INFLUENCES OF BEDROCK AND LANDFORMS ON FOREST-LINE FORMATION ON A VOLCANIC MOUNTAIN IN SOUTHWESTERN JAPAN

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Abstract The structure and causal factors of a forest line, the boundary between mountainous forests and non-forest vegetation, were studied on Mt. Daisen, Japan, to clarify the long-term influences of volcanic evolution on vegetation. A distinct forest line formed at between 1100 and 1300 m elevation, which coincided with the geological boundary of the lava dome and talus deposits. No forest stands were able to develop on the summit lava dome because of poor soil development, and the position of the forest line was controlled not by macroclimatic or topoclimatic conditions but rather by the immature soils on the lava dome that formed during the late Pleistocene to early Holocene.

Key words: forest line, mountain slope evolution, soil development, volcano, lava dome

1. Introduction

Clarifying landform dynamics is essential in understanding vegetation structure in Japanese mountainous areas characterized by volcanic and tectonic activities (Sakai and Ohsawa 1994; Kikuchi 2001). In particular, landforms on volcanic mountains are subject to frequent changes caused by eruption and active erosion. Japan has 348 Quaternary volcanoes (Committee for Catalog of Quaternary Volcanoes in Japan 1999), and several studies have been conducted in Japan to examine the relationships between the regeneration processes of forests and both the physical environments and volcanic disturbances caused by lava flows, tephra falls, and debris avalanches (Tsuyuzaki 2001). However, most of these studies have dealt with vegetation changes over years and decades, and they have mainly investigated the early stages of ecological succession following volcanic evolution. Few studies have examined the long-term relationships between vegetational development and the slope evolution of volcanic mountains (Nakamura 1992; Kamijo and Okutomi 1993).

Long-term influences of mountain evolution on vegetation warrant further investigation because soil development on the new surface created by an eruption occurs over a long time. A volcanic mountain usually consists of slopes of different ages and various kinds of surface materials. This can

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create a mosaic of physical environments within a mountain area, leading to the development of heterogeneous vegetation. It is important to clarify landform effects on vegetation over a timescale of centuries and millennia, as well as at a timescale of years and decades. This study examined the structure and causal factors of a forest line, the boundary between mountainous forest and non-forest vegetation, on a volcanic mountain, to elucidate the long-term influences of volcanic evolution on the present vegetation.

2. Study Area

This study was conducted on Mt. Daisen in Tottori Prefecture, southwestern Japan (Fig. 1). Mt. Daisen is a large Quaternary composite volcano that includes clustered and overlapping lava domes and associated lava and pyroclastic flows (Tsukui 1984; Tamura *et al*. 2003). The eruptive activity began in the middle Pleistocene and continued until approximately 20,000 years ago, when a summit lava dome formed in the mapped area (Tsukui 1984). The peak of the mountain is 1729 m in elevation.

The mean annual temperature at Daisenji Meteorological Station (705 m above sea level) is 10.5ºC, and the mean annual precipitation at the Daisen Automated Meteorological Data Acquisition System (AMeDAS) station (875 m above sea level) is 2796 mm. The mountain is located on the coast of the Sea of Japan, and the prevailing winds from the northwest result in a great deal of snow in winter. The maximum snow depth often exceeds 200 cm at the Daisen AMeDAS station.

Two major vegetation zones have developed on Mt. Daisen. Below approximately 1200 m, *Fagus crenata* and other deciduous broad-leaved trees form the mountainous forest zone; above this altitude is a deciduous broad-leaved shrub zone that has no distinct dominant species (Miyawaki 1983). The latter zone includes coniferous shrubs dominated by *Taxus cuspidata* var. *nana* and meadows dominated by *Calamagrostis longiseta* and *Arcterica nana*.

