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RESEARCH ARTICLE

Pollen distribution in large freshwater lake of arid region: a case study on the surface sediments from Bosten Lake, Xinjiang, China

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Abstract The interpretation of the pollen records from lake sediments is always hampered by a lack of information relating to different pollen production, transportation, deposition, and preservation. It is important to understand the modern process of pollen sedimentation and its climatic implications. This paper presents results from a palynological study on 61 surface sediments samples from Bosten Lake, the largest inland freshwater lake in China. Our results suggest that Chenopodiaceae and *Artemisia* dominate the modern pollen assemblages and have stable percentages at most sites of the lake basin except for the estuary area. Pollen *Artemisia*/Chenopodiaceae ratio is about 0.5, indicating the dry climate of the region. Principle Components Analysis (PCA) of pollen data can identify the pollen samples as several ecological groups from different parts of the lake. Pollen transportation dynamics and the mixing effect of lake currents and waves on pollen deposition have affected the pollen assemblages. The distribution of *Typha* pollen seems to be affected by the location where the parent plants grow. *Picea* pollen has higher percentages at estuary area, suggesting fluvial transport. Pollen concentration has high values at the central part of the lake basin due to the sedimentation focusing process effect. Our results suggest that the pollen assemblages of the sediment core from the central part of the lake can potentially record the regional vegetation history.

Keywords Bosten Lake, surface sediments, pollen analysis, sedimentation focusing

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1 Introduction

The arid central Asia has a fragile ecological system, which is highly sensitive to global climate change (Chen et al., 2000; Wünnemann et al., 2003). The wide distributed lake sediments in this region can provide important archives of past environmental and climatic evolution histories. Palynological research has been an essential way to reconstruct the palaeoecological environment. However, the interpretation of the pollen records becomes quite difficult due to the poor understanding of the relationship between pollen and vegetation (Sun et al., 1994). Therefore, it is important to study pollen dispersal and transportation process (Horowitz, 1992; Song and Sun, 1999), including drainage pollen distribution in surface soil/moss (Li, 1991; Herzschuh et al., 2003; Cheng et al., 2004), river- and air-borne pollen dispersal processes (Chmura and Liu, 1990; Zhu et al., 2002a, 2003a, b), and pollen distribution in lake surface sediments (Horowitz, 1969; Sun and Wu, 1984; Luly, 1997; DeBusk, 1997, Xu et al., 2005). However, in the arid region of China, the pollen distribution model in large freshwater lake is still unclear because most of the lakes in this region have dried up during the past decades due to natural climate change and human activity. In this paper, we investigate the pollen distribution within Bosten Lake, the largest inland freshwater lake in China, to explore the main process and model of how pollen records regional vegetation.

2 Study area

Bosten Lake (41°56'N–42°14'N, 86°40'E–87°26'E, elevation 1048 m a.s.l.) is located on the southern slope of Tienshan Mountains and lies in the southeastern part of Yanqi Basin between the Tienshan and Taklimakan Desert.

The Yanqi Basin is bordered by the Tienshan Mountains in the north and west and by the Kuruktag Mountains in the south. Bosten Lake, with an altitude of 1048 meter above sea level (m a.s.l.), a surface lake area of ca. 1000 km^2, a maximum water depth of 16.2 m, and an average depth of 8 m, is the largest inland freshwater lake in northwestern China (Cheng, 1995). Bosten Lake is hydrologically connected with 13 rivers flowing into the lake, with the four major rivers accounting for 96% of the total water input. The lake discharges water to the Kongque River, which flows to Lop Nur (Fig. 1).

