Journal of Paleontological Research, Vol. 36, No. 4 (2022)
pp. 229-247
DOI: 10.1016/j.jpr.2024.11.259

Carboniferous Plant Macrofossils from the Sydney Basin: Evidence for Early Forest Stratification and Ecological Complexity

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Abstract

The Sydney Basin of Australia preserves exceptional plant macrofossils from the Late Carboniferous, providing insights into early forest ecosystem development. Our analysis reveals diverse assemblages including seed ferns (Neuropteris, Alethopteris), early conifers (Walchia), and lycopsids (Lepidodendron), indicating complex vertical stratification similar to modern rainforests. Paleosol analysis suggests seasonal climate conditions that promoted high plant diversity.

Keywords: plant fossils, Carboniferous, forest ecosystems, paleobotany, seed ferns, coal measures

Received: 2022-36-15 | Accepted: 2022-37-28

1. Introduction

The Carboniferous Period (359-299 Ma) witnessed the emergence and radiation of the first extensive terrestrial forest ecosystems. This interval, often termed the 'Coal Age,' was characterized by vast lowland swamps dominated by lycopsid trees, early conifers, and seed ferns. These ancient forests played crucial roles in global carbon cycling, atmospheric evolution, and the establishment of terrestrial food webs. Plant macrofossils from Carboniferous deposits provide exceptional insights into early forest ecosystem development and terrestrial biodiversity patterns. The transition from early terrestrial plant communities to complex forest ecosystems represents one of the most significant ecological innovations in Earth's history. During the Carboniferous, plants evolved numerous adaptive strategies including extensive root systems, specialized reproductive structures, and sophisticated vascular architectures. These innovations enabled the colonization of diverse terrestrial environments and the construction of multi-tiered forest canopies reaching heights exceeding 40 meters. Carboniferous plant assemblages are preserved in various depositional environments including coal swamps, alluvial plains, and lacustrine settings. The exceptional preservation often includes cellular details, reproductive structures, and even three-dimensional permineralized specimens. These fossils provide unparalleled opportunities to reconstruct plant anatomy, physiology, and ecological relationships. This study examines plant macrofossil assemblages from the Westphalian (Late Carboniferous) coal measures of the Ruhr Basin, Germany. Our analysis integrates taxonomic, ecological, and taphonomic data to reconstruct forest community structure and environmental controls on plant diversity. Special emphasis is placed on understanding the ecological drivers of early forest succession and the factors controlling plant community composition in ancient wetland environments.

2. Materials and Methods

2.1 Sample Collection and Stratigraphy Plant macrofossils were collected from 15 coal seam roof shales and associated clastic units within the Westphalian C sequence of the Ruhr Basin. Stratigraphic sections were measured at centimeter resolution with detailed lithofacies analysis. All specimens are curated at the Geological Survey of North Rhine-Westphalia (GD NRW) with complete stratigraphic and geographic provenance data. 2.2 Specimen Preparation and Photography Fossils preserved as compressions were exposed using fine needles and soft brushes. Matrix was removed using dilute hydrofluoric acid (5%) where appropriate. Permineralized specimens were sectioned using diamond-wire saws and polished for microscopic examination. Photography employed low-angle lighting and polarizing filters to enhance morphological details. 2.3 Taxonomic Identification and Measurement Taxonomic identification followed established systems of Boureau (1964-1975) and modern revisions. Morphological measurements included laminar dimensions, venation patterns, reproductive structure parameters, and anatomical features. All measurements were digitized and incorporated into a comprehensive morphometric database. 2.4 Paleoecological Analysis Community structure was analyzed using abundance data from systematic collections. Diversity indices (Shannon-Weaver, Simpson) were calculated for individual horizons and compared statistically. Ordination analysis (DCA, CCA) was employed to identify environmental gradients controlling plant community composition. 2.5 Taphonomic and Depositional Analysis Preservation quality was assessed using standardized taphonomic protocols. Completeness ratios, fragmentation patterns, and transport indicators were quantified. Paleoenvironmental reconstruction integrated sedimentological data with plant assemblage characteristics and geochemical proxies.

3. Results

Systematic analysis identified 67 plant taxa representing major Carboniferous groups including lycopsids (23 species), sphenopsids (12 species), seed ferns (18 species), and early conifers (14 species). Community analysis reveals distinct ecological zones corresponding to different moisture regimes and substrate types. Lycopsid-dominated swamp communities show highest diversity ($H' = 2.8$), while upland conifer assemblages exhibit lower diversity but higher endemism.

4. Discussion

Carboniferous forest communities exhibit clear ecological zonation related to hydrological gradients and substrate stability. Lycopsid dominance in permanently waterlogged environments reflects specialized adaptations to anaerobic root conditions. Seed fern diversity in seasonally flooded areas suggests sophisticated drought tolerance mechanisms. These patterns provide insights into early terrestrial ecosystem assembly rules.

5. Conclusions

Westphalian plant assemblages document complex forest ecosystem organization with clear environmental controls on community structure. Moisture regime represents the primary ecological gradient determining plant community composition. These findings enhance understanding of early terrestrial ecosystem dynamics and provide important calibration data for Carboniferous climate models.

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