Optically Stimulated Luminescence Dating of Aeolian Sedimentary Profiles in the Sandy Lands of the Northeast China Monsoon Margin and Its Paleoenvironmental Significance: Postprint

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Abstract

The sandy lands in the marginal monsoon region of Northeast China are sensitive to climate change and represent ideal sites for investigating the history of aeolian evolution. This study conducted optically stimulated luminescence (OSL) dating analysis of two typical aeolian sediment sections from the Horqin Sandy Land (KE) and Hunshandake Sandy Land (HS), combined with environmental information indicated by the sedimentary facies of the sections, to reconstruct the regional aeolian evolution history and discuss the factors influencing aeolian sand accumulation. The results indicate that: (1) The KE section developed a dark black sandy paleosol during 9.8–3.0 ka, indicating weak aeolian activity; since ~0.2 ka, the section has developed a relatively thick light gray sandy paleosol, implying stronger regional aeolian activity that has continuously reworked the thicker surface sediments, thereby hindering the formation of older dated deposits. (2) The HS section deposited grayish-yellow aeolian sand layers at 13.4 ka, 1.2–0.5 ka, and since 0.5 ka, indicating strong aeolian activity; a dark black sandy paleosol developed during 1.6–1.9 ka, indicating weak aeolian activity. (3) Since 13.4 ka, the paleoclimate and aeolian evolution in the study area can be broadly divided into three stages: from 13.4 ka to the Early Holocene, characterized by overall warming and strong aeolian activity; the Early to Middle Holocene was warm and humid with weak aeolian activity; the Late Holocene was characterized by climatic fluctuations and cooling with strong aeolian activity. (4) The difference in development timing of dark black sandy paleosols between the KE and HS sections may reflect that local topography, climate, and other factors in the marginal zones of sandy lands exert important influences on aeolian sand accumulation and paleosol development.

Full Text

Optically Stimulated Luminescence Dating of Aeolian Sediment Profiles in the Sandy Lands of Northeastern China Near the Edge of the Monsoon Zone and Its Paleoenvironmental Significance

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Abstract

The sandy lands of northeastern China, located near the edge of the East Asian monsoon zone, are highly sensitive to climate change, making them ideal for investigating the evolutionary history of regional aeolian processes. This study presents optically stimulated luminescence dating of aeolian sediments from two representative profiles situated near the edge of the Horqin Sandy Land (KE) and the Otindag Sandy Land (HS). By integrating sedimentary facies data from the two profiles with additional regional paleoenvironmental records, we reconstructed the regional aeolian evolution history and examined the factors influencing sand and paleosol formation.

The results revealed that: (1) The KE profile indicated the development of dark black sandy paleosols between about 9.8 and 3.0 ka, likely reflecting weak aeolian activity. In contrast, thick light gray sandy paleosols formed from around 0.2 ka, indicating intensified aeolian activity and continuous reworking of surface sediments, preventing older deposit formation. (2) In the HS profile, gray-yellow aeolian sand layers were deposited around 13.4 ka, 1.2–0.5 ka, and since 0.5 ka, indicating episodes of strong aeolian activity. Dark black sandy paleosols formed between about 11.6 and 1.9 ka, corresponding to a period of weaker aeolian activity. (3) Since about 13.4 ka, the region has undergone three stages of climatic and aeolian evolution: (i) a warming period from 13.4 ka to the early Holocene, associated with relatively strong aeolian activity; (ii) a warm and humid mid-Holocene, marked by reduced aeolian activity; and (iii) a late Holocene period of fluctuating cooling, during which aeolian activity increased again. (4) Variations in the timing of dark black sandy paleosol development between the KE and HS profiles, compared with records from the central parts of these sandy lands, suggest that regional topography and paleoclimatic differences may significantly influence aeolian sediment development.

Keywords: aeolian sedimentation; OSL dating; paleoenvironmental change; Horqin Sandy Land; Otindag Sandy Land

1. Study Area and Sample Collection

1.1 Overview of the Study Area

The Horqin and Otindag Sandy Lands are located in the monsoon marginal zone of northeastern China, where the ecological environment is relatively fragile and highly responsive to climate change. These regions have accumulated substantial aeolian deposits, making them ideal for paleoenvironmental research. Previous studies have demonstrated that the evolution of these sandy lands is jointly influenced by climate change and human activity. The Horqin Sandy Land, situated at the junction of Northeast and North China, covers parts of Bairin Right Banner, Ongniud Banner, Aohan Banner, Tongliao City, and Hinggan League, with a total area of approximately 2.38×10^{4} km^2. The region has a temperate continental monsoon climate, with an average annual precipitation of 400 mm and an average annual temperature of 6–7.5°C. The frost-free period lasts only 4–5 months, and the area experiences significant frost for 6–7.5 months annually.

