4-2001

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Recommended Citation

Cressler III, W.L., 2001. Evidence of earliest known wildfires. PALAIOS, 16, pp. 171-174.

Evidence Of Earliest Known Wildfires

(rrh: Cressler – Evidence of earliest known wildfires)

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ABSTRACT

The oldest known fossil charcoal to date is herein reported from a Late Devonian (Famennian 2c) fluvial deposit in the Catskill Formation of north-central Pennsylvania. The charcoal was found in an abandoned channel setting in association with abundant well-preserved macrofossil plant remains of Archaeopteris*,* Rhacophyton*, cormose lycopsids,* Gillespiea*, and cupulate and acupulate gymnosperms. Detailed anatomical preservation of the charcoal combined with its paleoecological setting suggests that in this landscape, mostly* Rhacophyton *burned, perhaps in association with an interpreted annual dry season. Alternating wet and dry seasons are indicated by the presence of paleovertisols. The fossil site where the charcoal was found also has yielded terrestrial arthropods, numerous fishes, and two early tetrapods.*

INTRODUCTION

The Late Devonian was the interval in Earth history during which forests first spread over large areas of the landscape (Scheckler, in press). Like modern forests, these earliest forests must have been dynamic ecosystems subject to cycles of disturbance and regeneration. One of the major sources of forest disturbance that has profoundly influenced the development of forests and their ecological relationships throughout their history is fire. Herein I report the earliest charcoal evidence of forest wildfires, discovered at a fossil locality that allows for a detailed analysis of its paleoecological significance. The fossil charcoal was found at a roadcut known as Red Hill, a Late Devonian fluvial deposit in the Duncannon Member of the Catskill Formation in Clinton County, Pennsylvania (Woodrow et al., 1995). Red Hill is already known for its diversity of animal fossils, including terrestrial arthropods (Shear, 2000), fishes (Daeschler, 1998, 2000a), and the oldest known tetrapods from North America (Daeschler et al., 1994; Daeschler, 2000b). The charcoal at Red Hill was found in association with an assemblage of fossil plants dominated by the progymnosperm *Archaeopteris,* the earliest known forest tree (Meyer-Berthaud et al., 1999). Until recently, the oldest previously well-authenticated charcoal in the literature has been of Early Carboniferous age (Cope and Chaloner, 1985; Scott, 2000). Devonian charcoal from within the LN miospore zone has now been reported from Germany (Rowe and Jones, 2000). Palynomorph analyses indicate an age of Famennian 2c for the charcoal from Red Hill (Traverse, in press). This older interval is equivalent to the VCo miospore zone, which is distinguished by the presence of *Grandispora cornuta* Higgs and *Rugispora flexuosa* (Juschko) Streel (Richardson and McGregor, 1986; Streel and Scheckler, 1990).

GEOLOGICAL SETTING

Red Hill is a 1-km-long south-facing roadcut exposure along Pennsylvania route 120 between the villages of Hyner and North Bend (41° 20' 30"N latitude and 77° 40' 30"W longitude). This outcrop consists of alternating channel sandstones, laminated floodplain siltstones, and paleosols (Fig. 1). These lithologies are typical of the Duncannon Member upper alluvial plain facies of the Catskill Formation. The charcoal and numerous well-preserved plant fossils were found in a dark-gray siltstone layer 9 meters up from the base of the outcrop (Fig. 2). Where this siltstone layer pinches out at its eastern end it truncates two layers below it, a red paleosol and a red laminated siltstone. The pinched-out portion of the dark-gray siltstone is end-to-end with the apex of a thin sandstone wedge that thickens to the east (Fig. 1). The sandstone wedge exhibits small-scale cross-bedded laminations accreting towards the apex of the wedge. The dark-gray siltstone is interpreted as derived from a silted-up oxbow lake. When the oxbow lake was an active channel, it scoured out the underlying paleosol that had been developing on a laminated floodplain siltstone. The eastern sandstone wedge is interpreted as derived from the deposition of sand on a point bar along the inside meander bend of the active river channel.