Bosten Lake is located in a typical temperate arid region. Meteorological records from Yanqi County station record a mean annual precipitation of 70 mm and a potential evaporation of 2000 mm. The region is characterized by desert vegetation. From higher to lower altitude, regional vegetation has six distinct zones: 1) snow and ice zone, above 3800 m a.s.l. with no visible plant; 2) alpine cushion plant, 3800–3500 m a.s.l., dominated by *Saboaldia tetrandra*; 3) alpine meadow, 3500–2800 m a.s.l., dominated by *Kobresia myosuroides*, *Carex polyphylla*, *Kobresia humilis*, and *Juncus triglumis*; 4) steppe, 2800–2100 m a.s.l., dominated by *Stipa*, *Poa tibetic*, and *Androsace sericea*; 5) desert steppe, 2100–1600 m a.s.l., dominated by *Neopallasia pestinata* and *Artemisia macroephala*; 6) desert vegetation, 1600–1050 m a.s.l., dominated by *Iljinia regelii, Ephedra przewalskii*, and *Salsola sp*. In addition, some intrazonal vegetation communities were also widely distributed, for example, some small area of *Picea schrenkiana* forests grow on the shaded slopes or valleys, some Ulmaceae trees grow in valleys, and some halophyte grows on alkaline soil. *Phragmites* and *Typha* plants grow in the swamp on the west side of Bosten Lake with a water depth of less than 2 m (Xinjiang Multi-disciplinary Investigation Group, CAS; Institute of Botany, CAS, 1978; Huang et al., 2004). The general vegetation pattern is shown in Fig. 1.

3 Methods

Sixty-one surface sediment samples were collected from Bosten Lake with a grid pattern (Fig. 2) by using GRAB sampler. For the pretreatment, 10–15 g dry sediment was used to do pollen analysis. One or two tablets of *Lycopodium* spores (about 12524 spores per tablet) were added to each sample for the pollen concentration calculation prior to chemical procedures. The pollen preparation procedures follow the standard method (Moore, et al., 1991) with minor modifications. Each sample was digested with HCl (10%), HF (40%), and filtered with 10 μm mesh. All the pollen grains were identified under NIKON microscope with ×40 object lens, and more than 500 pollen grains were counted for each sample with an average of 790 grains. Pollen diagram and ordination of pollen data were done with the free software C2 (Juggins, 2003).

4 Result

More than 20 pollen types have been identified in all the samples, including Chenopodiaceae, *Artemisia*, *Ephedra*, *Nitraria*, Polygonaceae, Gramineae, Cyperaceae, Compositae, *Typha*, *Myriophyllum*, *Picea*, *Pinus*, Cupressaceae, Cruciferae, Ranunculaceae, Rhamnaceae, *Tamarix*, *Zygophyllum*, *Ulmus*, Caryophyllaceae, Zydophyllaceae, *Salix*, *Thalictrum*, and *Pedicularis*. The dominant pollen types are Chenopodiaceae, *Artemisia*, *Ephedra*, Gramineae, Cyperaceae, Compositae, and *Typha*.

