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Special Topic:
Advanced Catalytic Materials for Environmental Application

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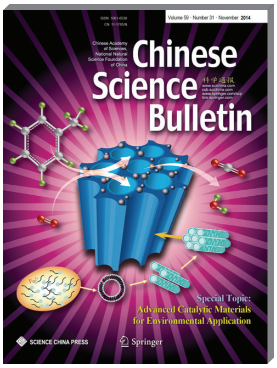

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COVER Volatile organic compounds (VOCs) cause serious atmospheric pollution, and most of them are harmful to human health. Catalytic oxidation is an efficient method for the removal of VOCs. The key issue is the development of high-performance catalysts. Although transition-metal oxides (MO_x) can act as catalysts, their performance is poor because of their low surface areas. High dispersion of M^{n+} or MO_x can be achieved by the incorporation of M^{n+} ions into a framework consisting of high-surface-area mesoporous molecular sieves or loading the MO_x onto the surface of a porous material. Mesoporous silicas such as SBA-15 have received much attention as catalysts because of their large pores, thick pore walls, and good hydrothermal stabilities. We synthesized high-surface-area, well-ordered mesoporous Fe-incorporated SBA-15 (Fe-SBA-15) and SBA-15-supported FeO_x (FeO_x/SBA-15), using one-step synthetic and incipient wetness impregnation methods, respectively. For a similar Fe surface density and space velocity, the Fe-SBA-15 catalysts showed better activities than the FeO_x/SBA-15 catalysts in the catalytic combustion of toluene. We concluded that the good performance of Fe-SBA-15 is associated with its large surface area, high Fe species dispersion, and good low-temperature reducibility. The cover image shows the fabrication process, pore structure feature, and toluene oxidation pathway of the Fe-SBA-15 and FeO_x/SBA-15 catalysts (see the article by Yujuan Zhang et al. on page 3993).

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Article

Geology

Changes in plant diversity on the Chinese Loess Plateau since the Last Glacial Maximum

Shujun Zhao · Zhongli Ding

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Abstract Changes in biodiversity during periods of global warming are of broad public concern. To study the effect of the warming process on the ecosystem, we carried out pollen analyses on samples from seven selected sections at Qingyang, Ningxian, Yangling, Binxian, Baoji, Yanshi, and Lingbao on the Chinese Loess Plateau in order systematically to evaluate changes in plant diversity since the Last Glacial Maximum (LGM). The plant richness indices (Simpson's diversity index and rarefaction analysis) indicated that the plant diversity of each section increased during the process of warming from the LGM to the Holocene Optimum, especially at Baoji and Lingbao. These results are consistent with many long-timescale geological records, which show that warming can increase biodiversity; therefore, the popular viewpoint that warming leads to biodiversity loss or species extinction needs to be re-examined.

Keywords Last Glacial Maximum · Holocene · Warming · Chinese Loess Plateau · Biodiversity

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1 Introduction

Biodiversity is an essential basis for maintaining a functioning ecosystem [1]. Some ecologists have inferred that warming would most likely cause biodiversity decrease; these inferences were mostly based upon numerical models and limited time observations [2, 3]. The effect of global warming on biodiversity has thus become a matter of intense interest. Contrary to expectations, however, some geological records show that biodiversity has tended to increase during some warm periods since 540 Ma [4]. These conflicting results may be due partly to the scarcity of detailed studies on biodiversity changes during periods in the past, which could be considered as an analog of future global warming episodes. It is clear that we need more records of biodiversity changes at different times and on regional scales in order to understand better the effects of warming on biodiversity.

The East Asian monsoon is a most active subsystem in Earth's climate system. Many modeling studies have indicated that global warming will lead to increased precipitation in East Asia [5, 6]. The CLP is located in the marginal zone of the East Asian summer monsoon. The vegetation of this region changes from forest-grassland into grassland and desert-grassland from the southeast to the northwest of the plateau [7]. This region is therefore very sensitive to climate change. During the past 20 ka, Earth's climate has experienced a gradual warming from the Last Glacial Maximum (LGM) to the Last Deglaciation (LD), and thence to the Holocene Optimum (HO); the biodiversity changes during this period have considerable significance for assessing the impact of global warming on the ecosystem. Loess-paleosol sequences provide valuable materials for research into the impact of warming upon biodiversity due to their widely distributed and continuously deposited eolian sediments [8–10].

Fossil materials are main indicators of biodiversity in the reconstruction of geological history [11], and palynological data are regarded as a reliable source in estimating past plant diversity [12]. In this paper, seven sections were selected from the Loess Plateau based on the magnetic susceptibility and median grain size of strata and discuss the influence of warming on the ecosystem through the analysis of pollen diversity.

