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Magnetostratigraphy and provenance of the Qingzhou loess in Shandong province

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Abstract: Loess deposits with varying thickness are widely distributed on the intermontane valleys and piedmont zones on the northern side of the central Shandong mountainous regions. However, the basal ages and material resources of the loess deposits are not clear. The paper studied the Qingzhou loess profile in Shandong with magnetostratigraphic and optical stimulated luminescence (OSL) methods and further investigated its main provenances with the mineralogical methods. The magnetostratigraphic results showed that the Brunhes/Matuyama (B/M) reversal boundary was not recognized, suggesting a basal age younger than 0.78 Ma. Extrapolations by sedimentation rates, based on the upper part depositional rate from the OSL age, the basal age of the Qingzhou loess is about 0.5 Ma. Until now, older loess deposits have not been reported on the northern side of the central Shandong mountainous regions. The results of the paper indicate that the loess deposits in this area might have strated from the Middle Pleistocene. The basal age of Qingzhou loess is approximately synchronous with the Xiashu loess in the middle-lower reaches of Yangtze River. Major components of clay minerals in the Qingzhou profile are dominated by illite. Other clay mineral compositions are mainly smectite, chlorite and kaolinite, which are similar with the Xifeng loess in the Loess Plateau. However, the contents of smectite and the ratios of illite and kaolinte in the Qingzhou loess samples are higher than those in the Xifeng loess samples of the Loess Plateau, indicating that the loess in the northern side of the central Shandong mountainous regions has different sources from that of the loess deposits in the Loess Plateau. The clay mineral analysis further reinforces the earlier conclusion that the marine strata exposed in the Laizhou Bay and the fluvial plain of the lower reaches of Yellow River during the glacier periods are the main material sources for the Qingzhou loess deposits, which is an indicator to the local aridification of the lower reaches of the Yellow River. Loess deposition in the central Shandong mountainous regions started at around 0.5 Ma. The age of Qingzhou loess is approximately synchronous with the ongoing high-latitude cold since the Middle Pleistocene, which indicates that strengthened East Asian winter monsoon was sufficiently energetic to bring substantial quantities of material from the marine strata exposed in the Laizhou Bay and the fluvial plain of the lower reaches of the Yellow River to the central Shandong mountainous regions. The results therefore suggest that both regional geological process and global changes were responsible for the formation of Qingzhou loess since Middle Pleistocene.

Keywords: Loess; magnetostratigraphy; sedimentology; material provenance; Qingzhou

The Chinese loess is distributed mainly between the north of Kunlun and Qinling mountains and the south of Altai, Alashan and Greater Khingan mountains, presenting a WWN-EES trend loess belt (Liu, 1965, 1985). Shandong province is located on the eastern margin of the loess belt. Based on geomorphic charcteristics, the loess distribution in Shandong province

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can be divided into two parts: one is littoral of Bohai Bay and islands region and another is the piedmont of the mountains in middle Shandong province (Cao *et al.*, 1987; Zheng, 1994; Wang *et al.*, 1999; Liu *et al.*, 2000; Zhang *et al.*, 2004; Peng *et al.*, 2007). The loess in the latter region spreads in east-west direction along the north side of hills. The thickness of the loess is varied, and the most are less than 30 m. The stratum of Qingzhou loess is the thickest one and is well preserved. So far, lots of studies about the origin, forming age and material provenance of the Qingzhou loess (Zheng *et al.*, 1994; Liu *et al.*, 2000; Zhang *et al.*, 2004; Peng *et al.*, 2007) were carried out. Field observation and systemic sedimentary analysis have proved the eolian origin of loess (Liu *et al.*, 2000; Zhang *et al.*, 2004; Peng *et al.*, 2007). However, there are controversial results about the chronology study of the Qingzhou loess due to different dating methods (Zheng *et al.*, 1994; Zhang *et al.*, 2004). As for the material provenance, Qingzhou loess have been considered mainly to be from the loose deposits of Yellow River's fluvial plain and to be exposed on Bohai Bay shelf during glacier periods, with little from the remote Asian inland deserts (Cao *et al.*, 1987; Zheng, 1994; Wang *et al.*, 1999; Liu *et al.*, 2000; Zhang *et al.*, 2004; Peng *et al.*, 2007). However, these opinions are mainly based on sedimentary studies. In this paper, we studied a loess profile named Fujia village in Qingzhou, Shandong province. The chronology of this profile was established by magnatostratigraphy and optically stimulated luminescence (OSL) methods. Combined with the early sedimentary studies (Liu *et al.*, 2000; Peng *et al.*, 2007) and the clay mineral analysis in this paper, the paleoenvironmental significance of the Qingzhou loess was discussed.