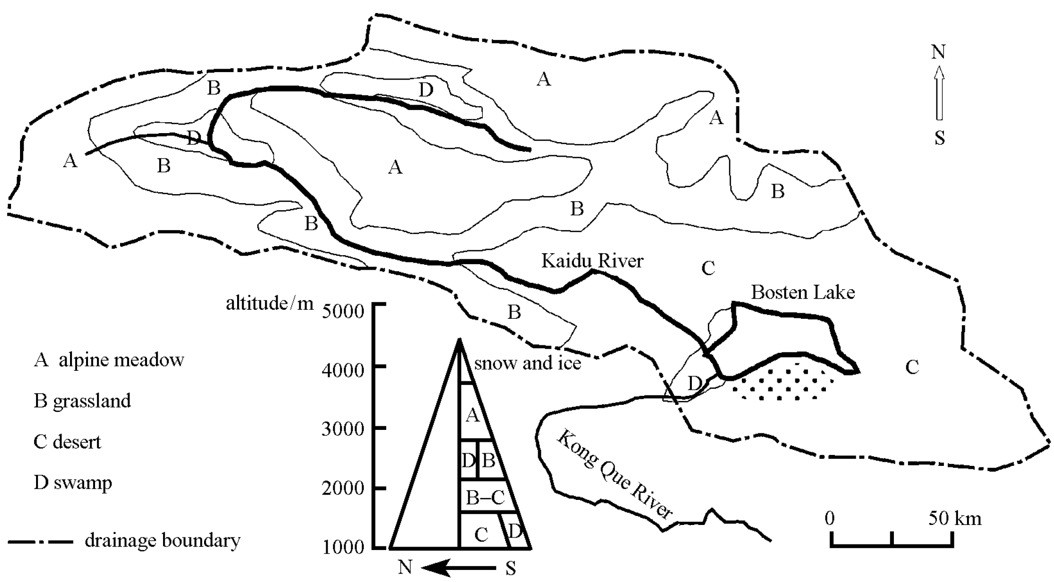

Fig. 1 Map of vegetation of Bosten Lake drainage

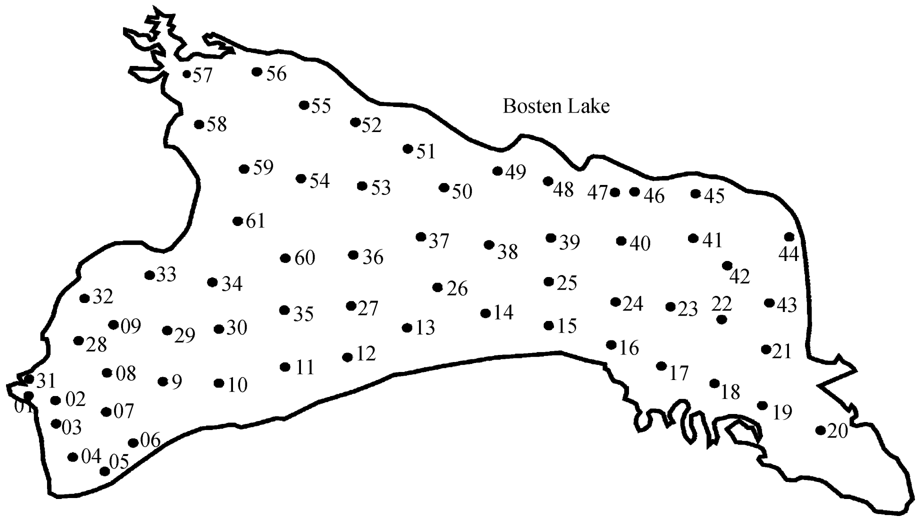

Fig. 2 Map of sampling sites in Bosten Lake

4.1 Pollen assemblages

Chenopodiaceae and *Artemisia* are the dominant pollen types in almost all the lake surface samples (see Fig. 3). The percentage of Chenopodiaceae is around 50%, and *Artemisia* accounts for about 20%. One of the main desert components *Ephedra* pollen percentage varies between 3% and 9%. The *Nitraria* pollen changes around 1%. The other grassland pollen types, Gramineae, Compositae, and Cyperaceae have a sum of around 10%. The maximum percentages of Rhamnaceae and *Thalictrum* exceed 1%, but their average percentages are < 0.5%. *Picea* pollen is < 3%. *Typha* pollen has an average percentage of 8.6% with biggest variations.

Pollen concentration varies from 2100 grains/g to 69000 grains/g (Fig. 3). Previous studies show that the pollen concentration is connected with water depth (Sun and Wu, 1984; Huang et al., 2004; Zhao et al., 2007). The

