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# Distribution and formation of tephric-loess dunes in northern and eastern Japan

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ABSTRACT

We studied the genesis of the Esashi, Shiriyazaki, Isozaki-Ajigaura, and Takamagahara dunes and associated blowouts. These dunes are located at the top of coastal cliffs, and they are composed of marine sediments (sand and gravel), which are covered with layers of Japanese loam. We examined pH(NaF) and pH($H_2O$) of samples from all dunes, and the grain size distributions, total carbon contents, humic properties, and colors (CIE-L*a*b*) of samples from the Esashi and Shiriyazaki dunes. In most samples, pH(NaF), an indicator of active aluminum, was ≥9.5. The grain size distribution in the Esashi and Shiriyazaki dunes was bimodal (with sand and silt–clay peaks), and their color, after removal of organic matter with $H_2O_2$, was similar to that of the loam. These findings show that the dunes are composed of marine sediments and loam eroded and reworked by the prevailing winds. Japanese loam is regarded as a kind of tephric loess. Thus, these dunes can be referred the tephric-loess dunes. The physicochemical properties of these tephric-loess dunes are similar to those of Kuroboku soil in that humus accumulation has been enhanced by the presence of active aluminum derived from the admixture of tephric materials.


## 1. Introduction

Eolian deposits in Japan can have either a unimodal or a polymodal grain size distribution. Coastal dunes typically have unimodal distributions, whereas the dunes whose grains originate from pre-existing deposits, including eolian dust from China, old dune sands, and Japanese loam (a tephric loess) have polymodal distributions (Shinbori et al., 1964; Kimura et al., 1972; Naruse and Inoue, 1983; Naruse., 1989).

Tephric loess was first recognized by Vucetich and Pullar (1969) to mantle the Mamaku Plateau, North Island, New Zealand (Lowe, 1994). This New Zealand loess consists mainly of reworked eolian rhyolitic tephric materials. According to the World Reference Base for Soil Resources (WRB; IUSS Working Group WRB, 2006; Description and diagnostic criteria are adapted from Hewitt, 1992), tephric materials consist of either tephra or tephric deposits (i.e., tephra that has been reworked and mixed with material from other sources, including tephric loess, tephric blown sand and volcanogenic alluvium). Japanese loam, which consists of brownish massive deposits, is composed of tephric materials mixed with eolian dust from China and local eolian dust (Hayakawa, 1995; Suzuki, 1995). Thus, Japanese loam can be regarded as a tephric loess.

Japanese loam is an important eolian deposit in Japan because it is extensively distributed, and not only plays a significant role in the soil formation as soil parent materials but also forms geomorphological features. In this study, we examined the contributions of Japanese loam (tephric loess) to the formation of dunes in four areas, Esashi, Shiriyazaki, Isozaki-Ajigaura, and Kashima, of northern and eastern Japan (Fig. 1). In this paper, the Japanese loam in each study area is referred to by its local name (i.e., Jinya loam at Esashi, Shiriyazaki loam at Shiriyazaki, and Kanto loam at Isozaki-Ajigaura and Kashima). The data of the Esashi and Shiriyazaki dunes were published previously (Tanino et al., 2003, 2013).

## 2. Regional settings of the study areas

### 2.1. Esashi (Tazawa) area

The Esashi dunes are distributed on top of the Ohma marine terrace (MIS 7, 40–75 m a.s.l; Ohmori, 1975; Koike and Machida, 2001), north of Esashi, Oshima Peninsula, Hokkaido (Figs. 1 and 2). The dunes are north of the Tazawa River valley at the top of a

