Quaternary International xxx (2015) 1–10

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

The relationship between past vegetation type and fire frequency in western Japan inferred from phytolith and charcoal records in cumulative soils

Jun Inoue [a, *], Ryota Okunaka [a, b], Tatsuichiro Kawano [c]

[a] Department of Geosciences, Osaka City University, 3-3-138 Sugimoto, Sumiyosi-ku, Osaka 558-8585, Japan
[b] Archaeological Research Consultant, Inc., 131 Shimohigashikawadu, Matue 690-0822, Japan
[c] West Japan Engineering Consultants, Inc., 1-1-1 Watanabe-dori, Chuo-ku, Fukuoka 810-0004, Japan

A R T I C L E I N F O

Article history:
Available online xxx

Keywords:
Fire frequency
Macrocharcoal
Grassland type
Phytolith
Holocene
Tonomine Plateau

A B S T R A C T

Phytolith and macrocharcoal records in cumulative soils were compared in five areas in western Japan, including two sites on the Tonomine Plateau where we examined those records. Past vegetation types, as represented by the compositions of phytolith assemblages, are closely related to macrocharcoal fluxes, regardless of age, suggesting that in Japan, fluxes in cumulative soils could be an indicator of fire frequency. On the Tonomine Plateau, phytolith and charcoal records indicate that, in the middle and late Holocene (at least 5000 to ~1000 years ago), *Sasa* and Panicoideae species in a temperate climate. At least for approximately the last 600 years the Japanese pampas (*Miscanthus sinensis*) grassland has undergone annual burning. The results from the Tonomine Plateau site of this study and from four other sites suggest that macrocharcoal fluxes in cumulative soils of >10 particles $\cdot$ cm^{-2} y^{-1} indicate a high frequency of fires, resulting in the dominance of Andropogoneae species. Dominance of *Pleioblastus* species under the influence of fire was observed in soils with a charcoal flux of 2–10 particles $\cdot$ cm^{-2} y^{-1}, suggesting that the species flourished under a moderate frequency of fire (possibly every several years or more). In soils with a charcoal flux of less than ~1 particles $\cdot$ cm^{-2} y^{-1}, there was no influence of fire on vegetation, and *Sasa* and *Pleioblastus* species flourished where the vegetation type was determined primarily by the climatic conditions. These findings indicate that macrocharcoal fluxes and phytolith assemblages exhibit a consistent relationship that is independent of age, and that macrocharcoal fluxes are linked to fire frequency, thus suggesting that the frequency of fire has determined the vegetation type in these areas. Therefore, phytolith and charcoal records in cumulative soils provide a context for quantitatively understanding the influence of fire on vegetation patterns in the past.

1. Introduction

In Japan, forests are widely distributed under warm and humid climate conditions. However, in some areas, grasslands develop because of human disturbance in the form of intentional fires. In Japan, grass has played an important role in Japanese culture; for example, Japanese pampas grass had been traditionally used as a building material (e.g., for thatch roofing) and as a fertilizer (Iwaki, 1971; Tsujino, 2011). Records of phytolith and macrocharcoal in cumulative soils suggest that most grasslands in Japan developed as a result of intentional fires or have been maintained through repeated cycles of fire for hundreds or thousands of years (e.g., Takaoka and Yoshida, 2011; Miyabuchi et al., 2012; Okunaka et al., 2012).

Phytolith records provide general information on local vegetation in closed habitats (e.g., Piperno, 1988; Stromberg, 2004). The flux or concentration of macrocharcoal in cumulative soils generally represents fire frequency at or near the collection site, as macrocharcoal particles are not transported far from their source (fire area) before settling (e.g., Whitlock and Larsen, 2001). In most cases, cumulative soils are several or tens of thousands of years old, providing a continuous record of environmental change during the Holocene (e.g., Kawano et al., 2012; Miyabuchi et al., 2012; Okunaka et al., 2012). While the grasslands in these areas likely developed under conditions of frequent fires, fire frequency in the area has not

* Corresponding author.
E-mail address: juni@sci.osaka-cu.ac.jp (J. Inoue).

http://dx.doi.org/10.1016/j.quaint.2015.02.039

been evaluated quantitatively and the relationship between fire frequency and past vegetation types remains unclear.

In this study, we examined phytolith and macrocharcoal particles in cumulative soils on the Tonomine Plateau of central Japan, where annual fires are used to enhance grasslands (mainly Japanese pampas grass: *Miscanthus sinensis*). These particles help clarify the historical relationship between fire and vegetation in the local area during the Holocene. The phytolith assemblage and charcoal flux have been recorded in cumulative soils at four sites in western Japan. We compared these results to the results of our study to determine whether there is a consistent relationship between vegetation shifts and charcoal flux in these soils. Vegetation as represented by the phytolith assemblage is closely related to macrocharcoal flux, and that the flux may be an indicator of fire frequency.

2. Study Site

The Tonomine Plateau, which has an area of approximately 1 km^2, is at an altitude of 800–900 m (Fig. 1). Several streams run through the plateau and wetlands are distributed around the streams, especially in the lower parts of the plateau. Meteorological data for the area is recorded at Ikuno Climatological Station (35°10′00″N, 134°47′30″E; elevation: 320 m), located approximately 10 km from the plateau. The mean annual temperature (1981–2010) in the region is 13.1 °C and annual precipitation (1981–2010) is 2021 mm (Japan Meteorological Agency website: www.jma.go.jp). On the Tonomine Plateau, the warmth index (WI) is 78.3 and the cold index (CI) is −15.2. The WI and CI were calculated according to the following equations (Kira, 1991): $WI = \sum(T_m - 5)$, when T_m is greater than 5 °C, and $CI = \sum(5 - T_m)$, when T_m is less than 5 °C, and where T_m is the monthly mean temperature (°C).