2 Materials and methods

We selected seven loess-paleosol sections on the CLP along two different transects: the Yangling, Binxian, Ningxian, and Qingyang sections along a south–north transect; and the Baoji, Yangling, Yanshi, and Lingbao sections along a west–east transect (Fig. 1). The stratigraphic division and nomenclature of these sections have been described by Yang and Ding [9] based on grain size analysis and the pedogenic characteristics. Samples were taken at 5–10 cm intervals from the strata of the sections dated from the LGM (above L1-1 horizon). We measured magnetic susceptibility and median grain size first. Horizons of the LGM, the LD, and the HO in each section were identified based on magnetic susceptibility, median grain size data, and pedogenic characteristics. Samples for pollen analysis were selected within these three periods (Fig. 2). Pollen was extracted by the sieving and heavy-liquid

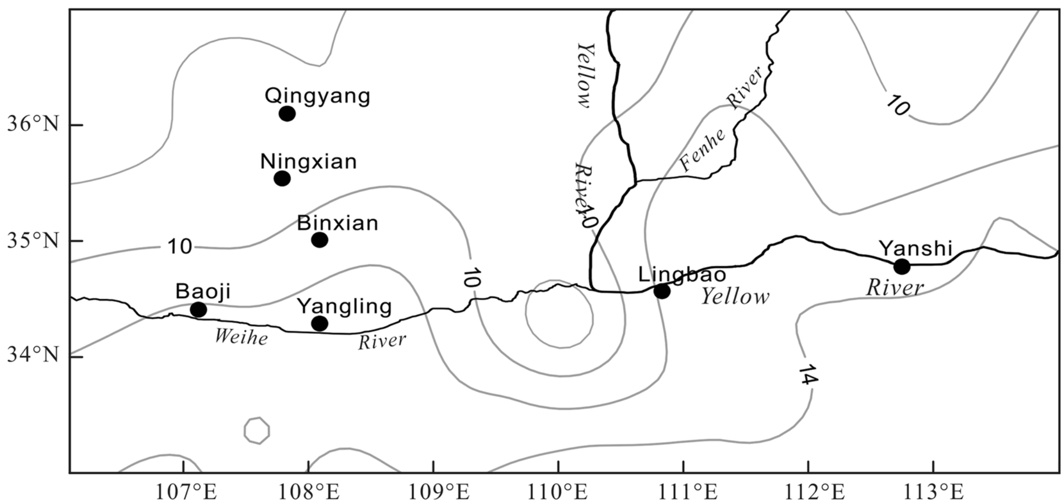

Fig. 1 Study site locations. Solid dots show the location of the studied sections on the CLP. The gray isolines indicate the mean annual temperature

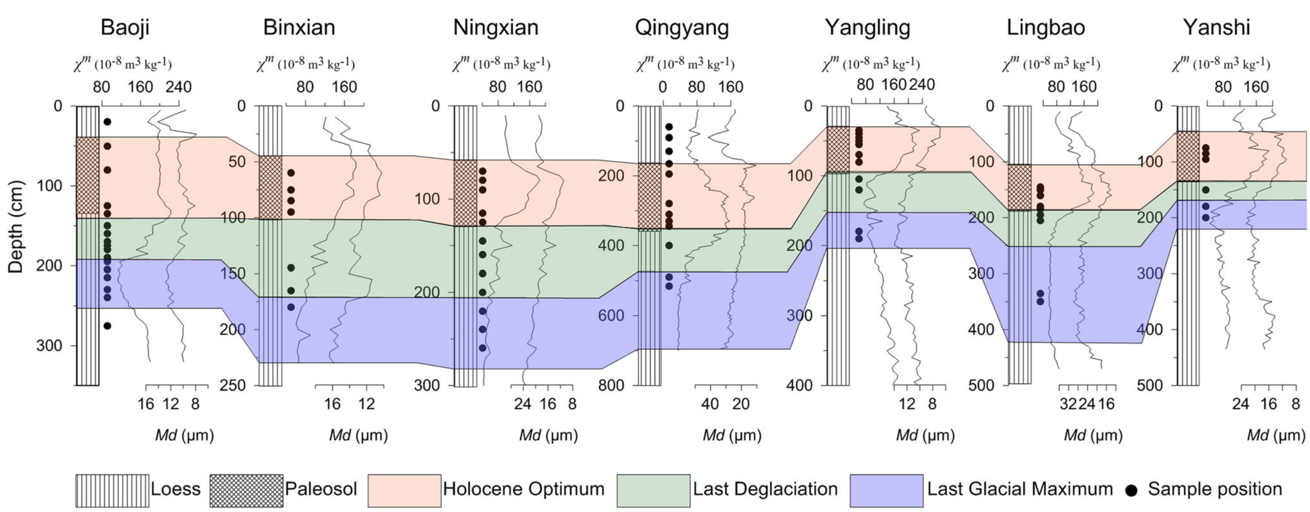

Fig. 2 Map showing the division of LGM, LD, and HO periods and pollen sample positions in each section. The magnetic susceptibility and median grain size curves are also shown

method developed by Li et al. [13]. In brief, samples with a weight of 100–150 g were dissolved by hydrochloric acid, extracted by heavy liquid, and purified by hydrofluoric acid.

