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Original Articles

Insights on historical expansions of desertification in the Hunlun Buir and Horqin Deserts of Northeast China

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ABSTRACT

In this study, a cluster of similar aeolian sand ages from different sections in the deserts of Northeast China was used to as an indicator of historical expansion of desertification that resulted from the extensive accumulation of aeolian sands. Our results indicate that throughout the last 2 ka, three clear expansions of desertification occurred in the two deserts studied: from 300 to 790 CE, from 1030 to 1250 CE, and from 1560 CE to the present. Comparisons between these three intervals of desertification expansions in terms of climatic change and human activity have revealed that desertification expansions before 1700 CE were caused mainly by climatic change, whereas anthropogenic impacts controlled the expansions more dominantly since 1700 CE. The results also reveal that desertification reversal, which had commenced by the 1980s in the deserts of Northeast China, will continue to progress in the twenty-first century with the continuous implementation of grazing exclusion and rotational grazing policies, even without artificial revegetation, because of an increasingly warm and wet climate trend.

1. Introduction

The Hulun Buir and Horqin Deserts of Northeast China are mosaics of mobile and vegetation-stabilized aeolian sands (Li and Yang, 2016). Both deserts are located along the northern boundary of the modern East Asian summer monsoon zone and in the farming-pastoral ecotone (Yang et al., 2017), and are sensitive to both climate change and human activity. Environmental changes in both deserts are represented primarily by desertification, mainly from the evolution of stabilized dunes into semi-stabilized and mobile dunes, and the reverse process of dune stabilization (Wang et al., 2008a).

At present, historical desertification in the deserts of Northeast China is primarily interpreted from historical documents; however, these documents were not written for the purpose of geographical study and generally provide imprecise information, which may result in different researchers reaching different interpretations (Huang et al., 2009). For the Horqin Desert, based on historical documents, Jing (2000) suggested that desertification expansion began during the Liao Dynasty (from 916 to 1125 CE), whereas Zhang (1989) suggested that expansion had previously occurred during the Northern Wei Dynasty (from 386 to 557 CE). Past desertification in the Hulun Buir and Horqin Deserts has also been reconstructed based on stratigraphic evidence. However, these reconstructions are focused on long time-scales, such as the late Quaternary (Yang et al., 2012; Yang and Ding, 2013) or the Holocene (Li and Sun, 2006; Zhao et al., 2007), and provide little information for the historical period because of relatively low resolution and non-continuous accumulation of aeolian sand-paleosol succession.

Aeolian sand and paleosols in aeolian sections are exceptionally useful proxies of paleoclimatic and paleoenvironmental changes (Lu et al., 2015; Wang et al., 2014), and the former is even more a direct and reliable indicator of desertification expansion (Huang et al., 2009). In this study, a large number of aeolian sand ages from different sections of the deserts of Northeast China were compiled to analyze their cumulative frequency distribution throughout the last 2 ka, which avoid ages interpolation between the dated parts of the individual sections and synthesized a relatively high-resolution continuous age sequence (Wang et al., 2014). In addition, particular sections at particular sites could be strongly influenced by local hydrological and moisture conditions, while common patterns of aeolian sand accumulation in the deserts of Northeast China should reflect regional desertification trends (Stauch, 2016; Wang et al., 2014). Based on this, we have identified periods of history within the last 2 ka characterized by expansion of desertification in the Hulun Buir and Horqin Deserts, and explored the implications of these historical phenomena for modern

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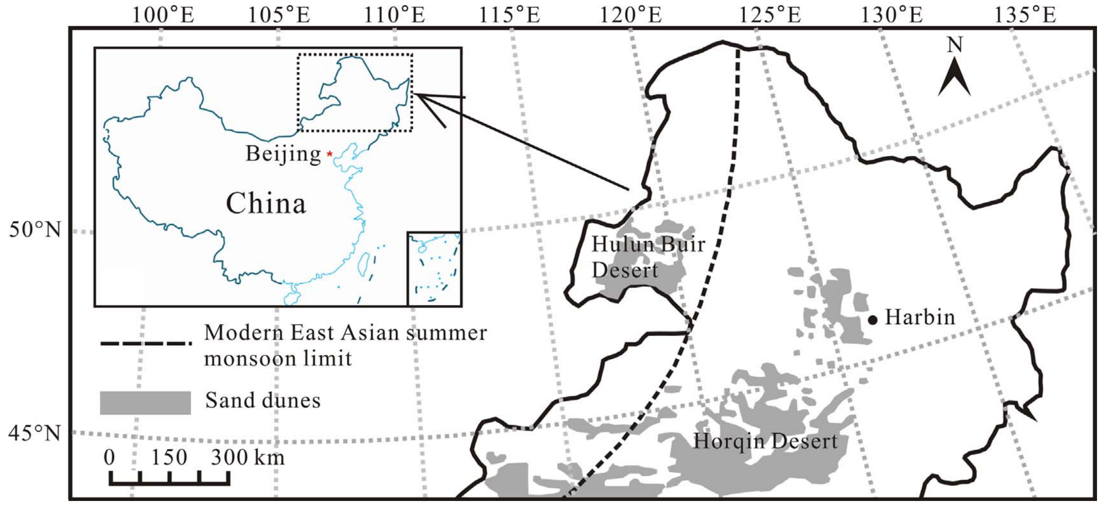

Fig. 1. Locations of the Hulun Buir and Horqin Deserts and the boundary of the modern East Asian summer monsoon (modified after Wang et al., 2009, 2014).

and future desertification.

