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Holocene resistant substrate and their roles in ecological safety of the Mu Us sandy land, Northern China

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A R T I C L E I N F O

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A B S T R A C T

Resistant substrata are the sediments that are abundant in organic matter and outcropped as near-vertical cliff faces due to erosion. Palaeoenvironment research on resistant substrata (including lacustrine and peat sediments and palaeosols) is an important aspect of Quaternary science. Previous studies in the Mu Us sandy land in Northern China have focused on paleoclimatic evolution and aeolian activity, but the relationships between resistant substrata and modern human activity, and their role as animal habitats, are poorly understood. In this study, we used remote-sensing images and field investigations to produce a synthesis of the distribution of resistant substrata, and subsequently analyzed their roles in ecological safety. The results showed that they are closely related to the presence and economic activity of the local people who use them as sources of stable litter for animals, or for human dwelling places, and for agriculture. Our findings indicate that because of the value of eutrophic peat as a natural fertilizer and its function as a water-retaining layer, the location of modern agricultural zones is closely related to the distribution of ancient peatland. We also formulate a preliminary plan for the use of peatland for the development and extension of modern agriculture. In addition, we also consider its role as a protective layer preventing the reworking of the underlying sands and the potential risks if it is overexploited. Our research is part of an attempt to focus attention on the relationships and potential applications of Quaternary research to environmental management and economic development of the region, emphasizing its utility for policy-makers and main stakeholders. Specifically, we anticipate that our study will provide a reference for subsequent efforts to balance economic development and resource conservation in this region.

1. Introduction

Deserts are an integral part of the Earth's surface, whose initiation and development were largely controlled by global climate change (Gao et al., 2001). The spatial distribution of the deserts of Northern China (N35°–50°, E75°–125°) was mainly established during the last glacial (Li et al., 2002; Lu et al., 2013; Yang et al., 2004; Yang et al., 2011). However, in the moist periods of the Holocene, the process of desertification was reversed, especially in the sandy lands or deserts of Ulan Buh (Zhao et al., 2012), Otindag (Jin et al., 2004; Lu et al., 2005), Mu Us (Lu et al., 2005), Hulun Buir (Li and Sun, 2006), and Tengger (Long et al., 2012), as indicated by the frequent occurrence of lacustrine sediments or palaeosols. As exemplified by the modern Mu Us sandy land, these Holocene deposits are frequently exposed in the form of a distinct vertical face or "cliff" (Fig. 1), reflecting their physical properties of hardness and compactness. Hence we collectively designate the lake sediments, peats and palaeosols that exhibit this characteristic as resistant substrata. Pei and Li (1964) proposed a similar terminology in their study of Salawusu River valley in the Mu Us sandy land.

Resistant substrata were once widespread in the Mu Us sandy land. Lacustrine or peat sediments mainly accumulated in the low-lying area on both sides of Wuding River (Salawusu River) and its tributary (Fig. 2), while palaeosols developed in areas of more elevated terrain. Research on resistant substrata in the region, including lacustrine sediments and palaeosols, was first conducted in the 1920s by Teilhard de Chardin and Licent (Chardin and Licent, 1924). In the southeastern low-lying region of the Mu Us sandy land, lakes and swampland gradually developed after the last deglaciation, and continued until the early Holocene. Rapid oscillations in lithology are often evident, represented by the intercalation of peat and lacustrine sediments (Li et al., 2003; Zhou et al., 1996). There were significant differences in the duration of Mu Us palaeo-lakes during the Holocene (Li et al., 1998; Li et al., 2012; Liu and Lai, 2012; Liu et al., 2017a), with multiple lakes existing in different areas at different times, and river meandering may be one of

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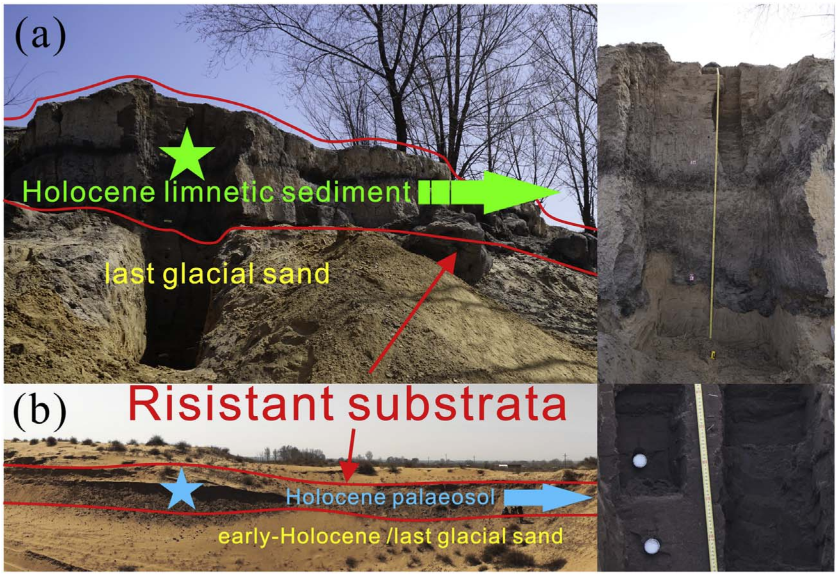

Fig. 1. Examples of Holocene resistant substrata in the Mu Us sandy land. (a) Shenshuitai (SST) peatlands; (b) the Wapianliang (WPL) profile, including a thick palaeosol. The locations of these profiles are shown in Fig. 2.