Biodiversity changes can be characterized by species richness and relative abundance [14]. Among the methods of diversity analysis, the Simpson diversity index [15, 16] mainly reflects the relative abundance of species and is less affected by lithology, whereas rarefaction analyses of species richness can be comparable for samples of different sizes [17]. Here, we employed MVSP [18] software and aRarefactWin software [19] to calculate the two indices with the objective of evaluating biodiversity changes since the LGM on the CLP.

3 Results

We analyzed a total of 87 samples for pollen assemblages in the seven sections and identified 72 pollen taxa. Herbaceous plants were prevalent (Table 1), dominated by *Artemisia*, Chenopodiaceae, and Compositae; Gramineae, *Ephedra*, Liliaceae, *Humulus*, and Zygophyllaceae pollen also emerged. Arboreal pollen such as *Pinus*, *Corylus*, and *Betula* could be found, and fern spore was rare (Figs. S1–S7 online).

Our palynological data demonstrated that the vegetation of the CLP has been grassland dominated by *Artemisia* since the LGM. Spatial comparison shows that the vegetation type has not undergone large changes from west to east, and the arboreal plant percentages increased significantly during the LD and HO. Meanwhile, from south to north, drought-tolerant herbs increase gradually while tree percentages diminish.

We compared the average Simpson diversity index during the three periods for each section (Table 2). Temporally, the Simpson diversity index had the lowest value during the LGM for each section in the three periods and displayed a remarkable increase with the process of warming. The Simpson diversity index reached the highest values during the HO period for most of the sections except for Ningxian and Binxian where the highest values were witnessed during the LD.

We selected one sample with abundant pollen types during each period for each section on which to perform the rarefaction analysis (Fig. 3). The rarefaction curve showed that the biodiversity during the LGM is obviously lower than that during the LD and the HO periods at all sections except for the Yangling and Qingyang sections, as shown by their intersected rarefaction curves (Fig. 3). The biodiversity of the Baoji and Yanshi sections increased markedly during the LD period.

Table 1 Pollen statistics from each section

Section	Location	Sample number	Average pollen number	Total number of pollen types	Herb pollen average (%)
Baoji	34.41°N, 107.12°E	17	127	65	92.3
Yangling	34.29°N, 108.09°E	11	204	34	85.1
Lingbao	34.57°N, 110.83°E	10	151	41	86.7
Yanshi	34.78°N, 112.75°E	6	89	31	88.6
Binxian	35.01°N, 108.09°E	7	117	31	91.5
Ningxian	35.54°N, 107.79°E	12	315	48	93.3
Qingyang	36.10°N, 107.83°E	12	340	51	93.1

4 Discussion

Our palynological data have shown that relative plant abundance and species richness on the CLP have both undergone an overall increase during the warming process since the LGM. The result is similar to the previous palynological studies from the CLP [20–22]. Recently, fossil charcoal records in Tianshui Basin of western CLP also showed a high biodiversity in the mid-Holocene [23]. Paleoclimatic studies from stalagmites [24], lakes [25], wetland [26], and loess sediments [27–29] have demonstrated that, from the LGM to the HO, the East Asian summer monsoon was enhanced and rainfall increased with rising temperature. Both of these factors led to an increased biodiversity on the CLP, where water is the main factor for plant abundance and distribution [30]. Some research showed that the vegetation pattern and vegetation diversity

Table 2 Simpson's diversity index during the LGM, LD, and HO periods at each site

Section	LGM	LD	HO
Baoji	0.33	0.46	0.63
Yangling	0.84	0.86	0.88
Lingbao	0.43	0.74	0.82
Yanshi	0.50	0.59	0.78
Binxian	0.48	0.50	0.46
Ningxian	0.44	0.47	0.45
Qingyang	0.49	0.52	0.62