1 Study area

Qingzhou city is located in the mid-west of the Shandong peninsula with a warm temperate and semi-humid climate. The mean annual temperature and precipitation are about 12.7°C and 750 mm, respectively. The city prevails northwesterly wind in winter and southeasterly wind in summer, respectively. The loess in Qingzhou mainly spread along the adjacent area between the north margin of the central Shandong Mountains and plain region of northern Shandong province. The research area (36°40′N, 118°27′E) is located in the west ditch of Fujia village, at the foot of Yunmen Mountain, 2-km southwest of Qingzhou city (Fig. 1).

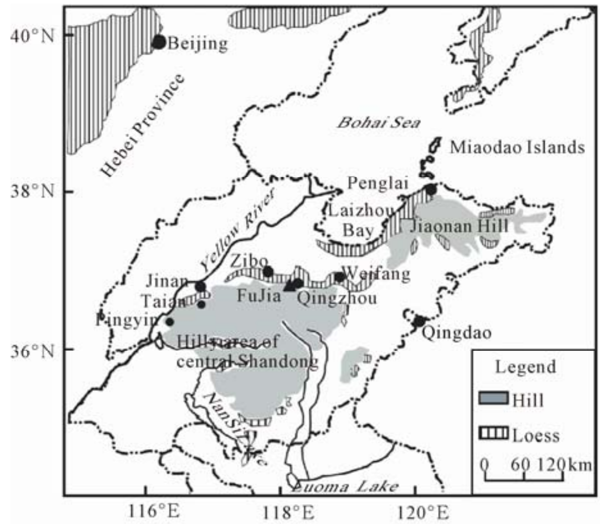

Fig. 1 Schematic map of the study area (modified after Zhang *et al.*, 2004).

The study area is a vertical loess cliff, about 28.2 m in thickness, and underlain by fluvial sand. Except for a 0.5–1 m weathering surface layer, the profile can be divided into four parts based on stratigraphic characteristics:

(1) Modern plough horizon. It is 0.85 m in thickness;

(2) The Holocene loess. It can be sorted into three layers according to the soil development: the upper and lower layers are dark brown soils; the middle layer is loess with lighter color and consists of clayey silts, rich of worm and root holes, and is 2.45 m in thickness;

(3) Malan loess. It is light yellow, silty sand, rich of joints, and occasionally has calcareous nodules about 1 cm in diameter, and is 3.7 m in thickness;

(4) Interbeds of reddish-brown soil and light reddish-brown or light yellow loess. Its color contrasts between soil and loess are not as evident as that of the quaternary loess-like soil in Chinese Loess Plateau. It can be separated into 12 layers of loess and soil in field, respectively. The soil layers of 7.05–8.8 m, 15.3–15.9 m and 20.2–20.7 m are darker in color and are easy to be identified. Besides, there are some bedrock particles with a diameter of 2 mm at 15.9–16.2 m layer, which may be attributed to the sheet flow carrying particle materials from the surrounding bedrock

mountains.

2 Materials and methods

2.1 The paleomagnetism samples and measuring

Based on the detailed field observation to the Qingzhou loess, a total of 92 oriented block samples were collected with sample spacing of 30 cm for paleomagnetic investigation. In addition, 564 samples at 5-cm intervals were collected for the analyses of magnetic susceptibility, using a Bartington MS2 meter. In the laboratory, all the block samples were cut into oriented cubic specimens with 2-cm edge length for measurement. All samples were subjected to progressive thermal demagnetization using MMTD-80 thermal demagnetizer (Magnetic Measurements Ltd., UK). Thermal demagnetization was performed in steps of 50°C to 500°C, and subsequently in steps of 25°C to 585°C. Remanence measurements were made using a 2G-760 U-Channel system manufactured by US 2G Company and performed in the Paleomagnetism and Geochronology Laboratory of the Institute of Geology and Geophysics, Chinese Academy of Sciences, China, where all equipment are installed in a magnetically shielded room (background field < 300 nT).

