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Pollen spectrum, a cornerstone for tracing the evolution of the eastern Central Asian desert

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ABSTRACT

The temperate desert in arid Central Asia (ACA) has acted as a thoroughfare for the ancient Silk Road and today's Belt and Road, linking economic and cultural exchanges between East and West. The interaction between human sustainable development and the dynamic change in the desert ecosystem in this region is an area of concern for governments and scientific communities. Nevertheless, the lack of a pollen spectrum of the dominant taxa within the temperate desert vegetation and a corresponding relation between pollen assemblages and specific desert vegetation types is an obstacle to further understanding the formation and maintenance of this desert ecosystem. In this work, we link pollen assemblages to specific desert vegetation types with a new pollen spectrum with specific pollen grains, specific plant taxa and related habitats, providing a solid foundation for further tracing the evolution of the desert ecosystem in eastern arid Central Asia.

1. Introduction

Forest, grassland, and desert are the three major terrestrial ecosystems on Earth. The deserts worldwide are divided into tropical and subtropical desert (S/N: 15–35°), warm temperate and temperate desert (N: 35–50°), and polar and alpine desert (Zhang, 2007). The arid Central Asia (ACA) desert that we have studied is a typical temperate desert (Li et al., 2015a; Robinson, 2015). The ACA desert has acted as a thoroughfare for the ancient Silk Road and today's Belt and Road (Li et al., 2015b), making economic and cultural exchanges between East and West possibole (Wu, 2007; Liu, 2015; Li et al., 2016). Numerous ancient city sites such as Tuyoq (Tang et al., 2014), Niya (Lin, 1996), Kaladun (Zhou, 1989), Yixun (Zhou, 1989) and Kroran (Loulan) (Xie, 2001; Wang, 2010) witnessed the rise and fall of civilization and related climate changes in the ACA. Thus, it is not difficult to understand why both governments and scientific communities have strong interests in exploring the formation and sustainable development of the ACA desert. Nevertheless, the limited references on past vegetation prevent us from further understanding and interpreting the formation and sustainable development of desert ecosystems because most studies focus on forest (e.g., Jackson and Kearsley, 1998; Lindbladh et al., 2000; Gosling et al., 2009; Ordonez and Williams, 2013; Dawson et al., 2016; Figueroa-Rangel et al., 2016) and grassland (e.g., Jacobs, 1999; Hoyt, 2000; Keeley and Rundel, 2005; Edwards et al., 2010; Ge et al., 2017), while few focus on desert (e.g., Shreve, 1942; Peinado et al., 1995; Mcauliffe and Devender, 1998).

Pollen assemblages preserved in the geological past can supply effective information on ancient vegetation, such as a list of taxa, dominant taxa, and vegetation types (Clark and Patterson, 1985; Minckley et al., 2012; Herzschuh et al., 2016). Increasing evidence demonstrates that different vegetation types, i.e., forest, grassland, and desert, can be recognized using pollen data at the level of the biome (Hevly et al., 1965; Brook et al., 1990; Orvis, 1998; Luo et al., 2007; Zhao et al., 2012; Flantua et al., 2015; Dallmeyer et al., 2017;

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Zhang et al., 2017). Furthermore, diverse types of forest (e.g., Björse et al., 1996; Calcote, 1998; Xu et al., 2005a,b; Lebamba et al., 2009; Qin et al., 2015) and grassland (e.g., Hoyt, 2000; Xu et al., 2005a,b; Qin et al., 2015) can be identified using pollen assemblages. However, whether different desert vegetation types can be distinguished by pollen data is unknown.

Certain pollen references about the ACA focused on the pollen morphology of selected modern desert plants at the local scale, e.g., Xi and Ning (1994) described the pollen morphological characters of 70 families, 191 genera and 283 species in NW China. Unfortunately, the dominant taxa in the ACA desert, such as Chenopodiaceae, *Calligonum*, *Ephedra* and *Nitraria,* were not included. In the Alaskan desert, Inner Mongolia, and NW China, Yan and Wan, 1999 reported the pollen morphology of 16 species of desert plants belonging to 8 families and 15 genera. Yan et al. (2003) described the pollen morphology of 12 endemic plants, and Wan et al. (2004) recorded the pollen morphology of 10 endemic plants, although none of these references aimed at distinguishing major desert vegetation types using pollen data.

In this work, we attempt to 1) depict a pollen spectrum of the dominant species in desert vegetation to improve the resolution and accuracy of pollen identification in the eastern ACA, 2) link specific pollen assemblages to major temperate desert vegetation types, and 3) plot distribution maps of each dominant species for a better understanding of the distribution patterns of these desert plants.