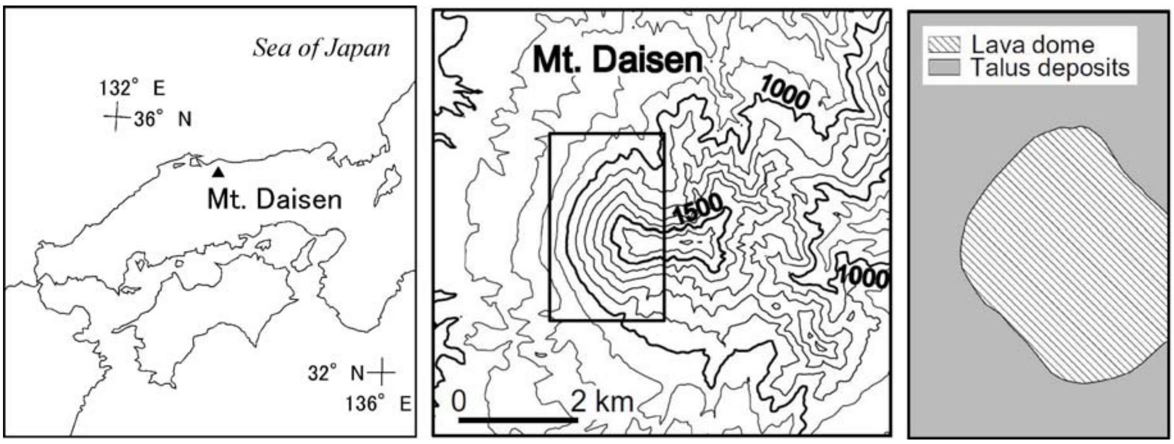

Fig. 1 Location of Mt. Daisen.

The boxed area in the middle map denotes the mapped area of geology (right map) and vegetation (Fig. 2). The schematic geological map is based on Tsukui (1984) and field observations.

3. Methods

Vegetation was mapped and classified into four cover types based on interpretation of color aerial photographs taken in 1974 (1:8000) and field observations made in 2006. The four mapped cover types were forest, shrub, meadow, and bare land.

Eleven plots, ranging from 25 to 400 m^2, were examined, on an altitudinal transect on the northern slope of the mountain, along a trail leading to the summit. The canopy height, maximum height, and maximum diameter at breast height of *F. crenata* and the canopy coverage of each species in the plots were measured. The term “canopy” is used here to refer to the top layer of both forests and shrubs.

Bedrock and soil profiles were recorded along the transect where soil erosion occurred on the trail.

4. Results

A distinct forest line was identified at an altitude of 1100 to 1300 m (Figs. 2 and 3). Most of the forest within the mapped area was either old-growth forest or young forest dominated by *F. crenata*. Included in this cover type were planted forest stands, which occurred mainly at lower elevations in the mountainous forest zone and were not found near the forest line. Above the forest line, shrubs dominated on north-facing slopes, while meadows dominated on south-facing slopes (Fig. 2).

The forest line occurred at approximately 1300 m on the investigated (northern) slope of the mountain. Canopy height decreased abruptly at the forest line, and the forest–shrub transition zone was narrow (Fig. 4). The canopy height of *F. crenata* was 20–25 m in areas below the forest line, but 5 m or lower in areas above the forest line, where *F. crenata* occurred sparsely.

In contrast to the sharpness of the structural change, floristic differences between the two sides of the forest line were not clear (Fig. 4). *F. crenata* and *Quercus crispula*, major canopy species in mountainous forests, also occurred among the shrubs above the forest line. Most of the other tree species found among the shrubs were in the sub-canopy layer of mountainous forests; *T. cuspidata* var. *nana*, *Salix sieboldiana*, and *Alnus crispa* subsp. *maximowiczii* occurred only above the forest line.

The position of the forest line on the mountain slope roughly coincided with the geological boundary of the lava dome and talus deposits; no forest stands were found on the summit lava dome (Figs. 1 and 2). Along the studied transect, mature soils were not observed on the lava dome, although bedrock with occasional overlying stones and boulders occurred (Fig. 4). Thin soils underlain by boulders were observed in the boundary area between the lava dome and talus deposits, where a narrow forest–shrub transition zone formed (approximately 1270–1290 m altitude; Figs. 2 and 4).