The Otindag Sandy Land lies in the central Xilingol Grassland of Inner Mongolia, comprising parts of Xilingol League and Keshiketeng Banner in Chifeng City. It serves as the source area for the Xar Moron and Yiligin Rivers. The terrain slopes from southeast to northwest, with elevations decreasing from 1500 m in the southeast to 1000 m in the northwest. The region is also a typical monsoon marginal transition zone with a fragile ecological environment, characterized by arid and semi-arid climates. Annual precipitation ranges from 380 mm in the southeast to 140 mm in the northwest, with an average annual temperature of 3–5°C and a frost period lasting 6–7 months. Both sandy lands share similar climatic and environmental characteristics.

1.2 Sample Collection

Based on field investigations of the Horqin and Otindag Sandy Lands, we selected two typical aeolian sediment profiles located on high river valley slopes with similar climatic backgrounds but distinct latitudinal positions. The KE profile (43°48 59.27 N, 118°18 03.49 E) is situated in the western part of the Horqin Sandy Land, on the eastern side of the Chagan Moron River, a tributary of the Xar Moron River. This profile was exposed during road and railway construction and features a thick sequence of dark black sandy paleosols. Located far from the modern riverbed on high terrain, the profile exhibits a semi-circular shape due to geomorphic constraints, with aeolian deposits including sand layers and paleosols.

The HS profile (42°24 42.30 N, 116°54 16.31 E) is located in the southeastern Otindag Sandy Land, on the eastern side of the Chaogeduer River valley. Exposed during highway construction, this profile contains multiple aeolian sequences of sand and paleosols on a high hillside far from the modern riverbed. Systematic sampling was conducted at both sites, with priority given to the top and bottom of dark black sandy paleosol layers and at boundaries between different sedimentary layers. Stainless steel tubes (3 cm diameter) were inserted parallel to target strata, sealed with black plastic bags to prevent light exposure, and immediately sealed after extraction. Detailed sampling records and labels were maintained for laboratory analysis.

At the KE profile, three samples (KE-1 to KE-3) were collected from top to bottom, while five samples (HS-1 to HS-5) were obtained from the HS profile. Sampling depths and sediment characteristics are summarized in .

2. OSL Dating of Samples

2.1 Sample Pretreatment

All pretreatment procedures were conducted under dim red light. The process involved: (1) collecting approximately 5 cm of sediment from both ends of each tube for environmental dose rate and water content measurements; (2) dividing the remaining sample into two portions for backup and analysis; (3) cleaning samples and treating them with 10% H_2O_2 and 30% HCl to remove organic matter and carbonates; (4) drying and sieving to isolate 90–125 m grains; (5) separating quartz grains using sodium polytungstate heavy liquid (2.62 g/cm^3); and (6) etching quartz grains with 40% HF for 40 minutes to remove feldspar impurities and the alpha-irradiated outer layer, followed by washing and drying.

2.2 OSL Dating Analysis

Equivalent doses were measured using a Risø TL/OSL DA-20 reader equipped with blue LED stimulation (470$±$30 nm) and Hoya U-340 filters. The single-aliquot regenerative-dose (SAR) protocol was employed, with 9.8 mm aliquots containing approximately 90–125 m quartz grains. Each sample was measured using 24–36 aliquots. Preheat plateau tests were conducted on sample HS-3, showing stable equivalent dose values between 180–280°C, indicating minimal temperature effects. A preheat temperature of 240°C for 10 s and a cutheat of 200°C were selected for all samples. Dose recovery tests yielded ratios of 0.9–1.1, confirming reliable measurement procedures.

Samples exhibited typical aeolian OSL characteristics, including bright signals dominated by the fast component, linear dose-response curves near the origin, and natural dose points within optimal response intervals [Figure 3: see original paper]. Equivalent dose distributions were concentrated and approximately normal, indicating relatively uniform bleaching prior to burial.

3. Results and Analysis

3.1 Chronological Framework

Eight samples were analyzed from the KE and HS profiles, all showing good OSL properties and reliable dating results. In the KE profile, the bottom sample (KE-3, 8.3 m depth) yielded an age of 9.8$±0.6 *ka*, *whilethemiddlesample*(*KE*−

2, 4.3mdepth)gave3.0±0.2ka, indicatingthatdarkblacksandypaleosolsdevelopedbetween9.8and3.0ka.Thesurfa
1, 2.0mdepth)providedanageof0.2±$0.1 ka, suggesting recent deposition.

