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Late Holocene aeolian sedimentation in the Tottori coastal dune field, Japan Sea, affected by the East Asian winter monsoon

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ABSTRACT

Many dune fields that have formed along the southern coast of the Japan Sea are influenced by the north-westerly winter monsoon, which transports beach sand landwards. The Tottori coastal dune field of the Japan Sea has not been disturbed much by human activities until the 20th century and thus is expected to provide a continuous record of the relationships between the winter monsoon and aeolian sedimentation. We examined new ground-penetrating radar profiles and optically stimulated luminescence (OSL) ages of quartz sand from transverse dune ridges in the western part of the dune field in addition to existing data in the eastern part. This allowed us to extend the study period to cover the past 1000 years and to effectively compare the sedimentary record with other coastal dune fields in East Asia and other palaeoenvironmental proxies. OSL ages from older dune sediments suggest considerable aeolian activity from the 10th to 12th century AD, whereas a hiatus of dune sediment record between the 12th and 15th centuries was detected. These results suggest that during the Medieval period aeolian activity was low or that extensive erosion removed most of the deposits. Since the late 15th century, dune sedimentation has apparently been broadly continuous, though with periods of higher and lower activity. In both of the eastern and western parts, most of the dune ridges accreted landwards, but clear seaward accretion occurred during the 18th century, possibly reflecting a decrease in wind strength that restricted sand transport. In contrast, two significant landward accretion events are inferred to have occurred from the late 15th to 17th centuries and around 1840, corresponding to periods of increased dust fall in China, which suggests an enhanced winter monsoon, and to cold periods suggested by the decline of the sunspot number. The timing of periods of inactive and active dune sedimentation, inferred from alternations of organic soil and aeolian sand, in other coastal dune fields of East Asia appears to be concordant with corresponding periods in the Tottori dune field. We thus propose that other Japan Sea dune fields may also provide a valuable record of East Asian winter monsoon fluctuations.

1. Introduction

The East Asian monsoon is not only one of the most important climatic phenomena in Asia; it also plays a significant role in the global climate system, affecting a range of earth surface processes (Wang et al., 2005; Clift and Plumb, 2008). Around the Japanese archipelago, strong north-westerly winds from the Siberian High, which develops around Mongolia and Lake Baikal, are dominant during winter (Fig. 1), whereas weaker south-easterly winds from the Pacific Ocean prevail in summer. Many dune fields that have formed along the southern coast of the Japan Sea are influenced by the north-westerly winter monsoon, which transports beach sand landwards. Thus, the dune fields can be expected to record fluctuations in the winter monsoon.

Few studies with modern techniques have investigated the stratigraphy of dune fields along the Japan Sea coast of Japan,

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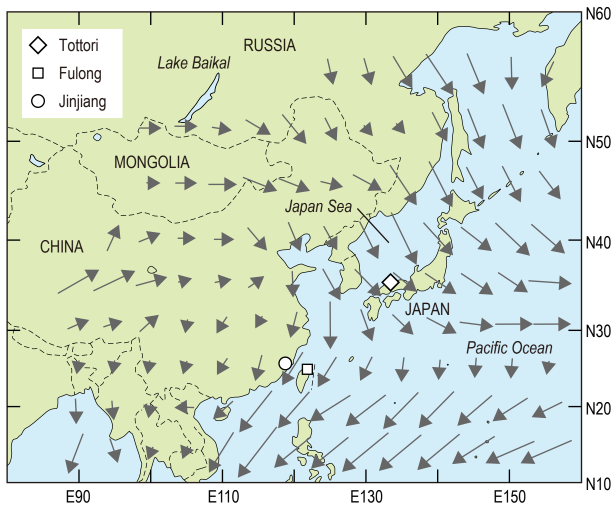

Fig. 1. Map of East Asia and the modern winter monsoon system. Arrows show the surface wind pattern in winter after Wang et al. (2005).

although it is the key to understanding past aeolian history. Endo (1986) established the chronostratigraphy of Holocene coastal dune fields in Japan based on dated archaeological relics and radiocarbon dates of organic materials and carbonates and showed that dune activation was synchronous among the studied dune fields, including those activated in the past 400 years. Historical documents indicate that Japanese coastal dune fields generally became stabilized by vegetation during the Medieval period. Then, reactivation of the dune fields in the 17th century led to afforestation efforts (Tateishi, 1974). Although Tateishi (1974) attributed the dune reactivation to social causes, the contrast between the Medieval period and Little Ice Age suggests that climate change may have triggered the dune reactivation.

Tamura et al. (2011a) combined ground-penetrating radar (GPR) surveys with optically stimulated luminescence (OSL) dating to clarify multi-decadal-scale formation processes of transverse dune ridges in the eastern part of the Tottori dune field, on the central southern Japan Sea coast, during the past 500 years. On the basis of their results, they hypothesized that the observed aeolian sedimentation recorded fluctuations in the winter monsoon and, in particular, that dune formation was reactivated around the beginning of the Little Ice Age. This hypothesis is supported by characteristic sediment record of coastal dune fields at Fulong Beach north-eastern Taiwan (Dörschner et al., 2012) and along the Jinjiang coast, Fujian Province, China (Hu et al., 2013). These dune fields are both affected by landward sediment transport by the winter monsoon, showing relatively calm conditions during the Medieval period and/or dune reactivation during the Little Ice Age.