The disturbance regime differed between areas above and below the forest line. Landslides on the lava-dome slopes formed broad areas of bare land in shrub and meadow areas above the forest line (Fig. 2). Debris flows caused by the landslides formed narrow wedge-shaped patches of bare land and shrubs in forested areas, locally pushing the forest line to lower elevations. Canopy-gap formation resulting from uprooting and snapping of *F. crenata* trees was often observed below the forest line.

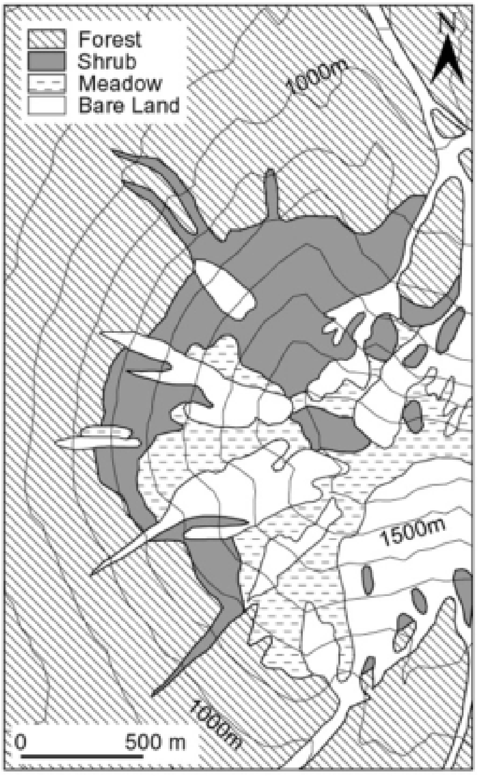

Fig. 2 Vegetation map of the western part of Mt. Daisen.
Contour interval is 100 m.

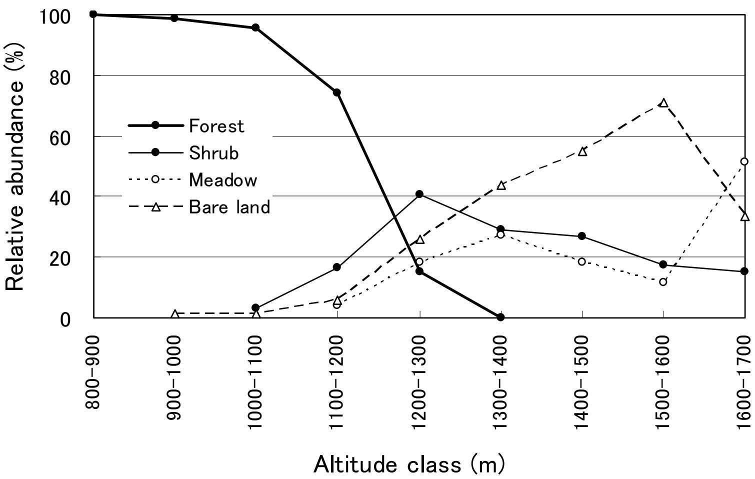

Fig. 3 Altitudinal distribution of vegetation on Mt. Daisen.
Elevation data are based on a 50-m grid digital map published by the Geographical Survey Institute of Japan.