This plateau is situated in the warmest area of the cool temperate zone and the climax vegetation in the region is a cool-temperate deciduous broad-leaved forest. However, most of the existing vegetation in the region consists of plantations of Japanese cedar (*Cryptomeria japonica*) and Japanese cypress (*Chamaecyparis obtusa*), or secondary forests of deciduous oak (mainly *Quercus serrata*). Most of the Tonomine Plateau is covered by grasslands dominated by Japanese pampas grass (*M. sinensis*). The grassland is burned intentionally every spring to enhance its survival. Although the history of intentional fires is unclear, it is likely that prior to the pre-modern period, the plateau was burned annually to sustain the *M. sinensis* grasslands, as noted by the Kamikawa Town Officer. In the Kamikawa region around the Tonomine Plateau, manors were developed starting in the 13th century (Abe and Sato, 1997).

3. Materials and methods

3.1. Materials

Thick black soils up to 80 cm deep are widely distributed on the Tonomine Plateau (Fig. 2). They are regarded as cumulative soils because the phytolith assemblages contained in them vary according to soil depth (see Section 4.1), and the age of humin found in the soil increases with soil depth (Table 1, Fig. 3). These facts indicate that the soils have grown upward over time.

We collected samples from soil profiles at two sites: Sites 1 and 2 (Fig. 1). In the soil profile at Site 1 (35°09′05″N, 134°41′25″E), the A horizon (black soils) occurs at 0–80 cm in depth, the B/A horizon at 80–90 cm in depth, and the B horizon (yellowish brown) at 90–100 cm in depth (Fig. 2). The A horizon is divided into eight horizons. In the soil profile at Site 2 (35°09′02″N, 134°41′07″E), the A horizon (black soils) occurs at depths of 0–60 cm, the A/B horizon at depths of 60–70 cm, and the B horizon (brown soils) at depths of 70–80 cm. The A horizon is divided into five horizons. Characteristics of the horizons at Site 1 and 2 are listed in Table 2. The formation of numerous horizons in the cumulative soils at different sites probably indicates that the soils are relatively undisturbed.

We collected soil samples approximately 10 cm thick from the soil profile at each site, such that each sample consists of a single soil horizon. We collected samples for analysis of phytoliths and macroscopic charcoal from a depth of 0–100 cm at Site 1 and from 0 to 80 cm at Site 2. We dated each soil layer using the radiocarbon dating of humin extracted by chemical treatment (Table 1, Fig. 3).

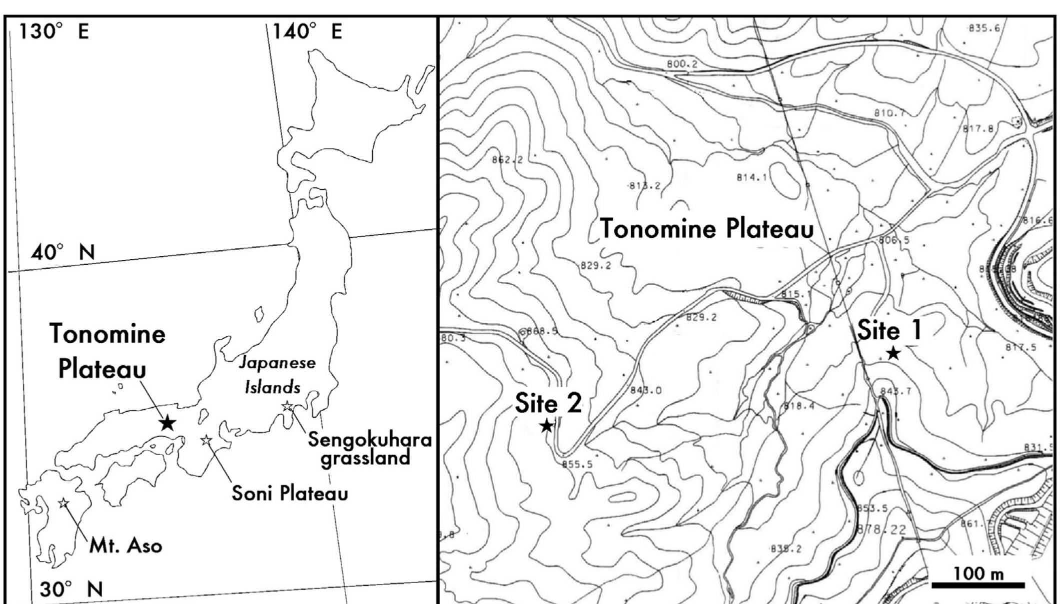

Fig. 1. Map of Japan (left) showing the sites where cumulative soils were sampled in the study (Tonomine Plateau) and previous studies. The topographic map (right) shows the location of the sampling sites in the study area. The map is part of the 1:5000 topographical map of Kamikawa Town, as issued by the Kamikawa Town Office.

Please cite this article in press as: Inoue, J., et al., The relationship between past vegetation type and fire frequency in western Japan inferred from phytolith and charcoal records in cumulative soils, Quaternary International (2015), http://dx.doi.org/10.1016/j.quaint.2015.02.039