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Study of modern pollen and stomata from surficial lacustrine sediments from the eastern edge of Tibetan Plateau, China

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ABSTRACT

To examine the relationships between pollen, conifer stomata and vegetation in high mountainous areas, the pollen and conifer stomata contents of surface sediments from 26 lakes in the eastern edge of the Tibetan Plateau were analyzed. Pollen analyses show that pine forests have distinct pollen assemblages that are characterized by high abundance of *Pinus* pollen and subtropical taxa such as *Castanopsis*, *Eurya* pollen. Detrended correspondence analysis (DCA) also indicates that pine forests can be distinguished from cold coniferous forests and the Alpine shrub and meadow based on pollen analysis. However, cold coniferous forests and the alpine shrub and meadow cannot be differentiated by pollen analyses. This is best illustrated by the DCA analysis, which shows that both plant communities are characterized by a higher abundance of pollen such as *Picea*, *Tsuga*, and *Quercus*. Analyses of stomata reveal that *Pinus* stomata only occur in samples collected from the regions with pine forests, and cold conifer stomata were not found in the Alpine lakes except for one lake, which was likely influenced by human activities. Therefore, conifer stomata appear to be an important tool that complements pollen analysis in reconstructing vegetation history of high mountainous areas, especially for tree line migration.

1. Introduction

The tree line position is considered to be primarily controlled by temperature and is potentially sensitive to climate change (Camarero and Gutierrez, 2004; Holtmeier and Broll, 2005; Korner and Paulsen, 2004; Lloyd and Fastie, 2003). The study of the long-term tree line history can help us understand how the ecological environment responds to climate change (Hofgaard and Wilmann, 2002; Kupfer and Cairns, 1996; Young et al., 2011). The studies of pollen, plant macrofossils and stomata are the main methods to reconstruct the tree line history (Birks, 1993; Birks and Birks, 2000; Macdonald, 2002). Among these methods, pollen analysis is the most common approach used to reconstruct the palaeovegetation, including the tree line history (von Stedingk and Fyfe, 2009). However, the relationship between pollen and vegetation is very complicated because many factors such as pollen production, dissemination, deposition, and the precision of taxonomic identification affect the accuracy of vegetation reconstruction. For example, pollen of *Pinus* and *Picea* can be transported for thousands of kilometers and occur in high percentage values in surface sediments of lakes in tundra areas (Clayden et al., 1996; Hansen et al., 1996). *Abies* and *Larix* pollen often display only small relative abundances in sediments collected from regions where they are dominant components of the vegetation (Gajewski, 1995; Pisaric et al., 2000; Ritchie et al., 1987). Since plant macrofossils can be identified to species level and are transported for a short distance, they can be used as an accurate proxy for vegetation reconstruction (Birks, 1993; Birks and Birks, 2000; Finsinger and Tinner, 2007). However, adequate and reliable plant macrofossils are not easy to obtain in sediments, especially cored sediments. The analysis of conifer stomata is another very useful method to reconstruct vegetation history (Hansen, 1995; Macdonald, 2002). Previous studies have demonstrated that conifer stomata can accurately indicate the nearby occurrence of source trees and play an important role in studying the vegetation and reconstructing tree line migrations in the Arctic and in Alpine areas (e.g., Clayden et al., 1996; Pisaric et al., 2000, 2001). The stomata record also can provide a reliable proxy for sudden tree line fluctuations such as 8.2 ka event in alpine mountains (Pisaric et al., 2003).