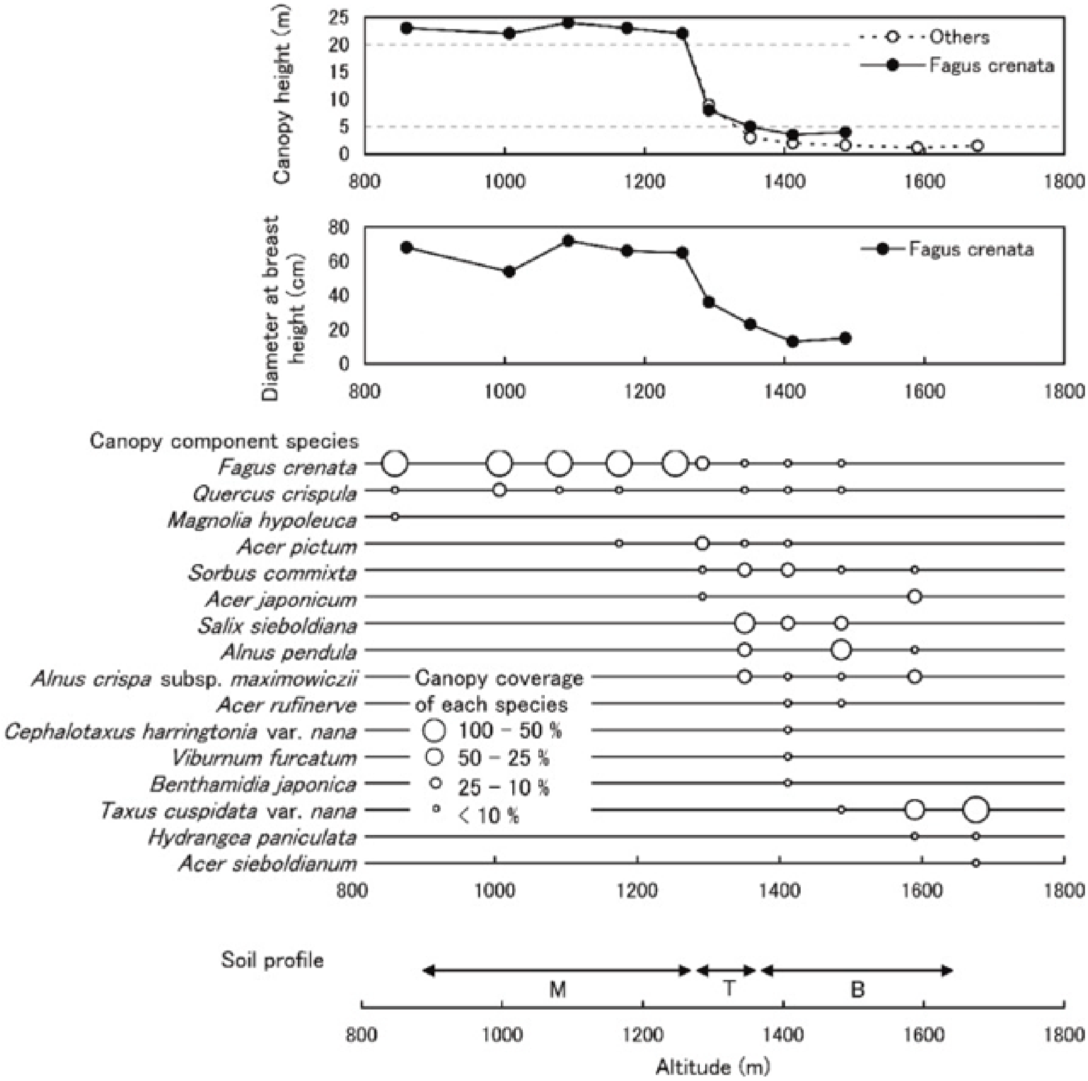

Fig. 4 Changes in the structure and composition of vegetation and the soil profile along an altitudinal gradient.

Abbreviations in the soil section are as follows: M, mature soil; T, thin soil underlain by boulders; B, bedrock with occasional overlying stones and boulders.

5. Discussion

Abrupt changes in forest canopy height and in the size of *F. crenata* along the forest line (Fig. 4) indicate that the formation of the forest line on Mt. Daisen was not due to decreases in air temperature. Trees near the forest line were rarely damaged by snow pressure or strong winds, suggesting that local climatic factors have little influence on the formation of the forest line. The occurrence of canopy species among the shrubs growing above the forest line suggests that these areas are sufficiently warm to allow the formation of forest vegetation.

The forest line was depressed not as a result of macroclimatic or topoclimatic conditions, but rather as a result of immature soil conditions on the summit lava dome. The position of the sharp forest line coincided with that of the lava dome perimeter (Figs. 1 and 2). The differences in soil structure on the two sides of the forest line were apparent (Fig. 4). Soil depth is one of the essential factors controlling tree height (Fujii *et al*. 2003). Such edaphic factors seem to be important on Mt. Daisen, although the clear delineation of forest lines has been examined based on both biological and physical factors (Armand 1992).