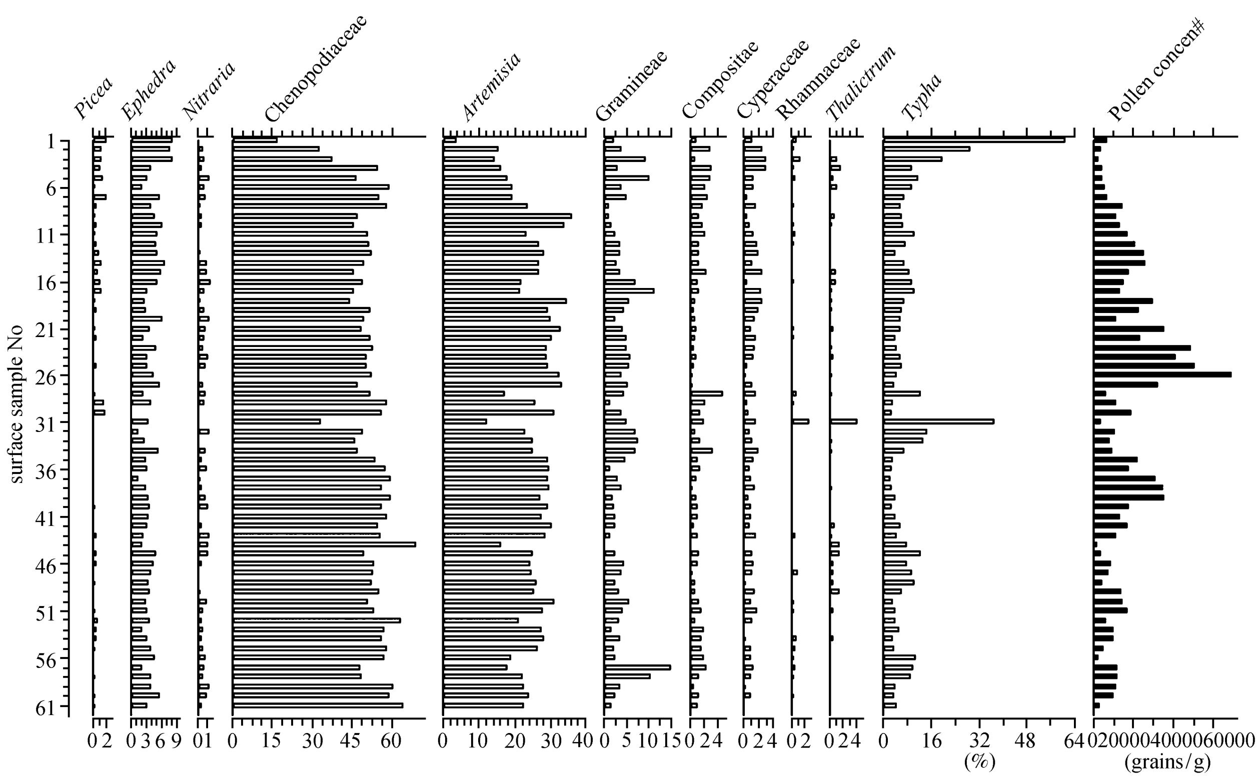

Fig. 3 Pollen assemblage of all the surface sediment samples. Only major taxa included

relationship between the water depth and pollen concentration can be plotted in Fig. 4, which suggests that pollen concentration generally increases with water depth.

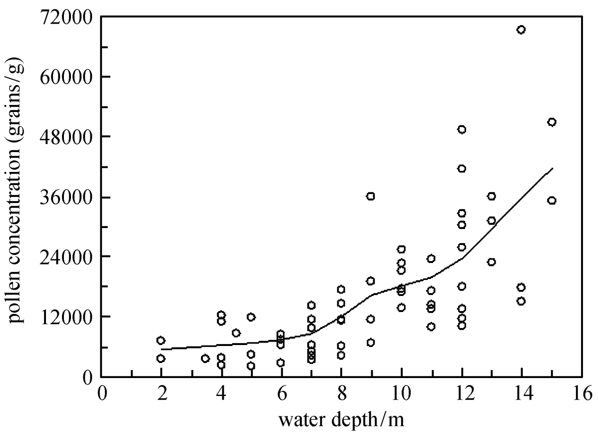

Fig. 4 Relationship between pollen concentration and water depth

4.2 Principal Component Analysis (PCA) of pollen data

Ordination was applied on the pollen data to explore the potential differences between the samples. PCA analysis result (Fig. 5) shows that Axes-1 explained 36% of the total difference and Axes-2 explains 14%. The species that contribute to the positive part of Axes-1 include *Typha*, *Ephedra*, *Picea*, Compositae, Cyperaceae, and Gramineae. The former three genera seem have higher percentages in the river mouth area and likely are mainly transported by river. The later three families have a common ecological source area of the upper grassland in the mountains. Moreover, on the negative side of Axes-1, Chenopodiaceae, *Artemisia*, and *Nitraria* account for the variations. These three types of pollen grains come from the large desert and dry steppe vegetation in the basin.