Here, we report additional GPR profiles and OSL ages obtained in the western part of the Tottori dune field that corroborate the multi-decadal-scale aeolian sedimentation reported in the eastern part (Tamura et al., 2011a). This new dataset allows us to extend the study period to cover the past 1000 years and explore the activation and possible stabilization of older dunes. By reconstructing dune activity over a longer period, we can more effectively explore possible causes of the observed dune activity fluctuations by comparing them with other palaeoenvironmental proxies (e.g., Yancheva et al., 2007). Our results also document rapid shoreline progradation, caused by harbour and jetty construction, in recent decades and associated changes in aeolian sedimentation.

2. Study area

The Tottori dune field is located on a coastal barrier (1 km wide by 16 km long) on the central southern Japan Sea coast (Figs. 1 and 2A) that consists of western (Koyama), central (Hamasaka), and eastern (Fukube) parts. Following Tamura et al. (2011a), we refer to the dune field on the central part of the barrier as the Tottori dune field. The Tottori dune field is 4 km long and 1 km wide and is bounded on the west by the Sendai River and on the east by a hill composed of Pliocene pyroclastic rocks that rises to more than 80 m above mean sea level (m a.s.l.) (Fig. 2C; Murayama et al., 1963). The Sendai River flows northwards through the back barrier and delivers granitic sand from the Chugoku Mountains to the coast. The sediment-filled back barrier forms the Tottori coastal plain, with the unfilled part occupied by Lake Koyamaike (Fig. 2A). Marine and brackish fossil shells found in the back barrier sediment suggest the area was occupied by a lagoon in the early to mid-Holocene, when post-glacial transgression reached a maximum (Akagi, 1972; Akagi et al., 1993). Tanigawa et al. (2013) reconstructed a Holocene relative sea-level curve using data from a drowned valley at Toyooka, about 60 km east of Tottori on the Japan Sea coast. Their curve indicates that relative sea-level reached a highstand around 7 ka and has been within ±1 m relative to the present level since then.

Geomorphologically, the Tottori dune field is characterized by three shore-oblique transverse dune ridges (Fig. 2C), the crests of which are normal to the NNW–WNW winds prevailing during winter and autumn (Fig. 2D; Kamichika, 1998). This dominant wind pattern is the winter monsoon pattern, when winds blow off the Siberian High Pressure system, which is centred on Mongolia and Lake Baikal (Fig. 1). Using wind data collected at Koyama (Fig. 2A) in 2009 by the Japan Meteorological Agency, Tamura et al. (2011a) estimated the annual sand drift potential (DP) and the resultant drift potential (RDP) (Fryberger and Dean, 1979) to be 638 and 298, respectively; thus, RDP/DP is 0.47 (Fig. 2D). The annual resultant drift direction is SSE, almost perpendicular to the dune ridge crests.

The three dune ridges have been numbered from I to III, from northwest to southeast (Fig. 2C). The three ridges are oriented oblique to the WSW–ENE-trending shoreline. The shore-facing north-eastern ends of dune ridges I and II narrow and pinch out, but dune ridge III abuts the bedrock at the eastern edge of the dune field (Fig. 2C). The crests of dune ridges II and III are 40–50 m a.s.l., and that of dune ridge I reaches a maximum height of 40 m a.s.l. The eastern part of the Tottori dune field is relatively unvegetated, but trees were planted on most of the western part in the early 20th century (Tateishi, 1974). The nearshore part of the western dune field, however, has become vegetated only in the past few decades. Only dune ridge II and the north-eastern end of dune ridge I currently have a downwind slip face (Fig. 2B). The shoreline of the dune field is occupied by a reflective microtidal beach with a narrow backshore. The shoreline has been mostly stable, or has eroded only slightly, during the past 40 years, except at its western end, where the construction of a harbour and jetty at the mouth of the Sendai River has caused the beach to prograde more than 200 m seawards since 1932 (Fig. 2C).

The stratigraphy of the Tottori dune field has been studied by using data from outcrops, borehole cores, and GPR, and has been dated by OSL (Toyoshima and Akagi, 1965; Toyoshima, 1975; Okada et al., 1999; Kodama et al., 2001; Tamura et al., 2011a,b). Dune ridges I and II consist of Holocene dune sand, whereas dune ridge III has a Pleistocene core that is covered by Holocene dune sand (Fig. 3). The Daisen-Kurayoshi Pumice (DKP) tephra (c. 55 ka; Machida and Arai, 2003) is interbedded in a reddish brown palaeosol that covers the Pleistocene dune. This palaeosol is exposed along dune ridge III in various places (Fig. 2C). Tamura et al. (2011b)