Sharp forest lines have been reported on nonvolcanic mountains in less snowy areas of Japan (Koizumi and Seki 1988; Shimizu 1994; Shimizu and Suzuki 1994). The summit areas of these mountains are covered with periglacial block fields that were formed during the last glacial period, and forest development is hindered by immature soils on the block fields. On Mt. Daisen, past mountain slope evolution also had long-term effects on the formation of the present forest line, with the position of the forest line controlled by immature soils on the lava dome, which was formed during the late Pleistocene to early Holocene.

In addition to the differences in the physical environments, the lava dome and talus-deposit areas differed in disturbance regimes. Landslides deformed the lava dome, and over the long term may have supplied sites for future forest development, as suggested by Horikawa and Yokogawa (1954). Debris

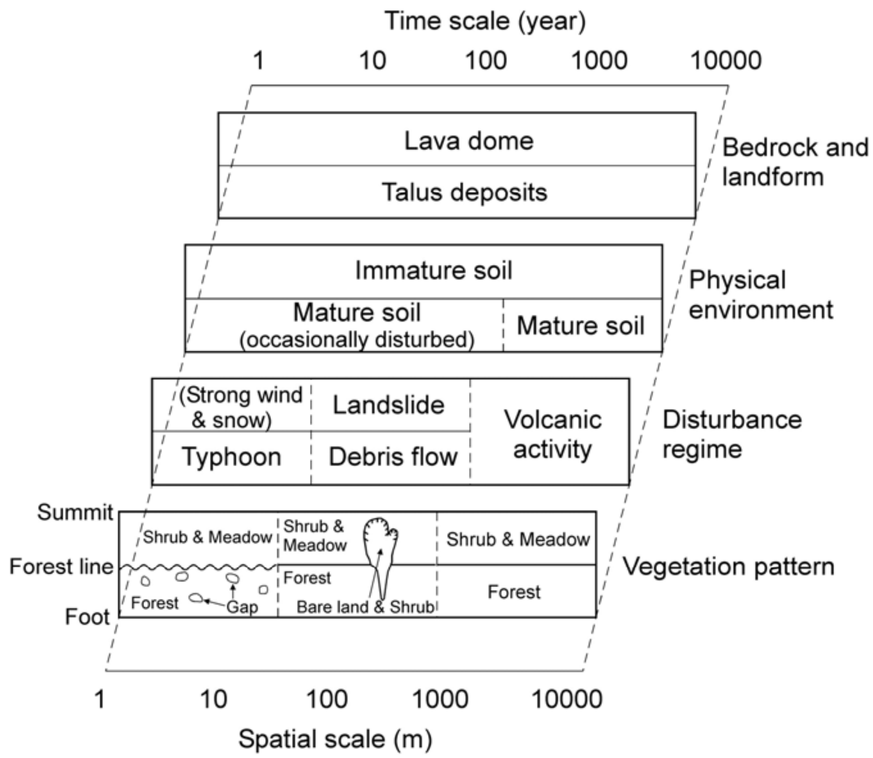

Fig. 5 Schematic showing the spatiotemporal distribution of vegetation and the associated environmental and disturbance factors.

flows caused by the landslides created large canopy openings and soil disturbance in the mountainous forest zone, and this type of disturbance greatly influences forest succession in the area (Yamamoto *et al.* 1995). Typhoons that cause canopy gap formation by tree uprooting and snapping are another major agent of forest and soil disturbance in the mountainous forest zone (Henbo *et al.* 2004).

In conclusion, the findings of this study suggest that the volcanic evolution of Mt. Daisen influenced the formation of the forest line. Differences in bedrock and landforms create differences in physical environments and disturbance regimes on the two sides of the forest line, controlling its altitudinal position (Fig. 5). Several studies have reported short-term depression of forest lines on volcanoes (del Moral and Grishin 1999), but the present study found long-term influences on the altitudinal position of a forest line.

Acknowledgments

This paper is dedicated to Professor Nobuyuki Hori upon his retirement from Tokyo Metropolitan University. The initial idea for this work was conceived during an excursion with Prof. Hori to the Mt. Daisen region in 1995. This research was partly supported by the Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (No. 17500705).

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