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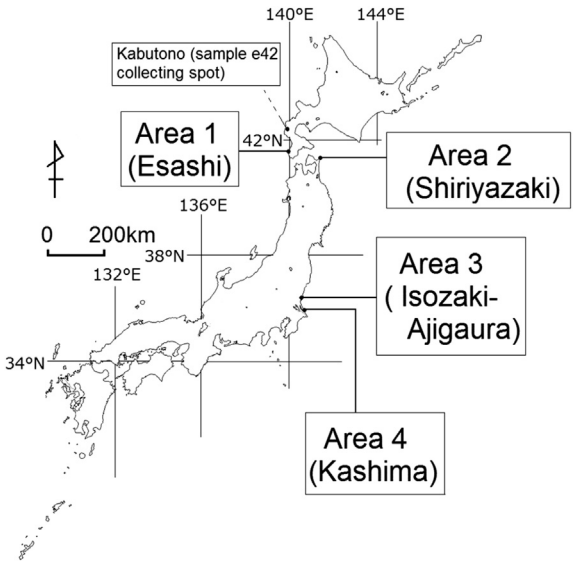


**Fig. 1.** Locations of study areas.

coastal cliff facing the Sea of Japan. The Ohma marine terrace deposits consist of marine sands and gravels, which overlie the rhyolite and dacite basement (Miocene) and are covered by Jinya loam (Sumi et al., 1970; Ohmori, 1975). The Esashi dunes are transverse dunes with a NW–SE orientation. At present, the prevailing winds tend to be westerly year-round (Fig. 2a–c).

We examined the Esashi dunes at outcrop E-1, where they overlie a 30-cm-thick buried black soil (E-BBS; Buried Black Soil is abbreviated to "BBS" hereafter) at the top of the Jinya loam (Fig. 2a and d; Tanino et al., 2003). In this 25-m-high profile, the dunes are composed of four sand layers (E-DS1–4; Dune Sand is abbreviated to "DS" hereafter) that are separated by buried humic sands (i.e., black sands E-BS1–4; Black Sand is abbreviated to "BS" hereafter). Accelerator mass spectrometry dates were obtained at Paleo Laboratory Co., Ltd. (PLD) on organic carbon in E-BBS and the black sands. In addition, the sequence includes two named and dated tephras.

The upper part of the Jinya loam is a compact silty loam with cracks, and the lower part is an alternation of coarse sand layers (old dunes) and sandy-loam layers. Radiocarbon ($^{14}$C) ages of 8585 ± 40 BP (No. PLD-1614; radiocarbon ages in this paper are conventional) in the lower part and 5075 ± 30 BP (No. PLD-1068) in the upper part were obtained from the 30-cm-thick E-BBS. E-BS1 is 40 cm thick, and its $^{14}$C age is 2295 ± 25 BP (No. PLD-1069). E-BS2 is 40 cm thick, and its $^{14}$C age is 1895 ± 25 BP (No. PLD-1070). The Baitoushan-Tomakomai tephra (B-Tm, ca. 1 ka; Machida et al., 1990; Hayakawa and Koyama, 1998; Machida and Arai, 2003) lies between E-BS2 and E-BS3 (Suzuki, 1992). E-BS3 is 25 cm thick, and its $^{14}$C age is 1055 ± 25 BP (No. PLD-1071). E-BS4 is 15 cm thick, and its $^{14}$C age is 375 ± 25 BP (No. PLD-1072). The Komagadake-d tephra (Ko-d, AD 1640; Arai et al., 1986; Machida and Arai, 2003) overlies E-BS4.

### 2.2. Shiriyazaki area

Shiriyazaki is at the northeast end of the Shimokita Peninsula, northern Honshu (Figs. 1 and 3). The peninsula juts out into the Tsugaru Strait, and its basement is composed primarily of rigid Shiriya Group (Mesozoic) rocks, which resist wave erosion. The Pleistocene Tanabu Formation (sand and silt) overlies the Shiriya Group and is overlain in turn by the Tanabu Marine Terrace deposits (MIS5e; Koike and Machida, 2001), which consist of sands and gravels and are covered by Shiriyazaki loam layers (Tsushima and Takizawa, 1977).