The section measured for the stratigraphic column (Fig. 2) was 15 m to the west of where the dark-gray siltstone layer pinches out. This reduced horizon averages 1 m in thickness over its exposed length of 167 m. Most of the deposition in the oxbow lake was through low-energy horizontal sedimentation of a suspended load of silt. Occasional higher energy movement of sediment into the oxbow lake is also indicated by a few sharply curved bedding surfaces.

MATERIALS, METHODS, AND RESULTS

Small black organic fragments were discovered on numerous bedding planes during the course of a quantitative paleoecological sampling of the dark-gray siltstone layer undertaken as part of the author's doctoral dissertation (Cressler, 1999). Twelve small sampling quarries were excavated through the width of the dark-gray reduced siltstone layer within a 74 meter portion at its eastern end.

The black organic fragments were determined to be charcoal according to well-established criteria (Scott, 1989; Jones and Chaloner, 1991). The fragments are brittle, have a silky luster, and form sharply fractured cuboidal blocks with a length-to-diameter ratio of less than 2 (Fig. 3). They make a black streak when rubbed on paper. The most important identification criterion establishing these fragments as charcoal is that some have well-preserved anatomical structures with cells that show open lumina and homogenized cell walls (Fig. 4).

All of the charcoal fragments so far observed from Red Hill that exhibit this preserved cellular structure appear to be stem fragments of the zygopterid fern *Rhacophyton*, distinguished by scalariform pitting on their tracheids (Andrews and Phillips, 1968). Macrofossil evidence of *Rhacophyton* is also abundant within the sampled layer. The charcoal fragments are mostly from 1.0 to 1.5 cm in length or smaller, but are poorly sorted. They are interspersed between and among well-preserved plant and fish fossils on numerous bedding planes. Some bedding planes are densely covered with charcoal fragments and form distinct horizons. Dense accumulations of charcoal also occur on some bedding planes together with recognizable branches of unburned *Archaeopteris* (Fig. 3). Charcoal is also found together with well-preserved and unburned dichotomous branches and cupules of early gymnosperms on some bedding planes. In addition to *Archaeopteris*, *Rhacophyton*, and the earliest gymnosperms, the vegetation growing in this landscape included cormose lycopsids, the stauropterid fern *Gillespiea*, and barinophytes. Based largely on the excellent preservation of the plant fossils, and their burial in a low-energy depositional environment, the charcoal and associated plant fossils are interpreted as parautochthonous, having been transported over a short distance into the oxbow lake from along its shores and the immediately adjacent floodplain.

DISCUSSION

In the Late Devonian, north-central Pennsylvania was located within tropical latitudes (Scotese and McKerrow, 1990). Bambach et al. (1999) have proposed monsoonal circulation patterns for the tropics of North America and Europe at this time. Indeed, paleosols with vertic features in the Red Hill outcrop indicate a climate with alternating wet and dry seasons. The presence of charcoal indicates that the Late Devonian paleoatmospheric oxygen level was at least 13%, the lower limit for combustion (Cope and Chaloner, 1980; Chaloner, 1989). Oxygen in the atmosphere may have reached this level earlier in the Phanerozoic or even the Proterozoic, but the fuel source for combustion only may have reached a sufficient biomass by the Late Devonian in order for charcoal to be readily evident.

The primary source of ignition must have been lightning. At maximum heights of approximately 30 meters, *Archaeopteris* trees would have been the main attractors of lightning strikes. So far, no charcoal attributable to *Archaeopteris* has been found at Red Hill, and well-preserved *Archaeopteris* branches appear above and below all the charcoal horizons, indicating the persistence of the *Archaeopteris* forests despite the fires. Perhaps an open structure of the forests in combination with their deep roots prevented catastrophic fires from affecting the forest trees themselves. Some *Archaeopteris* certainly must have burned, but it appears from the preponderance of evidence at Red Hill that the fires were a phenomenon that primarily affected stands of *Rhacophyton*. *Rhacophyton* has been reconstructed as a shallow-rooted plant, and would have become desiccated during the dry seasons. They would then have become vulnerable to fire ignited by lightning strikes during storms that marked the onset of the wet season. Charcoal and unburned plant material littering the surrounding floodplain were then washed into the oxbow lake during subsequent flooding.