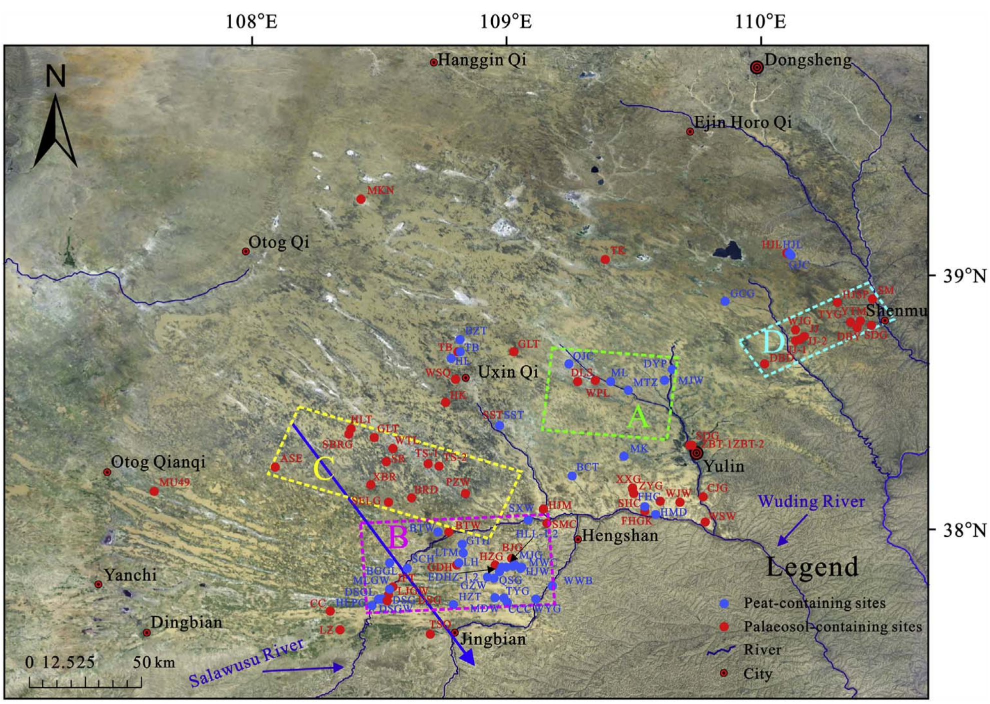

Fig. 2. Synthesis of the distribution of peat-containing and palaeosol-containing sites in the Mu Us sandy land. Dashed rectangles labeled A and B are areas of peat-dominated deposits, and C and D are areas of palaeosol-dominated deposits.

the factors responsible (Zhao et al., 2016). Overall, the size of the multiple lakes was relatively small and they may have developed as scattered, discontinuous lake-swamp environments within inter-dune swales (Zhao et al., 2016), which were distributed in wide and gentle depressions and river valleys in the Mu Us sandy land. Research has shown there are several palaeosol layers with different degrees of development (Jia et al., 2015; Liu et al., 2016; Miao et al., 2016; Wen et al., 2016; Zhou et al., 2009; Gao et al., 2001). Overall, the exposed resistant substrata in modern Mu Us sandy land, including the peat or sandy peat and the palaeosol and sandy palaeosol, mainly developed during the Holocene Climatic Optimum. Although these resistant substrata have been affected by wind and water erosion for thousands of years, they have survived because of their distinctive properties.

An ancient Chinese saying states that "people dwelled and banded together along the river" and it is clear that a riverine occupation strategy is common among both humans and animals. Our extensive field investigations indicated that most resistant substrata are exposed by natural river incision and these areas are often important for water supply and as a habitat for both modern humans and animals. On the topic of the relationship between resistant substrata and human or animal occupation, both Jia (1992) and Sun (2000) proposed that low productivity and poor farming methods in the Mu Us sandy land have led to the destruction and loss of Holocene sediments, thus greatly increasing the likelihood of the reworking of the sand deposits of the last glaciation. However, the distribution of resistant substrata, their ecological relationship with both animals and humans, and especially the significance of resistant substrata for modern agriculture, are poorly known. The Mu Us sandy land region has a relatively large human population and social and economic issues are strongly related to the occurrence of Holocene sedimentary deposits. This topic therefore warrants more detailed and systematic study.

The present study focuses on the resistant substrata of the Mu Us sandy land, especially the ancient peatland. We describe the roles of the resistant substrata, emphasizing their relationship with modern humans