In Fig. 5, sample label (small circle with sample No.) also are plotted on the diagram according to their PCA scores. It can be seen that the samples distribute quite concentrated which suggests that most of the samples have quite similar assemblages without big differences. However, some samples like #1, #2, #3, and #31, are located quite far from others, indicating that these samples' pollen assemblages are quite different. If we check the pollen assemblages in Fig. 3 and map of sampling sites in Fig. 2, it is obvious that these samples were collected from estuary region of Kaidu River, with higher percentages of *Typha*, *Picea*, and *Ephedra* pollen. Sample #44 also is quite far from the center in Fig. 5. This sample was collected from a site quite close to the eastern bank of the lake with quite high Chenopodiaceae pollen. According to the sample scores along the Axes-1 (the main variation direction), we also can group the sampling sites (Fig. 6) as positive value and negative value. We have marked circles on both the sampling sites and sample labels that have positive scores in the PCA ordination (Fig. 6). It is clear that the pollen assemblages from the areas close to the shores/banks are more or less different from that of the central part. It can be noted that, although the sample #44 has negative score, it is really different from other samples and is marked with circle as well.

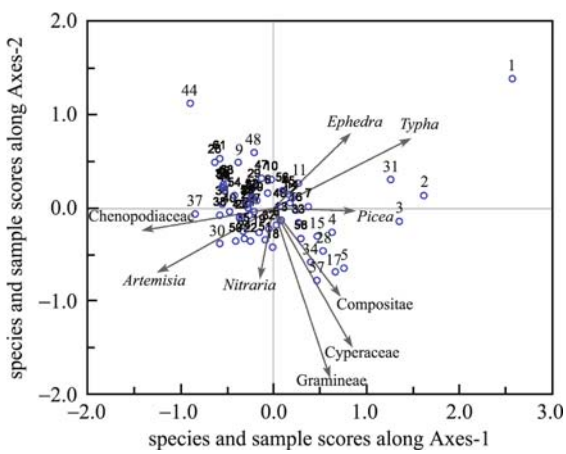

Fig. 5 Diagram of PCA analysis of pollen data

Some other pollens of *Pinus*, *Myriophyllum*, *Thalictrum*, Polygonaceae, Leguminosae, Caryophyllaceae, Cruciferae, and Zygophyllaceae sporadically appear in pollen samples. Due to their low percentages, it is difficult to explore PCA on these pollen data. Pollen types of *Thalictrum* and Rhamnaceae were also excluded from ordination due to their low percentages in the pollen assemblages.

5 Discussion

Most of the pollen grains, such as *Artemisia* and Chenopodiaceae, in the lake sediments are from desert and steppe zones in the basin. Moreover, the pollen transportation process is very likely related to wind and river/flood dynamics. The strong wind, like dust storm, in arid area can carry a lot of pollen grains within some kilometers. In this study, the pollen grains of *Artemisia*, *Chenopodiaceae*, and *Ephedra* could be blown up to the air and deposit on surface lake water. On the other hand, the wind also affects the pollen deposition process within the lake. Wind can cause lake currents and waves. In addition, the vertical/level movement of the lake water can induce redistribution of pollen grains in the lake. In semi-arid Australia, pollen assemblages of surface sediments and air samples from Lake Tyrell area match very well. It is assumed that the air-borne pollen contributes a lot to the pollen assemblages of Lake Tyrell, and water/river-borne pollen is not so important (Luly, 1997). The same phenomenon has been found in Lake Frome (Singh and Luly, 1991). The high percentages of Chenopodiaceae and *Artemisia* in Bosten Lake are a little overrepresented but

