Catena 85 (2011) 87–108

Contents lists available at ScienceDirect

Catena

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

Late Quaternary environmental change inferred from phytoliths and other soil-related proxies: Case studies from the central and southern Great Plains, USA

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ARTICLE INFO

Keywords:
Opal phytoliths
Paleosols
Sporormiella
Stable carbon isotopes
Charcoal
Great Plains

ABSTRACT

This study investigates stable carbon isotopes ($\delta^{13}C$), opal phytolith assemblages, burnt phytoliths, microscopic charcoal and *Sporormiella* spores from modern soils and paleosols in Kansas and Oklahoma. Grass and dicot phytoliths in combination with $\delta^{13}C$ are used as proxies for reconstructing the structure of grasslands and woodlands. Burnt grass phytoliths and microscopic charcoal are evaluated as proxies for reconstructing paleofire incidence. Concentrations of the fungal spore *Sporormiella* are used as a proxy for assessing large herbivore activity. These proxies were tested on various modern grassland communities of the central and southern Great Plains, including areas with bison, cattle, and small herbivores, and areas under different fire frequencies.

Opal phytolith assemblages and $\delta^{13}C$ values show that before cal 11 ka, C_3 grasses and woody plants predominated in areas that today are dominated by C_4 grasses. The origin of the shortgrass prairie dates back to about cal 10 ka. The origin of the tallgrass prairie, however, is not clear as phytolith data show variable assemblages throughout the Holocene (mixed-grass, tallgrass, and tallgrass–woodland mosaic). Different proxies (burnt phytoliths vs. charcoal) reveal different fire frequencies, but it is apparent that microfossil evidence for fire incidence is closely related to the abundance of woody plants in the landscape.

Before cal 12 ka, soils show somewhat elevated concentration of *Sporormiella*, but lower concentrations than the modern high-density bison and cattle grazing areas. Throughout the Holocene, *Sporormiella* frequencies are low, which suggests lower large ungulate densities and perhaps high mobility.

1. Introduction

Opal phytoliths in the North American Great Plains are a potential source of information for reconstructing structural changes in grasslands through time, thus compensating for the paucity of fossil pollen records in this region. Unlike other regions of the country the south-central Great Plains lack lakes and peat bogs, for continuous sequence, in addition to the poor preservation of pollen (Hall, 1995). Information provided by grass phytoliths has been used as proxy data for reconstructing growing season paleotemperatures by means of the proportions of short-cell phytoliths diagnostic of C_3 (cool season) to C_4 (warm season) grasses (Fredlund and Tieszen, 1994, 1997a). Studies of diagnostic phytoliths of non-graminoid flora (Geis, 1973; Klein and Geis, 1978; Bozarth, 1992; Blinnikov, 2005) have complemented phytolith-based vegetation reconstruction. Because generic woody plant phytoliths are readily identified, the dicot-grass (D/P) index has been used as an approach to reconstruct the degree of openness of the vegetation in tropical Africa (Alexandre et al., 1997). The D/P designation can, however, be misleading because not all dicot plants are woody. To resolve this issue, Fredlund (1998) devised the Woodland–Grassland Ratio. Additionally, opal phytoliths that exhibit discoloration by burning also have been used for paleofire reconstruction (Boyd, 2002), which supplements data from microscopic charcoal.

Opal phytoliths in the Great Plains have been extracted from a variety of deposits, including alluvial and playa fills. Particularly high concentrations of phytoliths occur in modern and buried A horizons, thus providing information regarding the history of plants occupying the soil. Opal phytolith and stable carbon isotope data have been used together as proxies for vegetation structure by combining graminoid and dicot plant phytoliths (Fredlund and Tieszen, 1997b; Baker et al., 2000; Kerns et al., 2001; Johnson et al., 2002; Sedov et al., 2003; Klassen, 2004). While $\delta^{13}C$ values determined from soil carbon may be used to estimate proportions of C_3 and C_4 plants, opal phytoliths permit separation of these photosynthetic groups into C_3 and C_4 grass subfamilies and a variety of dicot plants (Klassen, 2004).

In addition to opal phytoliths, soils contain assemblages of other microfossils (e.g., charcoal, spores, diatoms, mycorrhizae, and

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doi:10.1016/j.catena.2010.08.015

spherulites) that have great potential for reconstructing environmental conditions in biomes (Schaetzel and Johnson, 1983; Kurmann, 1985). For example, microscopic and macroscopic charcoal in soil has been used as a proxy for forest fires (Carcaillet, 2001; Gavin et al., 2003). Also, fungal spores such as *Sporormiella* have provided information on relative density of large herbivores occupying a soil surface (Burney et al., 2003; Davis and Shafer, 2006).

A multi-proxy approach using stable carbon isotopes and soil microfossils vastly increases the amount of information derivable for paleograssland reconstruction. This approach views the soil as an archive of microfossils produced by plants and animals. As horizons of grassland soils develop, organic matter and microfossils produced by the grasses create an accretion sequence as soil grass sod builds up. In other instances, where eolian and alluvial accumulation exceeds soil accumulation, vertical migration of top soil occurs, leaving former A horizons below the current horizons (i.e., cumulic soils). Consequently, a long record of microfossils can be recovered, often spanning hundreds and in some cases thousands of years. Similarly, soils buried within alluvium, loess, sand or other deposits typically preserve microfossil sequences that accumulated when the soils were at the surface.