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FIGURE 1. Photomosaic and corresponding field sketch of portion of Red Hill outcrop, with arrows showing lateral contact between charcoal and plant-fossil bearing dark-gray siltstone layer and sandstone wedge.

FIGURE 2. Stratigraphic column of the Red Hill outcrop 15 m to the west of where the dark-gray siltstone layer bed pinches out.

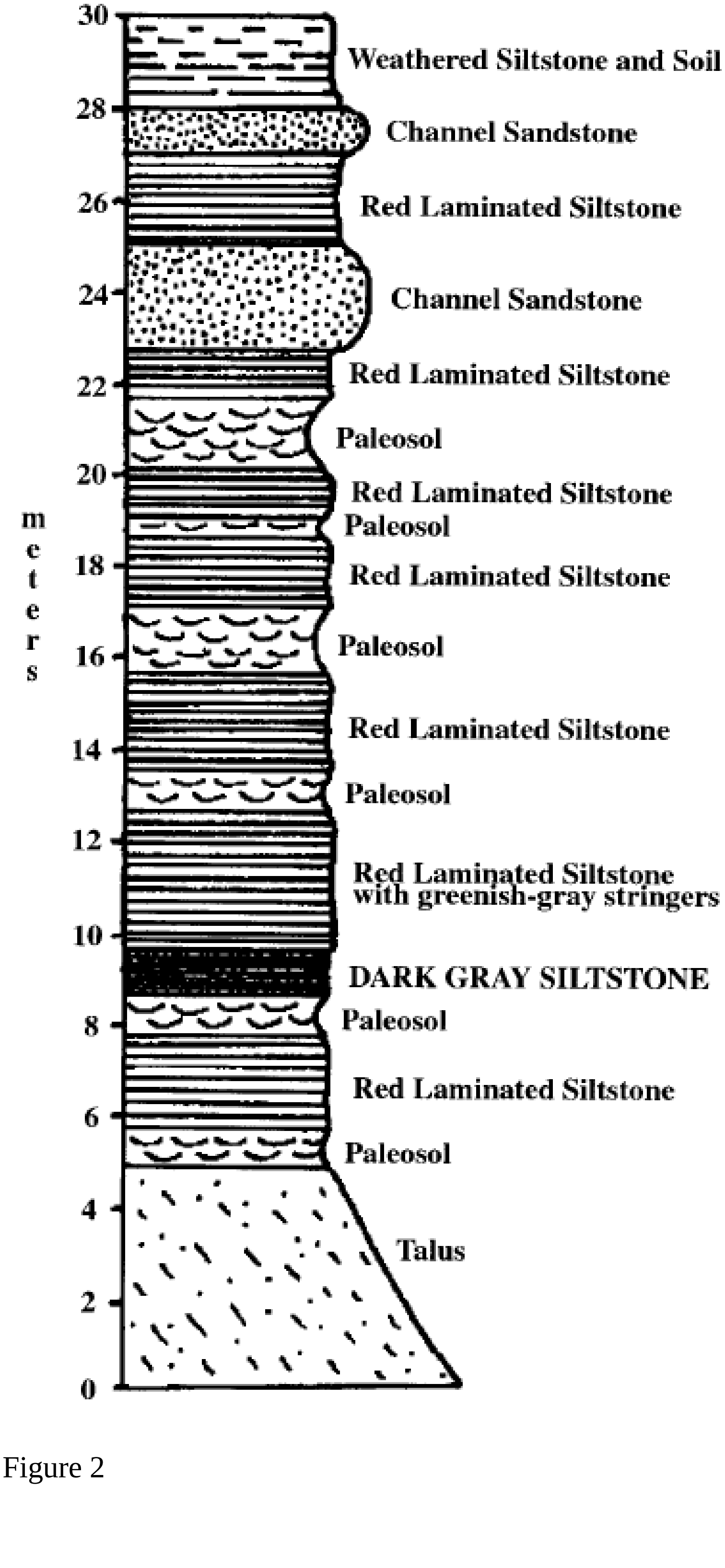
FIGURE 3. Hand specimen from Red Hill showing charcoal and unburned branch of *Archaeopteris* on the same bedding plane (scale bar in centimeters).

