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Stratigraphic distribution and significance of a 15 million-year record of fusain in the Upper Triassic Chinle Group, southwestern USA

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ABSTRACT

We document the occurrence of Upper Triassic fusain in northern Arizona, southern Utah and northern New Mexico in latest Carnian(?) to Norian-age alluvial strata of the Monitor Butte Formation and the Sonsela and Painted Desert members of the Petrified Forest Formation (Chinle Group). The fusain, identified by standard techniques of macroscopic and microscopic morphology, and resistance to chemical oxidation, is present at multiple stratigraphic horizons at several locations that are approximately correlative, although separated by several hundred km. The morphology of this fossil charcoal includes large, partially charred silicified to coalified logs, completely charred smaller limbs, charcoal fragments reworked in fluvial deposits, and particulate fusain disseminated in sediments. The apparent rarity of fusain in Triassic strata previously was cited as evidence for relatively low levels (compared to modern) of atmospheric oxygen and the consequent infrequent occurrence of wildfire during this time interval. However, our findings demonstrate a significantly greater abundance of fusain in Upper Triassic strata than previously acknowledged. Therefore, we suggest that wildfire was not an unusual occurrence during the Late Triassic. This conclusion supports recent experimental studies and geochemical models that indicate atmospheric oxygen levels at or above modern levels during the Late Triassic.

1. Introduction

The geologic record of fusain, the general term for macroscopic ancient charcoal (Scott and Damblon, 2010), extends as far back as the Silurian Period (Glasspool et al., 2004). Its near ubiquitous chronostratigraphic distribution has been cited as an indication that levels of atmospheric oxygen have not fallen below 12%, once considered the minimum for sustained burning of biomass (e.g., forest fires) under natural conditions, during most of the Phanerozoic (Cope and Chaloner, 1980; Chaloner, 1989). More recent work, however, now suggests that the minimum for sustained combustion of natural fuels is 15% (Belcher and McElwain, 2008). Nonetheless, the distribution of fusain is not uniform through time. During the Phanerozoic, the relatively greater abundance of fusain in Carboniferous strata, long noted in coal measures, has been interpreted as evidence of atmospheric oxygen levels (pO_2) significantly higher than the present atmospheric level (PAL) of 21%, potentially as high as 35% (Berner and Canfield, 1989; Berner, 1999, 2001, 2005, 2006; Scott, 2000; Jones et al., 2002). Certain geochemical models support the interpretation of a late Paleozoic high-oxygen atmosphere and cite a fossil record that includes gigantism in arthropods and the transition to a land-based existence among tetrapods (Berner et al., 2000, 2003). In contrast, geochemical models that present relatively low pO_2 throughout the Triassic Period (Falkowski et al., 2005; Berner, 2006) cite as evidence an apparent paucity of fusain in Triassic strata (Scott, 2000; Jones et al., 2002).

In the southwestern USA, fusain was first recognized and reported from strata of the Upper Triassic Chinle Group by Jones et al. (2002). The authors described fusain occurrences in the lower part of the group in exposures in Petrified Forest National Park (PFP) in northern Arizona, and remarked specifically on the apparent lack of descriptions of fusain from Triassic strata in general, from which the authors interpreted a general lack of Triassic wildfire activity. Zeigler (2002, 2003) and Tanner et al. (2003) also reported fusain from Chinle Group strata, but from younger strata in the Chama Basin of northern New Mexico. Tanner et al. (2006) described previously undocumented fusain in Chinle Group strata in northern Arizona. The most recent documentation of wildfire during Chinle deposition is from Byers et al. (2014), who described a silicified log from southeastern Utah on which they identified fire-scarring and subsequent continued wood growth.

The present study adds to the record of fusain in Upper Triassic strata in general, and contributes to our knowledge of wildfire activity in the Late Triassic by documenting the distribution of fusain in strata of the Chinle Group. We describe some previously unreported occurrences,

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Table 1
Carbon isotope analyses for Chinle charcoal: CWS = Cameron site (Sonsela Member); LPD = Little Painted Desert County Park (Sonsela Member); SQ = Snyder Quarry (Painted Desert Member).

Sample ID	$\delta^{13}C$ (VPDB)
CWS-1	−23.0
CWS-2	−23.1
CWS-3	−23.1
LPD-1	−22.8
LPD-2	−22.9
LPD-3	−24.7
LPD-4	−25.2
SQ-1	−20.8
SQ-2	−21.5

and elaborate on previous reports from northern Arizona, southern Utah and northern New Mexico by resampling known locations. Taken together, these reports demonstrate a record of frequent wildfire preserved on the present Colorado Plateau that spans a substantial portion of the stratigraphic range of the Chinle Group.

2. Methods

Fossilized wood with varied modes of preservation is common across most of the range of the Chinle Group. Siliceous permineralization is perhaps the best known form, but others, include charring (fusain), lignitization and coalification are also known. Occurrences of fusain in Chinle Group strata were confirmed using standard methods. In the field, fusain appears as blackened woody material that displays a macroscopic similarity to modern charcoal, including blocky fracturing (a pattern of semi-regular transverse and longitudinal fracturing), a fibrous or silky appearance on fracture surfaces, black streak and low density (<1.0).