In this area, the coastal cliff (15–20 m high) is formed along the shoreline. Many depressions called blowouts have developed at the top of the coastal cliff along the western coast, and the Shiriyazaki dunes are distributed behind these blowouts on the terrace (Fig. 3a and b; Ogasawara, 1951; Tanino et al., 2013). Dune morphologies include parabolic dunes facing west-northwest, seif dunes extending from west-northwest to east-southeast, and their transformations. The dunes are thus oriented parallel to the prevailing west-northwest winds in this area (Fig. 3c). Such winds are the typical winter monsoon in this area.

We examined the Shiriyazaki dunes at outcrop S-1 (10–15 m high) (Fig. 3a and d). In this section, the Shiriyazaki dunes consist of five sand layers (S-DS1–5) separated by buried humic sands (black sands S-BS1–4). These deposits overlie a buried black soil (S-BBS) developed at the top of Shiriyazaki loam. Radiocarbon dates were obtained on organic carbon by β counting at Nihon University laboratory (NU). S-BBS is 25 cm thick, and its $^{14}$C age is 8350 ± 165 BP (No. NU-966; Tanino, 2000). S-BS1 with a thickness of 60 cm is an alternation of thin sand layers and humus layers. A $^{14}$C age in the lower part of S-BS1 is 6690 ± 100 BP (No. NU-1204), and one in middle part is 6075 ± 95 BP (No. NU-1205). S-BS2 is 20 cm thick, and its $^{14}$C age is 2380 ± 75 BP (No. NU-1206); it also contains Sunazawa type pottery of the Middle of Early Yayoi period (300–200 BC) (Aomori Higashidori Village Board of Education, 1995). A 10-cm-thick tephra layer intercalated within S-DS3 was tentatively identified as B–Tm tephra (ca. 1 ka) because of its whitish color and stratigraphic position. S-BS3, which is 20 cm thick, is 15 cm above the B–Tm tephra. It contains Haji ware and Satsumon ware (about 800–1100 AD) (Aomori Higashidori Village Board of Education, 1995). S-BS4 is 10 cm thick, and its $^{14}$C age is 220 ± 60 BP (Okamoto et al., 2000). In S-DS5, charcoal is observed.

S-DS1 is 120 cm thick. It overlies S-BBS with a distinct boundary and consists of sorted coarse gray sand. S-DS2–5 are characteristically grayish or dark brown and have a sandy loam texture.

### 2.3. Isozaki-Ajigaura area

Isozaki and Ajigaura are adjacent sites on the Pacific coast of Ibaraki Prefecture, northeastern Kanto Plain, Japan (Figs. 1 and 4). The basement in this area is composed of rigid Nakaminato Group (Upper Cretaceous) rocks (Sakamoto et al., 1972). The Neogene Taga (siltstone and sandstone) and Hanareyama (pumiceous tuff) formations overlie the Nakaminato Group rocks and are overlain in turn by sands and gravels of the Miwa Formation (MIS 5e; Suzuki, 1989; Koike and Machida, 2001). The top of the Miwa Formation forms the Naka marine terrace surface, which is covered by Kanto loam. A 20–25 m high coastal cliff forms the seaward edge of the terrace.

The Isozaki-Ajigaura dunes (Ogasawara, 1948) are distributed at the top of the coastal cliff (Fig. 4a and b). At the bottom of the coastal cliff, the coast is rocky at Isozaki because the Nakaminato Group is exposed, and at Ajigaura there is only a narrow beach with a few small coastal dunes and coastal lowlands occupied by a backmarsh that is free of beach sand. The Isozaki dunes form indistinct hills at the edge of the coastal cliff (one dune is 6 m high; Fig. 4a). The dunes in the Ajigaura area are parabolic and less than 10 m high, behind northeast-facing blowouts. Unofficial wind data recorded at Isozaki fishing port indicate that the strongest prevailing winds are northeast and north-northeast winds.

In the Isozaki-Ajigaura area, we studied three outcrops (Fig. 4a and c). In section I-1 (Fig. 4c), which shows the upper part of the 20-m-high coastal cliff at Isozaki, the Kanto loam is 2 m thick and

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