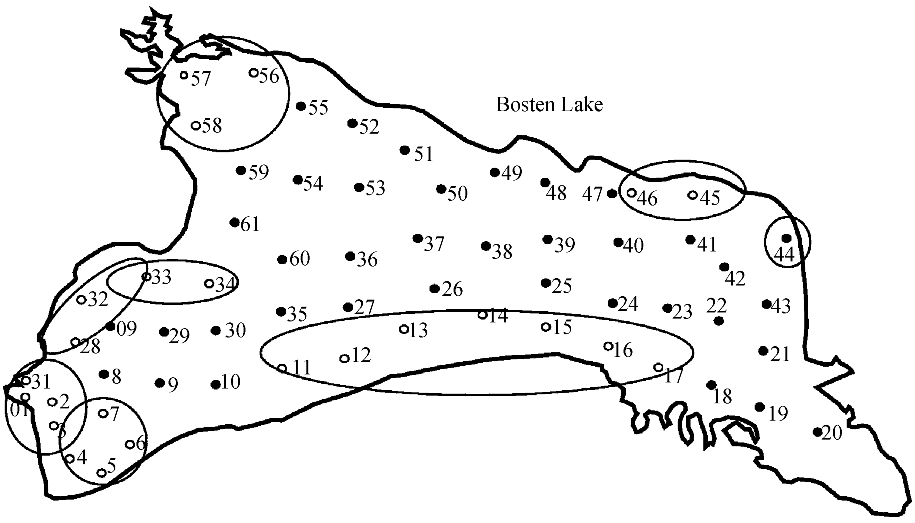

Fig. 6 Samples with positive PCA scores and their spatial distribution

generally agree with the plant abundance in the regional vegetation. The river/flood dynamics is also an important process of the sediment transportation including pollen grains in arid regions. This process has been discussed a lot in the semi-arid Shiyan River area by Zhu et al. (2002a, 2002b and 2003b). All of the dynamics and processes do exist in pollen transportation and sedimentation in arid regions.

The aquatic pollen is closely related to the distribution of its parent plant, which is also related to the lake water level situation. *Typha* pollen percentage is also affected by the hydrodynamic condition. In the estuary area, *Typha* percentage rapidly declines from 2 km away. Therefore, *Typha* percentage more or less is able to indicate the lake level or distribution of *Typha* plant. Cyperaceae and Gramineae pollen originate from both alpine grassland area and swamp land surrounding the lake. It is difficult to distinguish two source areas at present. Bunting (2003) suggests that Cyperaceae and Gramineae pollen cannot be transported as far as a few meters in high marsh region. However, Bosten Lake has a big river input, the Kaidu River, originating from the high mountain areas and could carry a lot of grass pollens into Bosten Lake. Therefore, we assume that Gramineae pollen is mainly from the alpine grassland (personal communication with John Dodson)[1)]. This hypothesis is also supported by its synchronous appearance of the Cyperaceae and Compositeae pollen in PCA ordination (Fig. 5).

The high percentages of *Picea* pollen at estuary area demonstrates that *Picea* pollen is mainly transported by water. *Picea* pollen in Bosten Lake might come from the small area of *Picea* forest growing in the valley of Kaidu River and the Tienshan Mountains north to Bosten Lake, or from the Yili Valley by wind transport, which is demonstrated by high *Picea* pollen in the surface soil samples from the high steppe land. Compared to pollen analysis of the Shiyang River drainage, *Picea* percentage in Bosten Lake sediments is much lower (Zhu et al., 2003a), probably due to the small area of spruce forest in Bosten Lake drainage. The lower percentage of *Picea* at the other samples in the lake is $< 1\%$, which might be air-borne *Picea* and could be regarded as a background input. This hypothesis is supported by low proportion *Picea* pollen in the surface soil sample collected from the Gobi-desert (unpublished data) and the #44 sample.

A/C ratio is an important indicator of the humidity variations in arid, semiarid area (Gasse et al., 1991; Xu et al., 1996; Liu et al., 2002; Demske and Mischke, 2003). The potential mechanism is that the Chenopodiaceae mainly grow in the desert area, in this area (like surface soil sample #20 and #21), and *Artemisia* plants need more moisture in the growing season. Therefore, A/C ratio generally can represent relative changes of steppe to desert vegetation/plants, which also indicates regional humidity changes. Chenopodiaceae and *Artemisia* should be dominant pollen types in the pollen assemblages (Sun et al., 1994), when the A/C ratio is used as a humidity indicator. Caution is also needed when the sampling site is close to the lake shore. Therefore, a sediment core from the lake center should be a more ideal choice for reconstructing regional vegetation history.