The eastern edge of the Tibetan plateau is rich in plant species, occurring at different altitudes and in different vegetation types or zones. Previous pollen studies indicate that modern *Pinus* pollen often exhibits high relative abundance in pollen spectra of different altitudinal vegetation zones and can reach over 40% even in areas where no pine trees grow (Jarvis and Clay-Poole, 1992; Shen et al., 2013; Xiao et al., 2011). Although vegetation zones can be often discriminated by their dominant species, large uncertainties still exist because pollen, particularly that of *Pinus,* which is specially adapted to wind transport, can be dispersed over very long distances and over large altitudinal ranges. A study of modern pollen from lake surface sediments suggests that different vegetation zones spanning over 3600 m above sea level

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cannot be distinguished by pollen spectra (Xiao et al., 2011). Therefore, pollen analysis needs to be supplemented by megafossil and cuticular studies for precise reconstructions of the vegetation history of high mountain areas. A study of modern pollen and stomata from surface soil and moss polsters from Yunnan Province, China, has demonstrated that conifer stomata are a very useful tool for distinguishing different vegetation types (Shen et al., 2013). In this study, we conduct modern pollen and stomata analyses of surface sediments from 26 lakes at the eastern edge of the Tibetan Plateau to investigate whether dispersed conifer cuticles, identified on the basis of the stomata morphology, can be used to help distinguish different vertical vegetation zones in high mountainous regions. Our study could provide improved protocols for interpreting the Late Pleistocene and Holocene plant fossil records collected from lacustrine sediments of the Tibetan Plateau and other high mountainous regions.

2. Materials and method

2.1. Study area

The study area is located at the southeastern edge of the Tibetan Plateau, which is characterized by high mountains and deep valleys (Fig. 1). The elevations increase gradually from the southeast to the northwest, and the mean elevation of northwestern part is above 4000 m with the maximum elevation exceeding 5000 m. The mean elevation of the southeastern part is just above 2000 m.

The precipitation of the area is influenced by the Asian southwestern monsoon. However, there are great variations in and temperature and precipitation among different geomorphologic units. In general, the temperature decreases gradually from the southeast to the northwest because of the changes in latitude and elevation. This area can be divided into two parts. In the southern part (northwestern Yunan Province and southwestern Sichuan Province), *Pinus yunnanensis* forests stand at 2500–2800 m above sea level (a.s.l.) with single trees growing at up to 3200 m. The cold temperate coniferous forests that occur at 2800–3200 m are primarily composed of *Tsuga* spp., *Acer*, and *Abies*. Cold coniferous forests and cold sclerophyllous evergreen *Quercus* forests occur at elevations between 3000 and 3900 m. The tree line, which is dominated by *Abies* or *Picea*, appears at 3900–4100 m. Above the tree line, alpine shrub communities and meadows occur. The dominant shrub species include *Rhododendron*, *Quercus*, *Sabina*, and *Berberis*. The main meadow taxa consist of Gramineae, Cyperaceae, Compositae, Liliaceae, Gentianaceae, and Umbelliferae.

In the northern part (western Sichuan Province and southeastern Qinghai Province), *P. yunnanensis* forests and *Quercus* forests grow at elevations of 1800–2400 m. At elevations between 2400 and 3200 m, *Pinus densata* and *Quercus* shrubs occupy the southern slopes, and mixed coniferous-broad leaf forests that are dominated by *Tsuga*, *Acer*, and *Betula* grow on the northern slopes. Cold coniferous forests dominated by *Abies, Picea*, and *Larix* grow at elevations of 3200–4000 m. The tree line often lies at 3800–3900 m and can reach up to 4000 m at some areas (Wu, 1980). The alpine shrub and meadow communities grow above the tree line.