2. Materials and methods

The study area is located in NW China, part of the ACA desert covering the Junggar Basin, Tarim Basin, Alashan Plateau, Hexi Corridor, Qaidam Basin and a portion of the Tibetan Plateau (Zhang, 2007). Hot and dry summers and cold and frosty winters alternate in the eastern ACA desert. Precipitation is usually less than 150 mm/y, potential evaporation is greater than 2000 mm/y, while the mean annual temperature is approximately 5–9 °C (Zhang et al., 2016). The vegetation types in the eastern ACA desert are diversified (Wu, 1980; Zhang, 2007; Zhang et al., 2016). Wu (1980) recognized 4 vegetation types, i.e., semi-dwarf arbor desert, shrubby desert, semi-shrub and dwarf semi-shrub desert, and cushion dwarf semi-shrub desert (Table S1). Based on the scheme of Wu (1980), Zhang (2007) subdivided the 4 types into 7 types (Table S2). For instance, the shrubby desert is subdivided into temperate shrubby desert and temperate shrubby steppe desert, and the semi-shrub and dwarf semi-shrub desert is subdivided into temperate semi-shrubby and dwarf semi-shrubby desert, temperate succulent holophytic dwarf semi-shrubby desert, and temperate annual graminoid desert (Fig. S1).

Pollen grains of 56 species were extracted from voucher specimens (Table S3) from the PE herbarium at the Institute of Botany (herbarium code: PE). Pollen grains were acetolyzed by the standard method (Erdtman, 1960) and fixed in glycerin jelly. Standard procedures were followed for light microscopy (LM) and scanning electron microscopy (SEM). All pollen grains were observed and photographed at a magnification of ×400 or 1000 under a Leica 4000 instrument. At least 20 pollen grains were measured for each species. The average values and the variation ranges were used to describe the pollen morphological characters. The fine characteristics of exine ornamentation were observed under SEM.

The pollen morphological terminology follows the overview of Hesse et al. (2009) and Punt et al. (2007). For instance, Punt et al. (2007) divided the pollen shapes into prolate (1.33–2.00), subprolate (1.14–1.33), spheroidal (0.88–1.14), and suboblate (0.75–0.88) based on their P/E ratio values. The P/E ratio of each pollen grain was calculated using the polar axis diameter (P) and equatorial diameter (E). Hesse et al. (2009) defined pollen size as very small (<10 μm), small (10–25 μm), medium (26–50 μm), large (51–100 μm), and very large (>100 μm) based on the pollen diameters. The distribution maps are plotted using the Google Maps and the species distribution data at the county level supplied by the Chinese Virtual Herbarium (http://www.cvh.ac.cn/).

3. Results

3.1. Depiction of pollen spectrum

The pollen features of the 56 species were tabulated according to pollen shape, size, aperture type, and ornamentation on exines (Table S4). The pollen shapes studied in this work were divided into spheroidal, subprolate and prolate types. Pollen sizes included small, medium, and large types. Aperture types covered 3-(-4)-colporate, pantoporate, 3-colpate and monoporate. The types of ornamentation on exines were striate-perforate, reticulate, foveolate, microechinate, echinate-perforate, microechinate-perforate, fossulate, psilate and granulate-perforate. The detailed descriptions of the pollen morphology of the 56 species are listed in the Supporting Information (Appendix S1 and Fig. S2-S12). Maps of the distribution of these 56 species in China are also provided (Fig. S13-S19).

3.2. Key to pollen

The key to pollen grains in the eastern ACA desert is based on the pollen spectrum described above.

1a. Apertures 10-50	2
1b. Apertures 0-3	10
2a. Pores 24-50	3
2b. Pores 10-24	6
3a. Pore membrane with “islands” of fused microechini	4
3b. Pore membrane with isolated microechini	5
4a. Pore diameter (1.1-) 2.0–2.4 (–3.3) μm	*Krascheninnikovia ceratoides* (Fig. 5p–t), *K. compacta*
4b. Pore diameter (0.9-) 1.1–1.2 (–1.5) μm	*Suaeda microphylla*, *S. physophora* (Fig. 6f–j)
5a. Diameter pore ca. 1.7–1.8 μm	*Halocnemum strobilaceum* (Fig. 4k–o), *Halostachys caspica* (Fig. 4f–j)
5b. Diameter pore ca. 2.1–2.4 μm	*Atriplex cana* (Fig. 4u–y), *Kalidium schrenkianum*, *Sympegma regelii*
6a. Pore membrane with fused microechini	*Haloxylon ammodendron*
6b. Pore membrane with isolated microechini	7
7a. Pore diameter 1.0–2.3 μm	*Gymnocarpos przewalskii* (Fig. 6k–o), *Halocnemum strobilaceum*, *Kalidium cuspidatum*
7b. Pore diameter (1.9-) 2.3–5.0 μm	8
8a. Diameter pore (3.6-) 3.9–5.0 μm	*Iljinia regelii* (Fig. 5a–e), *Salsola passerine* (Fig. 6a–e)