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Holocene aeolian activity in the Zoige Basin, northeastern Tibetan Plateau, China

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ABSTRACT

The Zoige Basin is located in the northeastern Tibetan Plateau, at an altitude of around 3500 m. To fully understand and assess the current status and future trend of aeolian activity in the Zoige Basin, it is necessary to reveal the history of aeolian activity of this region. In this study, 11 Optically stimulated luminescence (OSL) ages from three typical sections were used to reconstruct the history of aeolian activities in the region during the Holocene. The results of the chronologies show that the oldest OSL age (10.27 ± 0.81 ka) occurred in the early Holocene, but aeolian sediment deposition primarily occurred in the late Holocene, after around 3.20 ± 0.33 ka. In the whole Holocene, the aeolian activities of the Zoige Basin occurred contemporaneously with nearby sites in the northeastern Tibetan Plateau. Episodic weak aeolian activities were recorded in nearby sites in the northeastern Tibetan Plateau. However, we postulate here that the combination of a flat, low-lying landscape along with higher precipitation during the mid-Holocene resulted in this area being relatively insensitive to short term arid climatic changes and aeolian activity.

1. Introduction

The Zoige Basin is recognized as a “natural reservoir” for the Yellow River, as nearly 30% of the Yellow River's total flow originates from the basin's wetland. The basin displays the most extensive distribution of high-altitude peat bogs in the world. During the last decades, the eco-environmental problems in the Zoige Basin have received increasing attention due to the impacts of global warming and intensifying human activities (Harris, 2010; Shen et al., 2011; Xu et al., 2011; Yi et al., 2012; You et al., 2014). Because of its important roles in water conservation, biodiversity protection and wetland conservation, the Zoige Wetland National Natural Reserve was established as a provincial nature reserves in 1994, upgraded to national nature reserves by the State Council of China in 1998, and entered the List of Ramsar Wetlands of International Importance since 2008.

Since the 1950s, rapid shrinkage of the swamp has endangered the local terrestrial and aquatic ecosystems and the water supply of the upper Yellow River (Bai et al., 2008; Li et al., 2015). Since the 1970s, the water table in the Zoige peat-wetland faced a severe decline (Xiang et al., 2009). The lowering of the water table resulted from climate change and artificial drainage. It has enhanced the decomposition of peat deposits and accelerated carbon as well as methane emissions from peat respiration, which becomes a potential ecosystem crisis in the Zoige wetland (Chen et al., 2009; Guo et al., 2013). Furthermore, more of the previously stored carbon in the eastern Tibetan Plateau peatland will be re-emitted to the atmosphere if the aridity continues (Xu et al., 2013). According to remote sensing monitoring, the total area of the Zoige wetland has shrunk by 385 km^2 during 1986–2005 (Pang et al., 2010). Meanwhile, the aeolian desertification developed quickly with the degradation of grassland (Lu et al., 2013). According to the most recent remote sensing study, the area of aeolian desertified land was 3211 km^2 in 2000, accounting for 16.6% of the total land area in the Zoige Basin. The aeolian desertification occurring in the basin experienced a dramatic increase and decrease during 1975–2010: from 1975 to 1990, the total area of aeolian desertification increased by 2147 km^2 at a rate of 143 km^2 per year, while from 2005 to 2010 the total area decreased by 2587 km^2 at a rate of 517 km^2 per year (Hu et al., 2015). To fully understand and assess the current status and future trend of aeolian activities in the basin, it is essential to study its aeolian history.

The northeastern Tibetan Plateau is sensitive to climate change due

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to its special location (Chen et al., 1999), and aeolian sediments were widely distributed in the late Quaternary and Holocene. Based on the synthetic multi-disciplinary study of lake sediments from RH (32°54′N, 102°32′N) and RM (33°57′N, 102°21′N) cores, the climatic and environmental changes on centennial to millennial time scales were reconstructed in the Zoige Basin over the past 900 ka. (Chen et al., 1999; Shen et al., 2005; Wang and Xue, 1997; Wu et al., 1997; Wu et al., 2000; Xue et al., 1998). In addition, pollen records (Guo et al., 2013; Zhao et al., 2011) and peat from this basin were also studied to reveal the palaeoclimate of the Holocene (Wang et al., 2010; Xu et al., 2013; Yu et al., 2006; Zheng et al., 2015; Zheng et al., 2007). Aeolian activities in Gonghe Basin and Qinghai Lake Basin were recently reported (Liu et al., 2013; Liu et al., 2012; Lu et al., 2015; Qiang et al., 2013). In the catchment of the Donggi Cona, 51 OSL ages from aeolian sediments were presented and analyzed to explain the process of aeolian activities (Stauch et al., 2012). However, the history of aeolian activity and its corresponding driving factors in the Zoige Basin is poorly understood due to very limited chronological studies. Up until now, aeolian sediment deposition in the Holocene was only reported based on seven ^{14}C ages, ranging from 2600 to 220 a BP (Zou and Wang, 1995).

Sand and dune fields in the Zoige Basin are composed dominantly of fine and medium sand indicating high wind speeds (Lehmkuhl et al., 2014). The high speed winds have also produced loess deposits in the leeward portion of the basin. The loess on the mountain slopes close to Songpan (in the lee of this basin) was observed in the beginning of the 20th century (Lehmkuhl et al., 2014). Furthermore, analyses of the particle size of loess deposited from the Tibetan Plateau to the Sichuan Basin indicates that the size decreases gradually, which suggests that the Tibetan Plateau could be a potential dust source for the down wind loess sediments and even for the Chengdu clay (Yang et al., 2010). The Zoige Basin is the closest possible dust source area to Chengdu Plain with a distance of about 300 km. Therefore, to reveal the history of aeolian activities in this basin it is helpful to understand its potential influence to the nearby areas.