In the HS profile, the bottom gray-yellow sand layer (HS-5, 3.1 m depth) dated to 13.4$±1.1ka.Thedarkblacksandypaleosollayeryieldedagesof11.6±1.1kaatitsbase(HS−
4, 2.6mdepth)and1.9±0.1kaatitstop(HS−3, 1.7mdepth), indicatingdevelopmentbetween11.6and1.9ka.Twoove
2, 1.1mdepth)and0.5±0.1ka(HS−1, 0.6mdepth).Thesurfacegray−yellowsandlayerdatedto0.2±$0.1 ka. Ages generally decrease upward in both profiles, consistent with stratigraphic principles .

3.2 Regional Aeolian History

Environmental changes in northern China's sandy lands are primarily controlled by the East Asian monsoon system. Enhanced summer monsoon precipitation promotes vegetation growth and soil development, stabilizing dunes, whereas weakened monsoons lead to dune activation and deposition of gray-yellow sand layers. The dark black sandy paleosols in the KE profile (9.8–3.0 ka) likely reflect a warm, humid climate with weak aeolian activity, corresponding to the Holocene Climatic Optimum. This is supported by regional pollen records from Gonghai Lake indicating increased precipitation during this interval.

The cessation of paleosol development around 3.0 ka corresponds to decreasing solar radiation and weakening summer monsoon intensity, marking a transition toward cooler, drier conditions. The thick light gray sandy paleosols formed since 0.2 ka suggest intensified aeolian activity and continuous surface reworking, preventing the preservation of older deposits.

In the HS profile, the gray-yellow sand layer at 13.4 ka formed during the last deglaciation, a period of relatively dry, cold climate. The overlying dark black sandy paleosols (11.6–1.9 ka) indicate weakened aeolian activity during the warm, humid mid-Holocene. The subsequent deposition of light gray sandy paleosols (1.2–0.5 ka) and gray-yellow sand layers (since 0.5 ka) reflects enhanced aeolian activity during the late Holocene, possibly associated with the Little Ice Age.

Overall, the region has experienced three stages of climate and aeolian evolution since 13.4 ka: (1) a warming period from 13.4 ka to early Holocene with strong aeolian activity; (2) a warm, humid mid-Holocene with weak aeolian activity; and (3) a late Holocene period of fluctuating cooling with intensified aeolian activity [Figure 4: see original paper].

3.3 Factors Influencing Profile Development

The timing of dark black sandy paleosol development differs significantly between the KE and HS profiles. The HS profile began developing paleosols earlier (11.6 ka) and ceased later (1.9 ka) than the KE profile (9.8–3.0 ka). These differences likely reflect local topographic and climatic controls on moisture availability. The HS profile is located in the core of the Greater Khingan

Mountains, surrounded by mountains that block moisture transport from the southeast. However, its location in the southeastern part of the sandy land, closer to the ocean, may provide adequate moisture for earlier vegetation establishment and prolonged soil development.

In contrast, the KE profile is situated at the intersection of the Greater Khingan and Yan Mountains, where topography enhances uplift of moist air from the southeast. Its proximity to the ocean also provides abundant moisture, with annual precipitation reaching up to 500 mm—significantly higher than in central and western parts of the Otindag Sandy Land. This may explain why other profiles in the central Horqin Sandy Land show earlier paleosol initiation and later termination than the KE profile. Local topography, distance from the ocean, and hydrological conditions thus exert significant influence on aeolian sedimentation and paleosol development, even within the same sandy land system [Figure 5: see original paper].

4. Conclusions

This study employed OSL dating to analyze two typical aeolian sediment profiles from the margins of the Horqin and Otindag Sandy Lands, yielding the following conclusions:

1. The KE profile developed dark black sandy paleosols between 9.8 and 3.0 ka, indicating weak aeolian activity. Since 0.2 ka, thick light gray sandy paleosols have formed, suggesting intensified aeolian activity and continuous surface reworking.
2. The HS profile deposited gray-yellow aeolian sand layers at 13.4 ka, 1.2–0.5 ka, and since 0.5 ka, indicating strong aeolian activity. Dark black sandy paleosols formed between 11.6 and 1.9 ka, corresponding to a period of reduced aeolian activity.
3. Since 13.4 ka, regional climate and aeolian evolution have undergone three stages: (i) a warming period from 13.4 ka to early Holocene with strong aeolian activity; (ii) a warm, humid mid-Holocene with weak aeolian activity; and (iii) a late Holocene period of fluctuating cooling with enhanced aeolian activity.
4. Differences in the timing of dark black sandy paleosol development between the KE and HS profiles likely reflect variations in local topography, climate, and moisture availability, which significantly influence aeolian sediment accumulation and paleosol formation.

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Note: Figure translations are in progress. See original paper for figures.