International, 2018, 479: 34-41.

[26] Xu Q H, Zhang S R, Gaillard M, et al. Studies of modern pollen assemblages for pollen for pollen-based dispersal-deposition-preservation process understanding reconstructions of past vegetation, climate, and human impact: A review based on case studies in China[J]. Quaternary Science Reviews, 2016, 149: 151-166.

[27] Luo Chuanxiu, Zheng Zhuo, Pan Anding, et al. Distribution of surface soil spore-pollen and its relationship with vegetation in XinJiang, China[J]. Arid Land Geography, 2007, 30(4): 536-543.

[28] Yang Z J, Zhang Y, Ren H B, et al. Altitudinal changes of surface pollen and vegetation on the north slope of the Middle Tianshan Mountains, China[J]. Journal of Arid Land, 2016, 8(5): 799-810.

[29] Huang Cixuan, Ailisi Fengkangbo, Rang Fulangsuowashi duobuleimei. A study on pollen in surface soil from the western Xizang[J]. Arid Land Geography, 1993, 16(4): 75-84.

[30] Xu Juan, Zhang Baiping, Zhu Yunhai, et al. Distribution and geographical analysis of altitudinal belts in the Altun-Qilian Mountains[J]. Geographical Research, 2006, 25(6): 977-984.

[31] Cour P, Zheng Z, Duzer D, et al. Vegetational and climatic significance of modern pollen rain in northwestern Tibet[J]. Review of Palaeobotany and Palynology, 1999, 104(3-4): 183-204.

[32] Zhang Y J, Duo L, Pang Y Z, et al. Modern pollen assemblages and their relationships to vegetation and climate in the Lhasa Valley, Tibetan Plateau, China[J]. Quaternary International, 2018, 467(7): 871-877.

[33] Wu Peng, Hui Chaomao, Xue Yadong, et al. Vegetation characteristic in the habitat of Wild Bactrian Camel in the northern slope of Altun Mountains[J]. Forest Inventory and Planning, 2014, 39(3): 58-62.

[34] Wu Tongwen, Li Jianghai, Yang Menglian. The aeolian bedforms and the reconstruction of Late Holocene wind direction in Qaidam basin[J]. Acta Scientiarum Naturalium Universitatis Pekinensis, 2018, 54(5): 1021-1027.

[35] Fang Xiaomin, Wu Fuli, Han Wenxia, et al. Plio-Pleistocene drying process of Asian inland- sporopollen and salinity records from Yahu Section in the central Qaidam basin[J]. Quaternary Sciences, 2008, 28(5): 874-882.

[36] Yang Ping, Xie Zongkui, Yuan Xiujun, et al. Palaeoecological characteristics and its palaeogeographic significance of the Jurassic in northern margin of Qaidam basin[J]. Journal of Palaeogeography, 2006, 8(2): 165-173.

[37] Xu Qinghai, Li Yuecong, Yang Xiaolan, et al. Quantitative relationship between pollen and vegetation in Northern China[J]. Scientia Sinica(Terrae), 2007, 37(2): 192-205.

[38] Luo C X, Lin G, Chen M H, et al. Characteristics of pollen in surface sediments from the southern South China Sea and its paleoclimatic significance[J]. Palaeogeography Palaeoclimatology Palaeoecology, 2016, 461: 12-18.

[39] Li Yuecong, Xu Qinghai, Xiao Jule, et al. Relationship between surface pollen and vegetation in some shrub communities of Northern China[J]. Scientia Geographica Sinica, 2007, 27(2): 205-210.

[40] Liu Xuejia, Dong Lu, Zhao Jie, et al. Dynamic state of desert vegetation productivity and its relationship with water-heat factors in China[J]. Arid Zone Research. 2019, 36(2): 459-466.

Note: Figure translations are in progress. See original paper for figures.