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Plant architecture and spatial structure of an early Permian woodland buried by flood waters, Sangre de Cristo Formation, New Mexico

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ABSTRACT

Natural molds of 165 stems were found in life position in a 1 m-thick sandstone bed, lower Permian (Wolfcampian), Sangre de Cristo Formation, northern New Mexico. The sandstone represents a single flood event of a river sourced in the Ancestral Rocky Mountains. Most of the flood-buried plants survived and resumed growth. The stem affinities are uncertain, but they resemble coniferophytic gymnosperms, possibly dicranophylls. Stem diameters ($N = 135$) vary from 1 to 21 cm, with three strongly overlapping size classes. Modern forest studies predict a monotonically decreasing number (inverse square law) of individuals per size class as diameter increases. This is not seen for fossil stems ≤6 cm diameter, reflecting biases against preservation, exposure, and observation of smaller individuals. Stems ≥6 cm diameter obey the predicted inverse square law of diameter distribution. Height estimates calculated from diameter-to-height relationships of modern gymnosperms yielded heights varying from ~0.9 m to >8 m, mean of ~3 m. Mean stand density is approximately 2 stems/m^2 (20,000 stems/hectare) for all stems >1 cm diameter. For stems >7.5 cm or >10 cm diameter, density is approximately 0.24 stems/m^2 (2400 stems/hectare) and 0.14 stems/m^2 (1400 stems/hectare). Stem spatial distribution is random (Poisson). Mean all-stem nearest-neighbor distance (NND) averages 36 cm. Mean NND between stems >7.5 cm and >10 cm diameter is approximately 1.02 m and 1.36 m. NND increases in approximate isometry with stem diameter, indicating conformation to the same spatial packing rules found in extant forests and other fossil forests of varying ages. Nearest-neighbor distance distribution passes statistical testing for normality, but with positive skew, as often seen in extant NND distributions. The size-frequency distribution of the stems is similar to those of Jurassic, early Tertiary, and extant woodlands; the early Permian woodland distribution line has the same slope, but differs in that the overall size range increases over time (Cope's rule). The early Permian woodland is self-thinning; its volume versus density relationship shows a self-thinning exponent between −1.25 and −1.5, within the range seen in some extant plant stands (−1.21 to −1.7).

1. Introduction

In situ fossil vegetation provides a direct record of spatial patterns, a class of information that is central to a modern ecological understanding of landscape dynamics (e.g., Legendre and Fortin, 1989; Turner et al., 2001; West et al., 2009). Such fossil assemblages provide a means to study the dynamic aspects of ancient ecosystems, systems that may differ from those of today in such critical ways as species diversity (e.g., Enquist et al., 2007) or the diversity of functional groups (e.g., DiMichele and Phillips, 1996). Preservation of standing vegetation in the fossil record is rare, even more so assemblages that are spatially extensive or have not undergone significant partial deterioration of the least resistant elements. Nonetheless, there are a considerable number of reports of buried upright stems, and these tend to be concentrated in those strata that also are widely exposed by economic activities, such as mining, leading to a somewhat biased distribution in time and space (see Paleozoic summary in DiMichele and Falcon-Lang, 2011). The most desirable of these assemblages for pattern analysis, and its extension thereby to dynamics through the intermediary of ecological theory, are those in which evidence may be adduced for rapid burial of the living stand of plants; the best examples of such cases are ash fall deposits (e.g., Wing et al., 1993; Pfefferkorn and Wang, 2007; Opluštil et al., 2009; Wang et al., 2012), although rapid burial in floods, landslides, or mass movements also can provide an effectively instantaneous record of the spatial organization of original vegetation.

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In this paper, we describe 165 fossil stems from the lower Permian (Wolfcampian) interval of the Sangre de Cristo Formation of northern New Mexico (Fig. 1), representing part of a partially buried woodland (Figs. 2–9). We analyze this rare Paleozoic plant stand in terms of its dynamics and ecology, and compare it to younger, Mesozoic and Tertiary "forests" as well as to modern analogues.

2. Materials

2.1. Location, stratigraphy, depositional environment

The fossil vegetation on which this study is based is located in two Bureau of Land Management (BLM) flagstone quarries southwest of San Miguel, New Mexico. The larger of these (Figs. 2A dots on left, 2B–C, 3A), the main, or southeast, quarry, contains the majority of the stem specimens. It is designated New Mexico Museum of Natural History and Science (NMMNH) locality 9082 (National Museum of Natural History locality USNM 43827). Seventeen upright stems of similar character to those at NMMNH locality 9082 also were preserved at an additional quarry, to the northwest of the main quarry (USNM 43829) (Figs. 2A dots on right, 4A). Comparison of the stratigraphic sections at the two sites constrains the fossiliferous beds to the same stratigraphic level, but there is a covered interval between the two quarries. Above both quarries, however, is a distinctive coarse-grained, cross-bedded sandstone containing quartz and feldspar granules that forms a continuous ledge between the two localities. Within the northwest quarry there was evidence of more than one episode of burial, possibly of two plant stands representing successive episodes of colonization of the site following disturbance (Fig. 4).