LGM Last Glacial Maximum, *LD* Last Deglaciation, *HO* Holocene Optimum

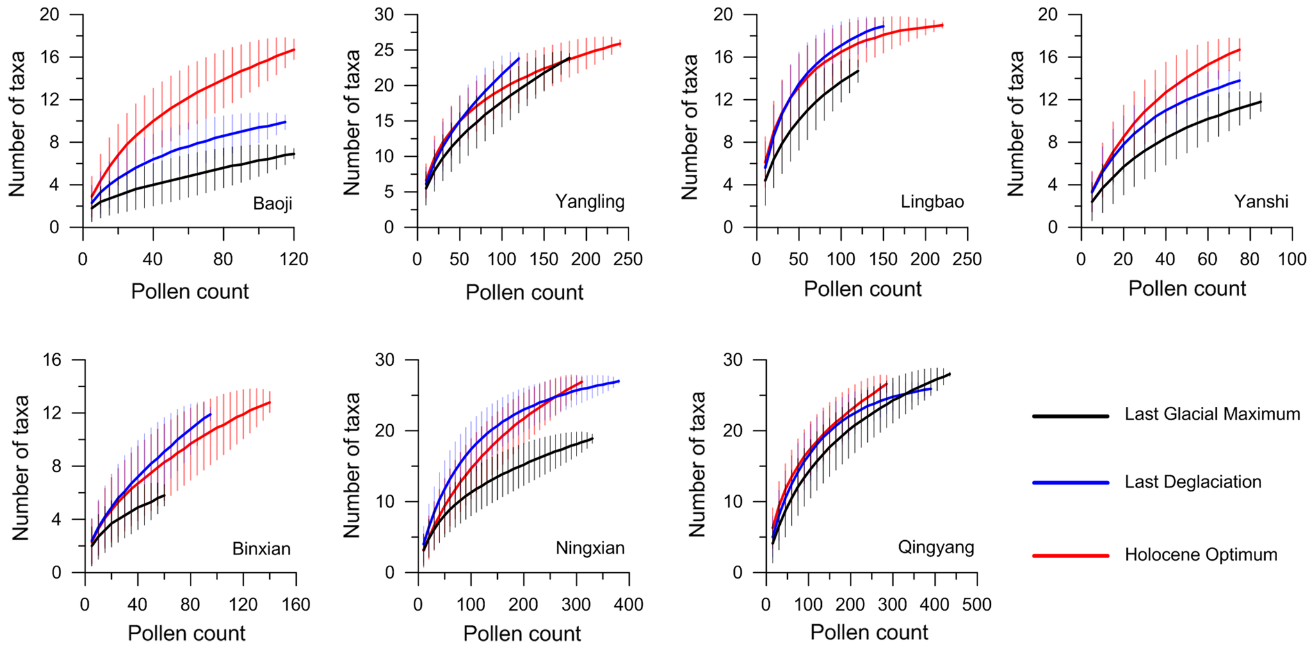

Fig. 3 The rarefaction analysis of pollen during the LGM, LD, and HO periods at each site

are strongly associated with the annual precipitation on in this area [31].

There are some differences between the IPCC's conclusion [32] and the geological evidence on whether warming will bring biodiversity decline, and this maybe caused by their different timescales. The former is an evaluation of the transient feedback of the ecosystem in response to warming, while the latter is usually an expression of an average situation in the time segment represented by samples, which may then be regarded as representing that ecosystem's climate equilibrium state. When we evaluate the effects of climate change through the transient feedback of the ecosystem, the ability of species to migrate during periods of climate change is one of the most important variables [33]. Recently, some researchers have defined the ability of species to migrate as equivalent to the velocity at which species move in order to maintain their native habitat temperatures; this is derived by dividing the spatial temperature gradient (°C/km) by the rate of increase in temperature (°C/a). In the IPCC's A1B scenario (a 2.8 °C increase in the global average temperature by the end of the twenty-first century), the global average velocity is projected to be 0.42 km/a [34]. A more recent study shows that, in recent decades, the median value of the velocities of 1,367 species moving to high latitude regions is 1.69 km/a [35]. This value is about two to three times higher than previous estimates, enough to relieve the pressures of survival triggered by increasing temperatures. At the same time, due to delayed responses [36] and individual physiological differences among species [37], a higher migration velocity may actually lead to an increase in biodiversity. Further studies on species migration velocity will bridge the big gap in assessments based on ecological and geological records.

5 Conclusion

Our palynological records on the CLP demonstrate that plant diversity increased with increasing temperatures in the East Asian monsoon region during the LGM, the LD, and the HO. This result is consistent with much other geological evidence based on longer timeframes. Ipso facto, warming leads to an increase in biodiversity rather than a decrease. Changes in biodiversity on the CLP since the LGM challenge the IPCC's viewpoint that "warming leads to biodiversity loss."

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Conflict of interest The authors declare that they have no conflict of interest.

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