Demagnetization results were evaluated on stereographic projections and vector end point orthogonal diagrams. The characteristic remanent magnetization (ChRM) directions were calculated by a "least-squares fitting" method (Kirschvink, 1980) with a minimum of five consecutive steps. Typical natural demagnetization diagrams (NRM) are shown in Fig. 2a–f. For most of the samples, a viscous magnetization component can be removed below 150–200°C, and a ChRM component was successfully isolated between 200°C and 550°C, with no remanence at 585°C (Fig. 2a–f),

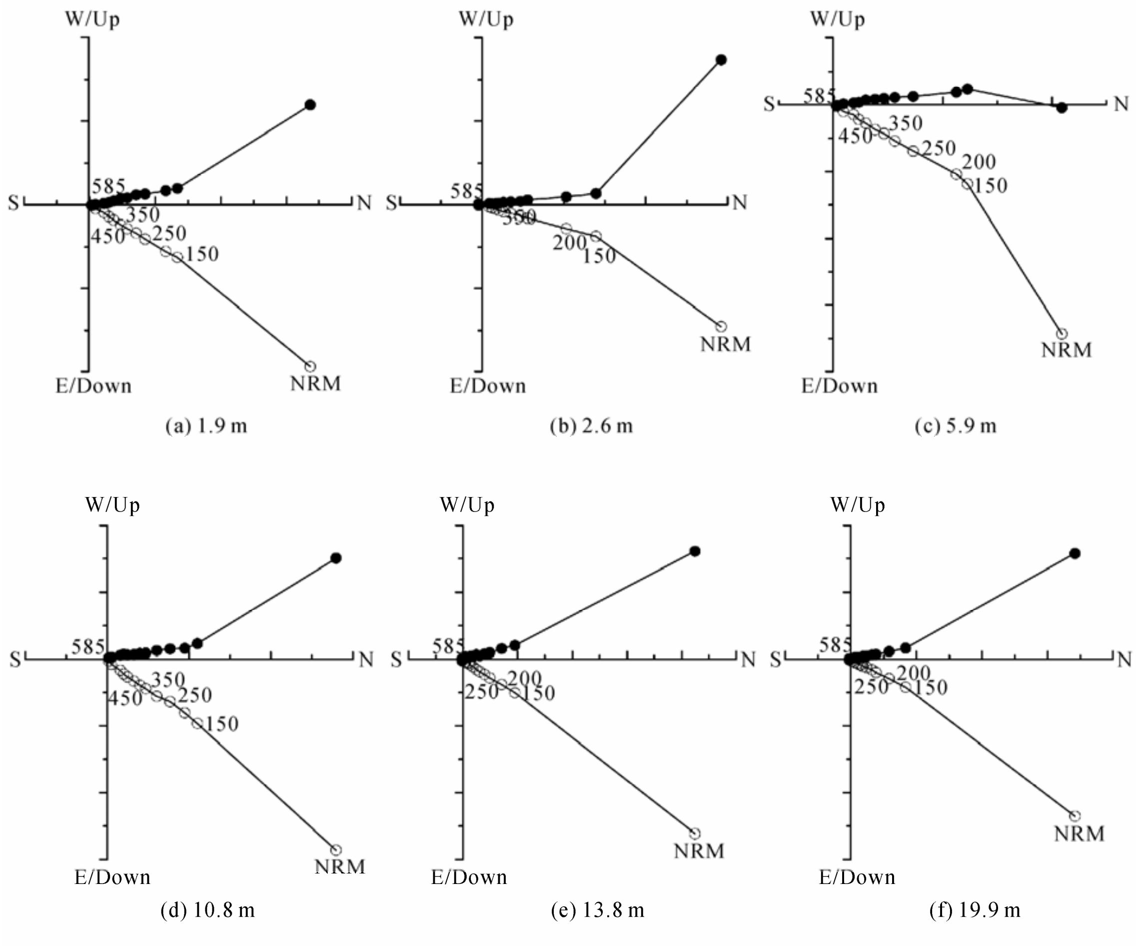

Fig. 2 Orthogonal vector plots of representative specimens from the Qingzhou loess profile. Solid and open circles represent vector endpoints projected onto horizontal and vertical planes, respectively. NRM means natural remanent magnetization.

which suggests the magnetic mineral in the study profile is magnetite. Only two samples showed unstable demagnetization trajectories so that ChRM directions could not be isolated.