Material displaying macroscopic characteristics of fusain was subjected to additional laboratory examination to differentiate fusain from other forms of fossilized wood, such as bituminous coal or lignite (or jet), which can share some features with fusain (Kelber, 2005, 2007, 2015). A characteristic of fusain is resistance to chemical oxidation as demonstrated by immersion in Schultze's reagent (Wood et al., 1996) for 24 h at 20 °C without significant maceration. The primary identifying characteristic of fossil charcoal is the preservation of cellular structure (open lumens) and cell-wall homogenization. Both features are visible in petrographic thin sections, but they are best confirmed

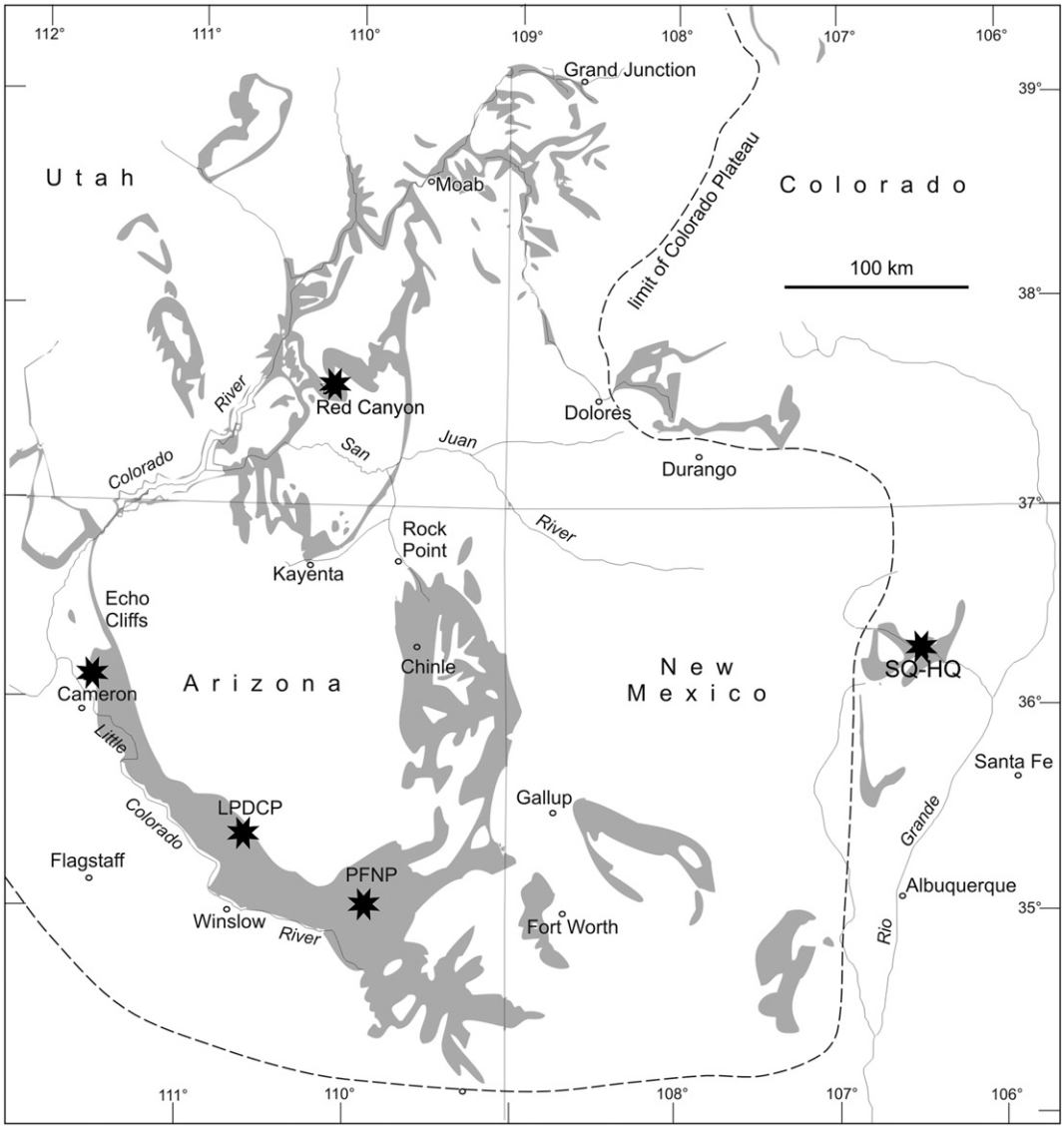

Fig. 1. Late Triassic charcoal occurrences in the Chinle Group described in this study (marked by stars) are: Red Canyon, southeastern Utah; the site north of Cameron, Arizona; Little Painted Desert County Park, north of Winslow (LPDCP); Petrified Forest National Park (PFNP); and Snyder Quarry site (SQ-HQ = Snyder Quarry, Hayden Quarry) in the Chama basin of New Mexico. Shaded area indicates outcrops of Chinle Group strata.