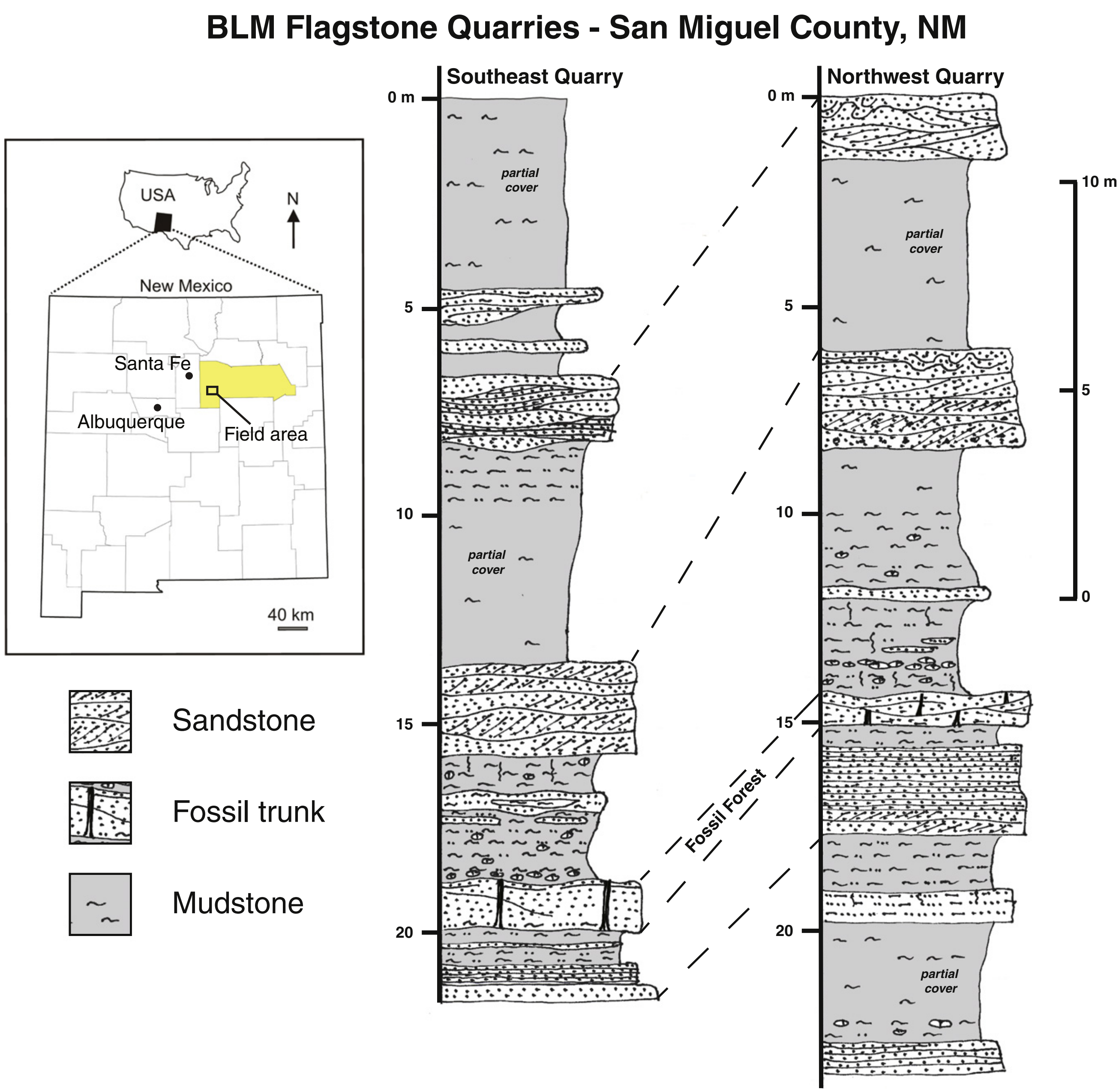

Fig. 1. Sangre de Cristo Formation. Left-to-right: Index map of New Mexico showing the location of the BLM flagstone quarries. Stratigraphic section in the area of the main, Southeast Quarry. Stratigraphic section in the area of the smaller Northwest Quarry. The position of the stem-bearing sandstone beds is noted. The sandstone beds above and below the stem-bearing sandstone interval have been physically correlated between the two exposures.