PCA analysis results suggest that the pollen assemblages from the sites close to shores/banks are not in accordance to that from the lake center. Therefore, it is better to use sediment cores from the lake center to reconstruct regional vegetation/climate.

The pollen assemblages from Bosten Lake are relatively simple compared to those from the humid area with diverse

1) private communication

vegetation, and it can potentially provide a kind of pollen dispersal model in large fresh-water lake of arid area. Like the other lakes, such as Dianchi (Sun and Wu, 1984), Daihai (Xu et al., 2005), and Hurleg Lake (Zhao et al., 2007), pollen is redistributed and concentrated with the sedimentation focusing effect. Therefore, pollen concentration generally increases with water depth. The different pollen assemblages and dispersal characteristics between Bosten Lake and the other lakes suggest that it is necessary to do some modern process investigation on the pollen dispersal, sedimentation, and representation in order to interpret fossil pollen records in different regions.

6 Conclusions

Some conclusions can be drawn from the discussions above:

1) Chenopodiaceae and *Artemisia* are the dominant pollen types in almost of the samples from the lake. The pollen A/C ratios are relatively stable and low and can generally represent the regional effective moisture.

2) Modern pollen from the Bosten Lake Basin are mainly from regional grassland and desert vegetation, and pollen assemblage of the samples from lake center generally records regional vegetation information and the possible main pollen dispersal dynamics is wind.

3) River, lake currents, and waves can affect the pollen deposition process within the lake, and pollen concentration is higher at the center than that of the surrounding shallow area. The mixing process makes samples from central part of the lake have similar assemblages.

4) Relatively high *Picea* pollen percentage at the estuary area is mainly caused by river-borne *Picea* pollen grains.

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References

Bunting M J (2003). Pollen-vegetation relationship in non-arboreal moorland taxa. Review of Palaeobotony and Palynology, 125: 285–298

Chen F H, Zhu Y, Li J J, Shi Q, Jin L Y, Wünemann B (2000). Abrupt Holocene changes of the Asian monsoon at millenial- and centennial-scales: Evidence from lake sediment document in the Minqiang Basin, Northwestern China. Chinese Science Bulletin, 46 (23): 1942–1947

Cheng Q C (1995). Research on Bosten Lake. Nanjing: Hehai University Press, 1–150 (in Chinese)

Cheng B, Zhu Y, Chen F H, Zhang J W, Huang X Z, Yang M L (2004). Relationship between the surface pollen and vegetation in Shiyang River drainage, Northwest China. Journal of Glaciology and Geocryology, 26(1): 81–88 (in Chinese with English abstract)

Chmura G L, Liu K B (1990). Pollen in the lower Mississippi River. Review of Palaeobotany and Palynology, 64(1–4): 253–261

DeBusk G H J (1997). The distribution of pollen in the surface sediments of Lake Malawi, Africa, and the transport of pollen in large lakes. Review of Palaeobotony and Palynology, 97: 123–153

Demske D, Mischke S (2003). Palynological investigation of a Holocene profile section from the Palaeo-Gaxun-Nur-Basin. Chinese Science Bulletin, 48(14): 1483–1487

Gasse F, Anold M, Fontes J C, Fort M, Gibert E, Huc A, Li B Y, Li Y F, Liu Q, Mélières F, van Campo E, Wang F B, Zhang Q S (1991). A 13000 year climate record from Western Tibet. Nature, 353: 742–745

Herzschuh U, Kuerschner H, Ma Y Z (2003). The surface pollen and relative pollen production of the desert vegetation of the Alashan Plateau, western Inner Mongonia. Chinese Science Bulletin, 48(14): 1488–1492

Huang X Z, Zhao Y, Cheng B, Chen F H, Xu J R (2004). Modern pollen analysis of the surface sediments from Bosten Lake, Xinjiang, China. Journal of Glaciology and Geocryology, 26(5): 602–609 (in Chinese with English abstract)

Horowitz A (1969). Recent pollen sedimentation in Lake Kinneret, Isael. Pollen et Spore, 11: 353–384