2.2 Sampling and experiments of optically stimulated luminescence and clay minerals

Optically stimulated luminescence (OSL) dating method has been widely used in loess chronological studies (Stevens *et al.*, 1989; Lu *et al.*, 2004). The buried time of loess can be calculated from total absorbed radiation dose divided by radiation dose rate. Total absorbed radiation dose is determined by existed specific minerals extracted from the sample with light and measuring the light emitted as a result. Three OSL samples were collected from the upper 10.5-m layer, then quickly wrapped and sealed up by black plastic preservative film for preventing from exposal and evaporation. The OSL was measured in the OSL dating laboratory in the Institute of Earth Environment, Chinese Academy of Sciences.

The analysis of clay minerals in sediments has been extensively applied in tracing and researching the evolvement of the paleoenvironment (Liu *et al.*, 1985; Chamley, 1989; Peng *et al.*, 2007). In order to further tracing the material provenance of the Qingzhou loess, two samples were collected from the unweathered loess layers for clay mineral analysis. The experimental procedure and data processing were determined according to Peng *et al.* (2007). The clay minerals were detected on X-ray diffraction in the same institute.

3 Results

3.1 The chronology of Qingzhou loess

The OSL results were shown in Table 1 and Fig. 3. The OSL age for the Holocene soils, S_{01} (2.1 m) is about 9.7 ka, close to the previous thermal luminescence (TL) age of 12.2 ka for S_{02}, and the age for the boundary of Malan loess and underlying paleosol is about 74.8 ka, close to the basal age of the Malan loess in the Chinese Loess Plateau (Lu and Zhao, 1991), suggesting this paleosol was formed during the last interglacial period. The measured OSL age also indicates that the loess at the depth of 10.5 m is about 185 ka old.

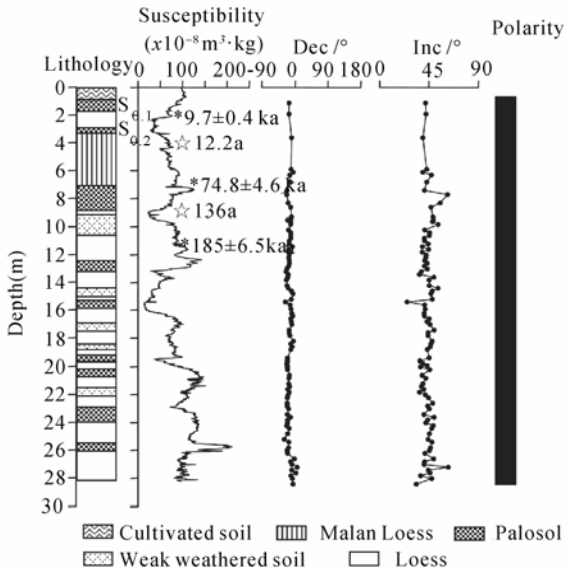

Fig. 3 Lithostratigraphy and magnetostratigraphy of the Qingzhou loess profile; *OSL ages in this study, ☆OSL ages from Liu *et al*. (2000)

The detailed magnetostratigraphic results showed that the Brunhes/Matuyama (B/M) reversal boundary is not recognized (Fig. 3), suggesting a basal age younger than 0.78 Ma. The result is consistent with the previous study (Liu *et al.*, 2000). By linear-extrapolation of the sedimentation rate based on the OSL ages, the basal age of the Qingzhou loess was calculated as 500 ka, consistent with the magnetostratigraphic results, thus further supporting the previous study (Liu *et al.*, 2000). The basal age of the Qingzhou loess is approximately synchronous with the Xiashu loess in the middle-lower reaches of the Yangtze River (Li *et al.*, 2001; Li *et al.*, 2002).

3.2 Clay mineral analysis

The X-ray diffraction patterns of clay minerals are given in Fig. 4. The patterns of each sample after different treatments clearly show that the clay minerals of

Table 1 OSL ages of the loess in the Qingzhou profile

Depth (m)	U (mg/kg)	Th (mg/kg)	K (%)	Water content (%)	Dose rate (Gy/ka)	De/Gy	OSL age (ka)
2.1	2.09±0.21	10.64±0.23	2.18	22.0	3.40±0.11	33.0±1.0	9.7±0.4
7.1	1.92±0.20	10.17±0.22	1.76	22.0	2.93±0.10	219.4±11.2	74.8±4.6
10.5	2.06±0.22	11.55±0.25	2.04	22.0	3.29±0.11	608.0±3.0	185.1±6.5

Qingzhou loess are mainly illite, secondly are smectite, chlorite and kaolinite. The semi-quantitative results (Table 2) also indicate that the clay minerals of the Qingzhou loess are mainly composed of illite, which is similar to that of the Mid-Pleistocene loess in Chinese Loess Plateau (CLP) (Liu, 1985; Peng *et al*., 2007). The Qingzhou loess contains more smectite, less chlorite and kaolinite compared with Malan loess of Xifeng (Peng *et al*., 2007). The ratios between illite and kaolinite in the Qingzhou loess are 15.9 and 20.2, respectively, which are much higher than that of the Xifeng loess (8.8).

