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Can biomass burning produce a globally significant carbon-isotope excursion in the sedimentary record?

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Abstract

Negative carbon-isotope excursions have been comprehensively studied in the stratigraphic record but the discussion of causal mechanisms has largely overlooked the potential role of biomass burning. The carbon-isotopic ratios ($\delta^{13}C$) of vegetation, soil organic matter and peat are significantly lower than atmospheric carbon dioxide (CO_2), and thereby provide a source of low ^{13}C CO_2 when combusted. In this study, the potential role of biomass burning to generate negative carbon isotope excursions associated with greenhouse climates is modeled. Results indicate that major peat combustion sustained for 1000 yr increases atmospheric CO_2 from 2.5× present atmospheric levels (PAL) to 4.6× PAL, and yields a pronounced negative $\delta^{13}C$ excursion in the atmosphere (~2.4‰), vegetation (~2.4‰) and the surface ocean (~1.2‰), but not for the deep ocean (~0.9‰). Release of CO_2 initiates a short-term warming of the atmosphere (up to 14.4 °C, with a duration of 1628 yr), which is consistent with the magnitude and length of an observed Toarcian excursion event. These results indicate that peat combustion is a plausible mechanism for driving negative $\delta^{13}C$ excursions in the rock record, even during times of elevated pCO_2.

Keywords: wildfires and biomass burning; negative carbon-isotope excursions; carbon isotopes of organic matter and atmospheric carbon dioxide; carbon cycle; wildfire emissions; Oceanic Anoxic Events; Cretaceous

1. Introduction

Scientific investigations of fire have evolved from examining fire as a local mechanism for transforming landscapes and altering soil processes to a supra-regional mechanism for shifting atmospheric chemistry and weather. Wildfires affect soil processes, erosion, growth and development of herbaceous plants, trigger post-fire growth and flowering, and fire-stimulated reproduction in woody plants [1–3]. The majority (~90%) of modern biomass burning is thought to be anthropogenic [4]; however, the impact of pre-anthropogenic fires on Earth-surface processes needs to be examined and placed in a geologic perspective, especially the influence on $\delta^{13}C$, temperature, and atmospheric CO_2.

Widespread tropical-forest and peat fires in Indonesia during 1997, combined with fires in central and South America and in boreal regions of Eurasia and North America, emitted 2.1×10^{15} g C, thereby doubling of the annual rate of CO_2 injected into the atmosphere [5,6]. Localized burning in areas of high biomass documented during the Indonesian wildfires substantially changed the global carbon balance [7,8],

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directly affecting the carbon isotopic composition ($\delta^{13}C$) of atmospheric gases. In addition carbon dioxide in air samples collected downwind from an experimental burn of a boreal forest possess an isotopic composition of −26.97‰ for ^{13}C [9] and methane produced by smoldering fires yields lower $\delta^{13}C$ values than CH_4 produced by flaming fires [10].

Sedimentary evidence of fires occurs in terrestrial ecosystems beginning in the Late Silurian–Early Devonian [11–15], when atmospheric levels of O_2 increased in association with the adaptive radiation of vascular land plants [16–18]. Combustion detritus is well represented in Mesozoic strata and is complemented by molecular evidence for polycyclic aromatic hydrocarbons (PAH) in marine and terrestrial sediments [19–26]. Carbonized/charcoalified floras and mesofossils (e.g., [19,20]), fusinite [21], and PAH [22–26] reported in recent studies of Jurassic and Cretaceous terrestrial deposits provide evidence of paleofires. The mid-Albian Gates Formation is one example of a unit containing combustion-derived inertinite >35% by volume of the seam, and has an apparent 20–40 yr cyclicity for fires [21]. Frequent wildfires and smoldering peat fires in ancient terrestrial ecosystems would directly impact the chemistry and the carbon-isotopic composition of the paleoatmosphere.

Proxy records of atmospheric CO_2 indicate marked variations through the Phanerozoic [27]. Models suggest a 30% increase in global lightning activity and cloud-to-ground lightning associated with doubled modern CO_2, increasing fire frequency [28,29]. Wildfires and associated biogeochemical interactions with both soils and the atmosphere could produce carbon isotope excursions akin to those in the rock record (e.g., Paleocene–Eocene boundary [30]) attributed to methane oxidation [31,32] or to enhanced carbon burial [33]. Using modern peat reservoirs for calculating their contribution through burning to negative $\delta^{13}C$ excursions in the rock record can lead to erroneous conclusions because the Holocene is markedly and consistently lower in peat products than all estimates for the Cretaceous (c.f., [34–36]). This paper tests potential links between wildfires and negative carbon-isotope excursions in the Cretaceous using a geochemical flux/reservoir model (Fig. 1). The results indicate that emissions from peat fires are a plausible mechanism for driving negative $\delta^{13}C$ excursions observed in the rock record, especially during times of elevated atmospheric CO_2, sea-level high stands, and widespread peat accumulation.

2. Method — modeling Cretaceous fires

2.1. Five-box model for terrestrial carbon

A simplified model (Fig. 1) is used to represent carbon-isotopic interactions among five reservoirs (atmosphere, vegetation, soil, and shallow and deep ocean) and six fluxes (productivity, respiration, leaf litter, fire, air–sea exchanges, and shallow–deep ocean exchanges) in a system open to burial of marine carbonate and organic matter (after [33,37]). Peat is an

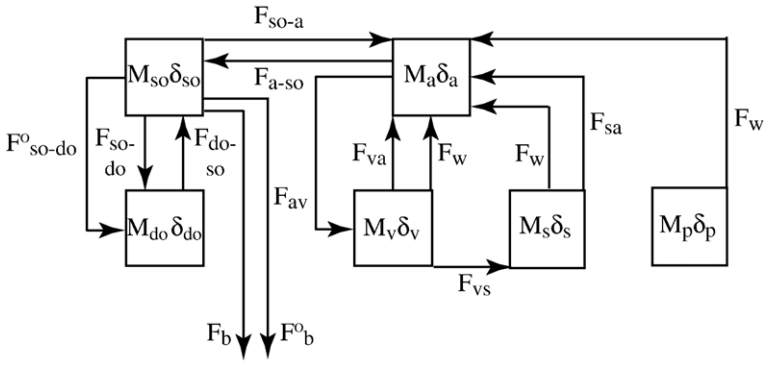

Fig. 1. Schematic model of the carbon-isotope system where the wildfire fluxes can contribute to atmospheric $\delta^{13}C$.