Horowitz A (1992). Palynology of Arid Lands. Amsterdam: Elseriver Science Publisher, 1–530

Juggins S (2003). C2 User Guide. Software for ecological and palaeoecological data analysis and visualisation. Newcastle upon Tyne: University of Newcastle,1–69

Li W Y (1991). Studies on dispersal efficiency of *Picea* pollen. Acta Botanica Sinica, 33(10): 792–800 (in Chinese with English abstract)

Liu H Y, Cui H T, Tian Y H, Xu L H (2002). Temporal-Spatial variances of Holocene precipitation at the marginal area of east asian monsoon influences from pollen evidence. Acta Botanica Sinica, 44(7): 864–871

Luly G J (1997). Modern pollen dynamics and surficial sedimentary processes at Lake Tyrrel, Semi-arid Northwestern Victoria, Australia. Review of Palaeobotony and Palynology, 97: 301–318

Moore P D, Webb J A, Collinson M E (1991). Pollen Analysis. Oxford: Blackwell Science, 39–62

Singh G, Luly J G (1991). Changes in vegetation and seasonal climate since the last full glacial at lake Frome, South Australia. Palaeogeogr. aphy Palaeoclimatology and Palaeoecology, 84: 75–86

Song C Q, Sun X J (1999). Advances in studies of Quaternary Palynology in China. Advance In Earth Sciences, 14(4): 401–406 (in Chinese with English abstract)

Sun X J, Du N Q, Weng C Y, Lin R F, Wei K Q (1994). Paleovegetation and paleoevironment of Manasi lake, Xinjiang, Northwestern China during the last 14,000 years. Quaternary Sciences, 3: 239–248 (in Chinese with English abstract)

Sun X J, Wu Y S (1984). Distribution and quantity of sporopollen and algae in surface sediments of the Dianchi lake, Yunnan Province. Marine Geology and Quaternary Geology, 7(4): 81–92 (in Chinese with English abstract)

Wünnemann B, Chen F H, Riedel F, Zhang C J, Mischke1 S, Chen G J, Demske D, Jin M (2003). Holocene lake deposits of Bosten lake, southern Xinjiang, China. Chinese Science Bulletin, 48(14): 1429–1433

Xinjiang Multi-disciplinary Investigation Group, CAS; Institute of Botany, CAS (1978). Xinjiang Vegetaion and Its Using. Bejing: Science Press, 1–378 (in Chinese)

Xu Q H, Li Y C, Yang X L, Xiao J L, Liang W D, Peng Y J (2005). Source and distribution of pollen in the surface sediment of Daihai Lake, inner Mongolia. Quaternary International, 136: 33–45

Xu Y Q, Yan S, Jia B Q, Yan S, Ni J (1996). Numerical relationship between the surface spore-pollen and surrounding vegetation on the southern slope of Tianshan Mountains. Arid Land Geography, 19(3): 24–30 (in Chinese with English abstract)

Zhao Y, Yu Z C, Chen F H, Ito E, Zhao C (2007). Holocene vegetation and climate history at Hurleg Lake. Review of Palaeobotany and Palynology, 145(3–4): 275–288

Zhu Y, Chen F H, Cheng B, Zhang J W, Madsen D B (2002a). Pollen assemblage features of modern water samples from the Shiyang River drainage, arid region of China. Acta Botanica Sinica, 44(3): 367–372

Zhu Y, Chen F H, Madsen D B (2002b). The environmental signal of an early Holocene pollen record from the Shiyang River basin lake sediments, northwestern China. Chinese Science Bulletin, 47(4): 267–274

Zhu Y, Chen F H, Liu H J, Cheng B, Huang X Z (2003a). Preliminary studies on the air-borne pollen in the Shiyang River drainage, arid China. Journal of Lanzhou University (Natural Sciences), 39(2): 100–104 (in Chinese with English abstract)

Zhu Y, Xie Y W, Cheng B, Chen F H, Zhang J W (2003b). Pollen transport in Shiyang River drainage, arid China. Chinese Science Bulletin, 48(14): 1499–1506