4 Discussion

So far, many studies have suggested that the Qingzhou loess are eolian origin and the eolian materials are mainly from the loose deposits covering the Yellow River's fluvial plain and the exposed Bohai Bay shelf on the northern region, secondly from the northwest inland arid areas, and little from the *in-situ* weathering materials of local basal rocks (Cao *et al*., 1987; Zheng, 1994; Wang *et al*., 1999; Liu *et al*., 2000; Zhang *et al*., 2004; Peng *et al*., 2007). These opinions were mainly derived from the comparison of the grain-size characteristics between the Qingzhou loess and the CLP loess. The clay mineral analysis showed that the Qingzhou loess is composed mainly of illite, similar to that of the CLP loess. However, the Qingzhou loess contains more amount of smectite and has higher illite/kaolinite ratios than Xifeng loess, implying different clay mineral composition between Qingzhou and CLP loess. As the analyzed samples are nearly unaffected by weathering and pedogenesis, representing the protoliths, this difference of clay mineral composition further supports the original speculation that material sources of Qingzhou loess are mainly from the Yellow River fluvial plain and the exposed Bohai Bay shelf.

The chronological result showed that the basal age of the Qingzhou loess is about 500 ka. There is no report about the eolian deposits which is older than the Qingzhou loess, and we didn't find any older ones during field observation in the whole Shandong province, indicating that the loess in Qingzhou region may start from Mid-Pleistocene. Previous studies about the Late-Pleistocene loess along the Bohai Bay (Cao *et al*., 1987; Han, 1987; Yu, 1999) suggested that Bohai Bay shelf could expose and became part of the arid and semi-arid area during glacier period along with the sea surface fall, consequently, the exposed and weathered marine sediments became the main source. Similarly, the basal age of the Qingzhou loess is about 500 ka, which may indicate that the exposed Bohai Bay shelf during glacier period and the Yellow River's fluvial plain had provided the materials for Qingzhou loess at that time. Additionally, some drill archives showed that there are several times of large-scale transgression and withdrawal since Mid-Pleistocene accompanying with vast marine sediments (Zhuang *et al*., 1999; Yao *et al*., 2006; Xiao *et al*., 2008). The coincidence be-

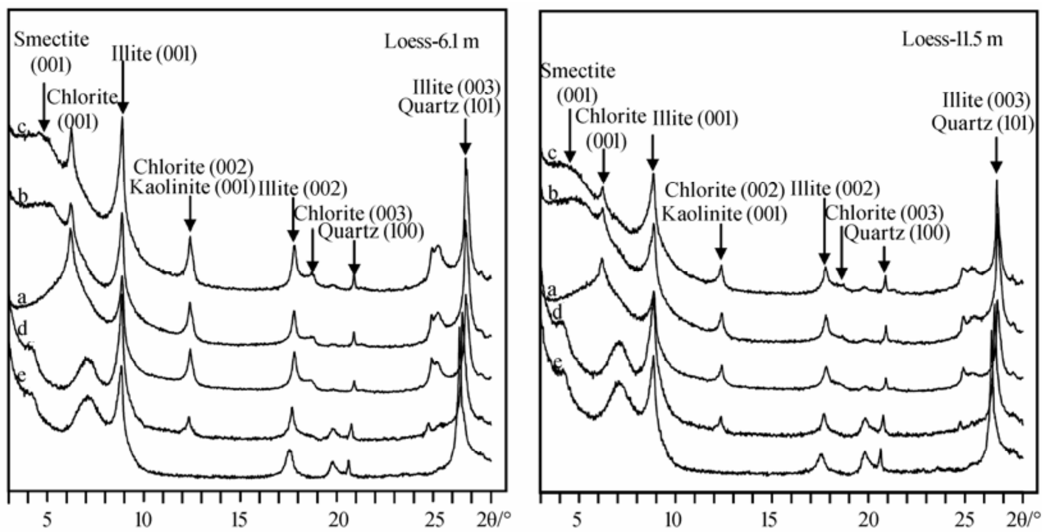

Fig. 4 XRD Diagrams of < 2 μm fractions from Qingzhou loess profile
a=$MgCl_2$; b=$MgCl_2$+ ethylene glycol; c=$MgCl_2$+ glycerol; d= $MgCl_2$+400°C; e= $MgCl_2$+550°C