2. Study area

The Zoige Basin is located in the eastern Tibetan Plateau between latitudes 32°17′N and 32°7′N and longitudes 101°30′E and 103°22′E, covering an area of 19,400 km^2. The majority of the area lies at altitudes > 3400 m above sea level, making this region has a cold, high-altitude climate. The Zoige Basin is surrounded by the Anymaqen Mountains to the northwest, the Minshan Mountains to the east, and the Qionglai Mountains to the south (Fig. 1).

Zoige Basin is a fault depression (pull-apart basin) formed during intensive uplifting of the Tibetan Plateau in the late Cenozoic period (Lehmkuhl and Spönemann, 1994; Wang and Xue, 1997; Xue et al., 1998). Originally, this basin was a paleolake (Zoige paleolake) with lacustrine sediments > 300 m thick in the center (Xue et al., 1998). The Zoige paleolake was cut open by the headward erosion of the Yellow River from 40 ka to 22 ka (Li et al., 2014; Wang et al., 1995). During the cutting period of the Yellow River, lacustrine sediment was gradually replaced by fluvial sediments, until 20 ka when it became occupied by fluvial sediment (Wang et al., 1995). These sediments provided an abundant sand source for subsequent wind erosion. At present, the Zoige Basin is characterized by wide meandering river valleys and lakes are distributed among low hills. The main rivers in the basin include the Yellow River and its tributaries, including the White River, the Black River, and the Jiaqu River (Fig. 1).

The northeastern Tibetan Plateau is influenced by the Asian monsoon and the westerlies (Henderson et al., 2010). The mean annual precipitation ranges from 654 to 780 mm, and the mean annual potential evaporation ranges from 1110 to 1273 mm. The mean annual temperature ranges from 0.7 to 3.3 °C and, as a result of this low air temperature, vegetation gross primary productivity is very low. The monthly precipitation is mainly concentrated between May and October, accounting for 89.2% of the annual total (610 mm). During the 6 months from October to April, the mean monthly temperature remains below 0 °C, and from December to February, the mean monthly temperature generally decreases to below − 5 °C (Hu et al., 2015). In this dry cold climate most vegetation stops growing or withers during Winter. As a result, vegetation cover decreases and the land becomes vulnerable to wind erosion.

The vegetation in this region is dominated by subalpine meadow and marsh vegetation. Thick loose plant remnants combined with the cold and wet climate provide favorable conditions for the development of marshes and peat. The soil mainly includes histosols and umbrisols. Arenosols has developed in some locations due to grassland degradation (Huo et al., 2013).

3. Sampling and methods

3.1. Sampling

Reactivated aeolian sediments are patchily distributed in the Zoige Basin, as shown in Fig. 3 with yellow. The reactivated aeolian sediments are mainly distributed on the terrace of the Yellow River and dome-shaped hills on the south of the Black River, which is a second-order tributary of the Yellow River. Remote sensing monitoring results shows that the area of sandy land in the basin was 99 km^2 in 2010 (Hu et al., 2015). Based on field investigations during four field trips in the Zoige Basin in the year 2008, 2012, 2014 and 2015, three aeolian sediment sections were selected and a total of 11 OSL samples were collected for dating to analyze the history of aeolian activity in the Zoige Basin (Fig. 1). All of the three sections were located in the reactivated areas, and Fig. 2 shows the landscape and geomorphic features of the three sections.

The discontinuous distribution length of aeolian sediment on these dome-shaped hills is around 30 km from west to east (Fig. 3). Section 1 (33°51′N, 102°34′E) is located on the top of a dome-shaped hill, the bottom of which is weathered gravels, and the top is covered by arenosols (Fig. 2). Nearby low-relief hill surfaces are all capped with aeolian sediments. About 30 cm from the top of Section 1 is composed of dark arenosols with abundant plant roots, and from 30 cm to the bottom is composed of gray yellowish fine sand without distinguishable stratigraphic break. Section 2 (33°56′N, 102°08′E) is a remnant outcrop of wind eroded sediment located on the second terrace of the Yellow River, nearly 1 km to the south of the Yellow River (Fig. 3). Active sand dunes dominate the ground surface and the height of the barchan dune is up to 10 m. This section has distinguishable stratigraphic units including three layers of dark arenosols, resting on medium fluvial sand (below 350 cm). In Section 2, the uppermost 90 cm is light brownish fine sand with low compaction. At 90–140 cm, 195–230 cm and 310–320 cm depth, dense dark paleosols developed well. Section 3 (33°47′N, 102°11′E) is also a remnant outcrop of wind eroded sediment, located on the floodplain of the Yellow River. Drifting sand and blowout are densely distributed in this area. The top soil of Section 3 has been eroded by wind, and the whole section is loosely cemented brownish fine sand except a layer of very weakly developed paleosols at the depth around 200 cm. As the aeolian sediment is quite thick, the base of the stratigraphic unit was not reached by Section 3.

3.2. Optically stimulated luminescence (OSL)

After removing the loose sediments covering on the side surface of the sections, the OSL samples were taken from freshly cleaned vertical sections using steel tubes (~22 cm long cylinder with a diameter of ~5 cm). The tubes were then covered with aluminum foil, sealed with opaque tape and wrapped in black plastic bags to avoid light exposure. In the OSL laboratory, the materials in the middle part of the sample tube which were not exposed to light were used to acquire equivalent dose (De) measurements. The samples were treated first with 10% HCL