Given the potential that opal phytoliths and other soil microfossils offer for paleoenvironmental reconstruction, the objective of this study was to analyze the combined records of, opal phytolith assemblages, burnt grass phytoliths, micro-charcoal density, and *Sporormiella* spores in order to reconstruct paleovegetation, paleofires, and paleograzing conditions (Fig. 1). Also, stable carbon isotope analysis of soil and sediment organic matter was included. This study presents multi-proxy records from modern soils and from sites with buried soils, and is part of a nascent research project named *Paleobiomes, Paleopastures and Paleofires*, whose goal is to create a database for a spatial distribution of grassland conditions in the central and southern Great Plains since the Last Glacial Maximum (Cordova and Johnson, 2007).

2. Study areas and sites

The modern reference sample sites for testing the microfossil records of this study are located in an array of vegetation communities within the central and southern Great Plains (Fig. 2). The areas studied include nature preserves, long-term research stations, wildlife management areas, state and national parks, and tribal and private lands (Table 1). The geographic distribution of study sites provided a wide range of temperatures, annual precipitation, precipitation seasonality, and geological and topographical conditions, as well as different controlled-fire regimes and grazing schedules.

The paleoenvironmental study sites are located in Kansas and northern Oklahoma (Fig. 2). Stratigraphic sections at the Kansas sites span the late Pleistocene and Holocene, whereas the two stratigraphic sections in Oklahoma span the late Holocene. In sum, one soil-stratigraphic site is located in the shortgrass prairie, four are in the tallgrass prairie, and one is in the sandsage grassland of the mixed-grass prairie.

3. Methods

3.1. Sampling

Modern surface sampling was conducted in reserves and parks where there is a record of fire and grazing (Table 1). The sampling locality was chosen in relation to fire frequency, the presence and stocking rates of large herbivores (cattle or bison). The selected sampling area was marked with a 2 m^2 quadrats. Five pinches of surface soil were collected at random places in each quadrat.

Soil sampling for plant microfossils (opal phytoliths, microscopic charcoal and *Sporormiella*) from stratigraphic sections varied based on soil horizon distribution. At the Kanorado, Ft. Riley 1 and 2, Claussen, and Cooper WMA sections samples were taken from A, AB and AC horizons. Increments varied depending on the thickness of the horizon; the 5 and 10 cm horizon were the most common. Our previous tests showed that B and C horizons are poor in phytoliths or not preserved. However, the bottom B and C horizons at Kanorado did contain a fair number of phytoliths. The Sand Creek TGP section, which consists primarily of A horizons, was sampled at 5 cm increments.

Samples for δ^{13}C analysis and organic carbon (OC) content were collected as subsamples split from the modern surface collections. At the paleoenvironmental study sites, discrete samples were collected from either cores or prepared profiles.

3.2. Stable carbon isotope analysis

Soil and sediment samples for δ^{13}C analysis of organic carbon (OC) were submitted to the University of Kansas W. M. Keck

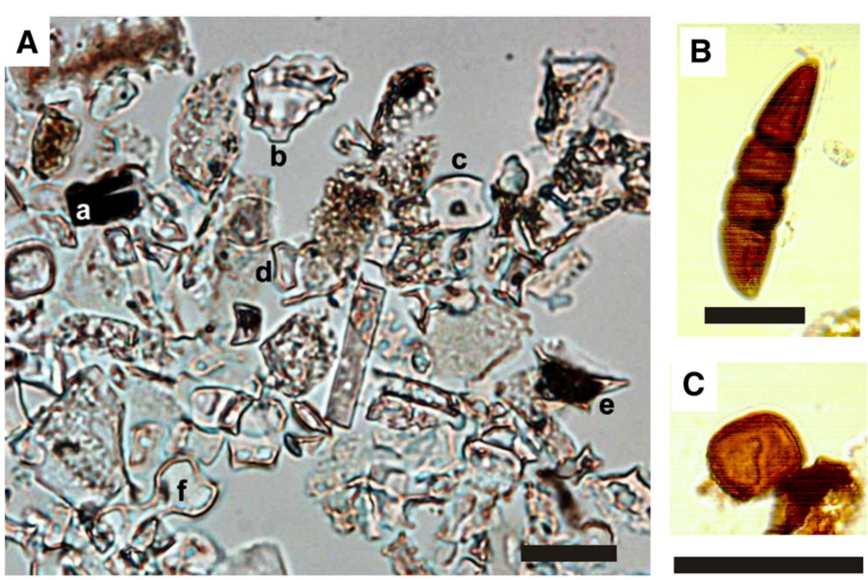

Fig. 1. A: Phytolith assemblage with charred particle (a), unknown dicot phytolith (b), saddle (c), saddle ellipsoid (d), burnt, conical phytolith, and bilobate (f). Scale line = 20 μm. B: Sporormiella spores, complete bundle (b), single spore. Scale lines = 10 μm.