Table 2 The clay mineral contents of the Qingzhou loess and the Xifeng loess (Peng *et al.*, 2007)

Samples	Length (m)	Illite	Smectite	Chlorite	Kaolinite	Illite/Kaolinite
		(%)				
WF245	6.1	69.2	19.6	6.9	4.4	15.9
WF460	11.5	73.7	18.6	3.8	3.9	19.5
Xifeng loess（*n*=5）		67.2	5.8	18.2	8.8	8.8

tween the basal age of the Qingzhou loess and the beginning of large-scale transgression around Bohai Bay further indicates that the formation of the Qingzhou loess is related to the regional environmental evolution of the Bohai Bay region.

It is noteworthy that the beginning of eolian deposits in Qingzhou region since Mid-Pleistocene is approximately synchronous to the beginning of Xiashu loess along the middle-lower reaches of Yangtze River (Li *et al.*, 2001; Li, 2002) that is far away from Chinese Loess Plateau, consistent with the global climate change in Mid-Pleistocene. As the global climate further became cold since 0.8 Ma (Lisiecki and Raymo, 2005), the expansion of global ice volume had produced profound effect on climate in the mid-high latitudes regions. This global cooling is expected to strengthen the Asian winter monsoon and enhance the aridity of northwest region, thus the eolian dust carrying by cold and dry current during glacier period can reach the Yangtze River region (Liu *et al.*, 1997). Also, the eolian dust from northwest regions can be carried by high-level current and reach the Shandong region, which becomes another material provenance of the Qingzhou loess. In this sense, the formation of the Qingzhou loess is not merely related to the regional environment, but also to the global climate change since Mid-Pleistocene.

5 Conclusion

In this paper the chronology and mineralogy of the Fujia village's loess profile in Qingzhou region were analyzed, and the major conclusions are as follows:

(1) The magnetostratigraphic results showed that the Brunhes/Matuyama (B/M) reversal boundary is not recognized in the Fujia village profile, suggesting that the basal age of the Qingzhou loess is younger than 0.78 Ma. By linear-extrapolation of the sedimentation rate based on the OSL ages, the basal age of the Qingzhou loess was 500 ka.

(2) The clay mineral composition of the Qingzhou loess are dominated by illite, then by smectite, chlorite and kaolinite, similar to those of the Chinese Loess Plateau, but the content of smectite and the ratio of illite/kaolinite are much higher, indicating the different clay mineral composition, supporting the previous study that the Qingzhou loess are mainly from the Bohai Bay shelf and the Yellow River fluvial plain.

(3) The chronological study showed that the basal age of the Qingzhou loess is about 500 ka, implying that the exposed Bohai Bay shelf during glacier period and the Yellow River fluvial plain had provided source materials for Qingzhou loess at that time. Besides, the forming age of the Qingzhou loess is close to that of the Xiashu loess and both are corresponding to global cooling, indicating that the origin of the Qingzhou loess has close relationship with the global climate change since Mid-Pleistocene.

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A Checklist on the Distribution of the Birds in Xinjiang was published

A book, A Checklist on the Distribution of the Birds in Xinjiang, was published by Science Press recently, which was mainly edited by Prof. Ming MA from Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences.

The book summaries the observations of birds in Xinjiang, Western China, including the Chinese name, Latin name, English name, subspecies name, distribution area, and ecological behavior. A total of 453 bird species (there are also 145 subspecies), which accounts for 34% of Chinese birds, and belongs to 21 orders, 65 families and 196 genera, have been recorded in Xinjiang. Ninety species of birds that are doubtful or problematic are listed and described in the appendix. All the literatures related to the Xinjiang avifauna have been rechecked in the appendix. Finally, 576 references were attached to the checklist.

The book provides good references for scientists, teachers, students and managers, who are engaged in researches on the agriculture, farming, forest, environment, wild animal and nature reserve managements.