2. Study area and methods

2.1. Study area

The Hulun Buir Desert has an area of 7200 km^2, a mean annual temperature of −1.3 °C, and a mean annual precipitation of 310 mm (Sun et al., 2016). The Horqin Desert has an area of 42,300 km^2, a mean annual temperature of 6.8 °C, and a mean annual precipitation of 366 mm (Li et al., 2017). These two deserts are both located in Northeast China (Fig. 1) and are characterized by a continental monsoon climate (He et al., 2013). In summer, the dominant wind direction is southeasterly; this wind transports moisture-laden air from the Pacific Ocean, and accounts for approximately 70% of the monsoonal rainfall that occurs in this region during this season. In winter, the prevailing wind direction is northwesterly, and results in cold and dry climatic conditions (Mu et al., 2016). The majorities of both deserts are covered in aeolian sand, and smaller regions are covered with meadow and chestnut soil. Halomorphic, dark brown, chernozem, chestnut-cinnamon, skeleton, cinnamon, bog, and alluvial soils are also present (Mu et al., 2016; Wang, 2011).

2.2. Data and methods

Layers of bulk organic matter in paleosols are commonly used for radiocarbon (^{14}C) dating, whereas quartz grains from aeolian sand and loess layers are typically used for thermoluminescence (TL) or optically stimulated luminescence (OSL) dating (Jia et al., 2015; Lu et al., 2015). Over the past several decades, paleoclimatic and paleoenvironmental studies in the Hulun Buir and Horqin Deserts have yielded numerous aeolian sand and paleosol age data from different sections. For this study, we selected stratigraphic ages throughout the last 2 ka according to the following criteria: (1) we only used actual ages determined through ^{14}C, TL, or OSL dating rather than ages obtained through correlation; (2) we eliminated ages without error ranges and ages that were not in chronological order within a particular section (Wang et al., 2014); and (3) we eliminated ages that were not from strata that was definitively described as either aeolian sand or paleosol. We collected as many age data as possible to maximize the reliability of the statistical results. Finally, we calibrated the ^{14}C ages using version 4.2.2 of the OxCal software (https://c14.arch.ox.ac.uk/embed.php?File=oxcal.html) prior to conducting statistical analysis.

In total, we collected 21 aeolian sand age data (all from OSL) and 16 paleosol age data (one ^{14}C age and 16 OSL ages) from 17 sections across the Hulun Buir Desert (Table S1; Supplementary information), and 37 aeolian sand age data (all from OSL) and 21 paleosol age data (two ^{14}C ages and 19 OSL ages) from 25 sections across the Horqin Desert (Table S2; Supplementary Information). The research time-scales of references in Table S1 and S2 all exceeded 2 ka, therefore, the stratigraphic ages we collected can cover the last 2 ka. Although the age data we collected were determined using two different methods, previous studies have indicated that OSL ages of aeolian sand (loess) and paleosol sections were in agreement with ^{14}C ages for the same deposits (Lai et al., 2009; Lu et al., 2015). Definite geographical coordinates were only available for nine and six sections in the Hulun Buir and Horqin Deserts, respectively. The geographical coordinates of the remaining sections, which were represented only as approximate locations on maps, were identified using version 2.22 of GetDate Graph Digitizer. Based on the stratigraphic characteristics of these sections described in the studies from which the data were obtained, the sections we collected age data were not repeated; their locations are shown in Fig. 2, and cover almost the whole scopes of the two deserts.

An aeolian sand age no doubt represented an aeolian sand accumulation event (Bristow et al., 2010; Huang et al., 2009). Therefore, a cluster of similar aeolian sand ages from different sections can be used as an indicator of regionally desertification expansion that resulted from the extensive accumulation of aeolian sands. The cluster phases of similar aeolian sand ages can be determined using cumulative frequency distribution analysis. Specifically, steeper cumulative frequency curves correspond to clusters of aeolian sand that resulted from desertification expansions. In spite of the fact that the redistribution of aeolian sand by wind processes reduced the number of older sand ages (Telfer et al., 2010; Bailey and Thomas, 2014), which may not be significant in the identification of short-term variation (Surovell and Brantingham, 2007), like our study, the oldest aeolian sand age from previous studies were no more than 2.0 ka (Tables S1 and S2; Supplementary Information). Paleosol in aeolian sections represents desertification reversal under rich vegetation cover. Therefore, the cumulative frequency of paleosol ages was used to as a comparison with aeolian sand ages in this study.

Reconstructed climate series covering the last 2 ka used in this study are presented in Table 1. Each decadal value of these series was derived using version 2.22 of GetDate Graph Digitizer. The negative temperature or precipitation (dry-wet index) anomalies indicate the climate is relatively cold or dry; in contrast, the climate is relative warm or wet when the temperature or precipitation (dry-wet index) anomalies are positive (Ljungqvist, 2010; Yang et al., 2002; Zheng et al., 2006). From traditional nomadic lifestyle to sedentary pastoralism to extensive agriculture, the human activities successively enhance. In general, in