FIGURE 4. Scanning electron micrograph of Late Devonian charcoal showing homogenized cell walls and cellular structure of *Rhacophyton* (SEM image by G. Harrison).

ACKNOWLEDGEMENTS

The author thanks E. B. Daeschler, D. Rowe, N. Delaney, and F. Mullison for their Red Hill field collaboration. Thanks to S. E. Scheckler, H. W. Pfefferkorn, W. A. DiMichele, B. LePage, and P. Wilf for valuable paleobotanical guidance. Thanks also to C. E. Savrda and R. A. Gastaldo for improving the manuscript. Most of all, thanks to Claire Brill for her technical and emotional support. This work was supported by student grants from The Paleontological Society, the Geological Society of America, Sigma Xi, the Paleontological Research Institution, and a summer stipend from the Penn Summer Research Stipends in Paleontology instituted by an anonymous donor.

Figure 1



30
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Weathered Siltstone and Soil
Channel Sandstone
Red Laminated Siltstone
Channel Sandstone
Red Laminated Siltstone
Paleosol
Red Laminated Siltstone
Paleosol
Red Laminated Siltstone
Paleosol
Red Laminated Siltstone
Paleosol
Red Laminated Siltstone
with greenish-gray stringers
DARK GRAY SILTSTONE
Paleosol
Red Laminated Siltstone
Paleosol
Talus

Figure 2

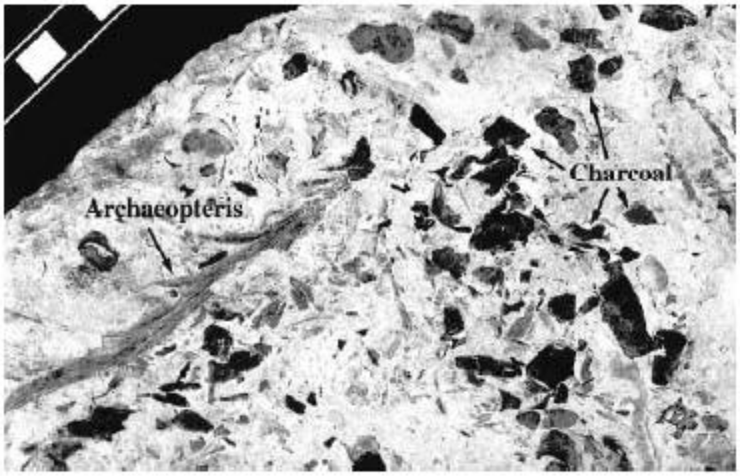

Figure 3

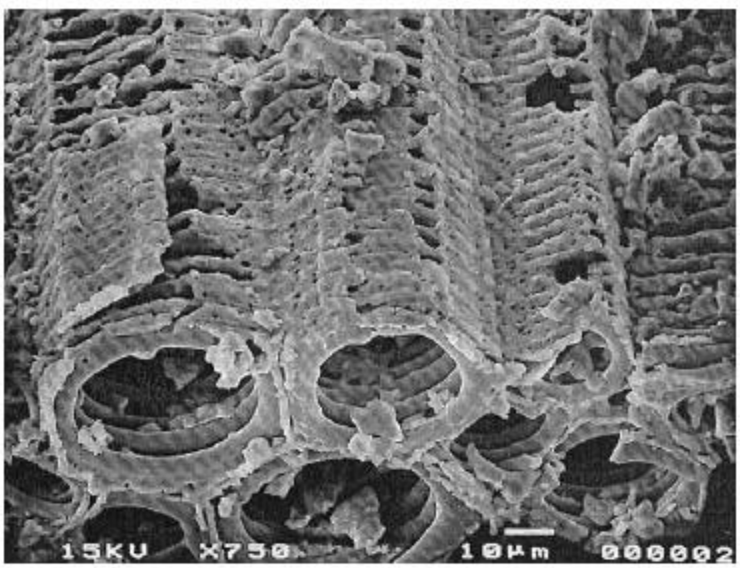

Figure 4