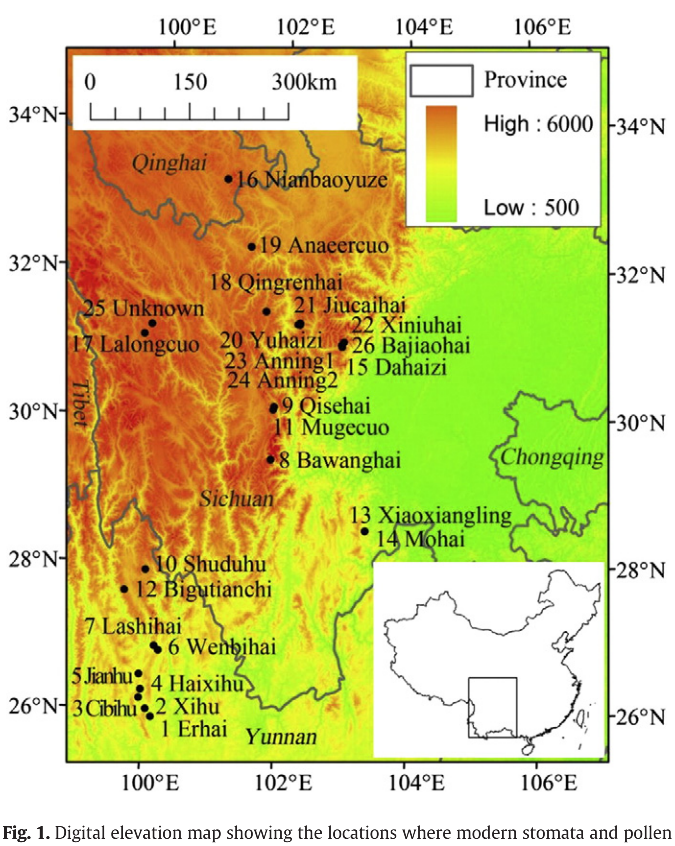

Fig. 1. Digital elevation map showing the locations where modern stomata and pollen samples were collected from the eastern edge of Tibetan Plateau.

2.2. Methods

The top 1 cm of lake-bottom sediments from 26 lakes were collected using a gravity corer between 2005 and 2009 (Table 1). The standard HF method was employed to extract pollen and dispersed cuticles from samples (Faegri et al., 1989). A tablet of *Lycopdodium* (27637 grains) was added to the samples prior to processing to calculate pollen and stomata concentrations. Pollen was counted to at least 500 terrestrial grains for each sample. A minimum of 10 stomata or 1000 *Lycopodium* grains were counted for each sample. The identification of stomata is based on the keys (Hansen, 1995; Sweeney, 2004; Wan et al., 2007) and our collected modern references. Since stomata found in lake sediments occur as isolated singular stomata and in small fragments of epidermis (MacDonald, 2002) that are distributed in a fashion similar to pollen (MacDonald, 2002), the percentages of stomata were calculated in the same way as for upland pollen, i.e., using the sum of total terrestrial plant pollen. The relative abundance of aquatic pollen and fern spores were calculated using all pollen and spore data. The calculation and graphic presentation was based on Tilia and TGView (Grimm, 1990, 2004). To study the relationship between modern pollen and vegetation data, detrended correspondence analysis (DCA) was performed based on terrestrial pollen percentages. Only those taxa reaching or more than 2% abundance in at least three samples were included in the DCA analysis. CANOCO 4.5 software was used to compute results and the pollen percentage data were converted by the square root transformation (Ter Braak and Smilauer, 1998).

3. Results and discussion

3.1. Results

A total of 136 families and/or genera pollen were identified from samples collected from 26 lakes and six families and/or genera on the basis of stomata (Fig. 2). Similar to what MacDonald (2002) mentioned, we observed that stomata occur mostly as isolated and occasionally in small fragments of epidermis that usually contains two or three stomata. Below is the characterization of pollen and stomata assemblages of different vegetation types in the study area.

3.2. P. yunnanensis forests

Surface sample pollen spectra from lakes in or near *P. yunnanensis* forests are dominated by *Pinus* (88.2–51.5%). *Tsuga* pollen was found in almost all samples but with low percentages (the highest 1.7%). Other tree pollen include evergreen *Quercus*, *Juglans*, *Eurya*, *Castanopsis*, *Carpinus*, *Alnus*, *Betula*, *Quercus*, and *Fraxinus* (Figs. 3 and 4). Herb pollen