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Tree-ring analysis elucidating palaeo-environmental effects captured in an in situ fossil forest – The last 80 years within an early Permian ecosystem

Ludwig Luthardt[a,b,*], Ronny Rößler[a,b], Jörg W. Schneider[b,c]

[a] Museum für Naturkunde Chemnitz, Moritzstraße 20, D-09111 Chemnitz, Germany
[b] Geological Institute, Technische Universität Bergakademie Freiberg, Bernhard-von-Cotta-Straße 2, D-09599 Freiberg, Germany
[c] Kazan Federal University, 18 Kremlevskaya Str., Kazan 420008, Russian Federation

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ABSTRACT

The early Permian Chemnitz Fossil Lagerstätte (Leukersdorf Formation, Chemnitz Basin, SE Germany) represents a diverse T^0 assemblage of a fossil forest ecosystem around the Sakmarian-Artinskian transition (290.6 ± 1.8 Ma), which was preserved by pyroclastic deposits of a multi-phased volcanic eruption. The multi-aged plant community consists of predominantly hygrophilous elements, which grew on an alluvial plain mineral substrate under sub-humid conditions, representing a wet spot environment. Strong seasonality triggered the formation of annual tree rings in arborescent woody plants, such as pycnoxylic gymnosperms, medullosan seed ferns and calamitaleans. From several hundred fossil trees, the 53 best-preserved specimens were selected and investigated in detail by measuring 2,081 tree rings in individual sequences of up to 77 rings. Ring sequences were analysed by standard dendrochronological methods to determine both annual growth rates and mean sensitivity. Morphological and statistical analyses on single tree rings reveal different tree-ring types according to the different plant groups. Pycnoxylic gymnosperms have distinct and regular tree rings, whereas medullosan seed ferns and calamitaleans show indistinct and regular tree rings as well as so called event rings.

Results reveal differences between plant groups regarding their physiological reactions or adaptations to seasonal fluctuations. In comparison to pycnoxylic gymnosperms, both medullosan seed ferns and calamitaleans exhibit reduced growth rates and more sensitive reaction to environmental perturbances as water deficiency pointing to comparably lower adaptation to seasonally dry palaeoclimate. In this context, event rings are in many cases traced back to plant physiological stress during particularly severe drought periods. Altogether, these fossil trees serve as sensitive environmental archives, which shed light on growth conditions several decades back in time from the entombing eruption.

1. Introduction

Ancient in situ terrestrial ecosystems are rarely preserved in the geological record. They provide information on composition of life communities and palaeoecological processes such as organism interactions and metabolic processes (DiMichele and Falcon-Lang, 2011; Césari et al., 2012; Wang et al., 2012; Opluštil et al., 2014). Moreover, fossil ecosystems reflect their surrounding environment responding to palaeoclimate and its variations through time (Montañez et al., 2016).

Trees represent a natural data storage system, which records the biological reactions of living organisms to changes in their environment (Creber, 1977). Consequently, tree-ring analysis has become established as an important method in forestry, chronology and climatology (Schweingruber, 1996; D'Arrigo et al., 2006; Esper et al., 2012; Mbow et al., 2013; Schollän et al., 2015). In modern forest ecosystems, these methods are applicable in many varying climatic regions of the world, ranging from the cold temperate zones to warm tropical regions (Falcon-Lang, 2005a). The formation of tree rings in individuals is often seasonally driven and influenced by both external factors such as local light and water conditions, competition pressure, underground morphology or catastrophic events, and internal factors such as genetic ability to form tree rings, ontogenetic development or inherited physiological adaptations (Creber and Chaloner, 1984; Chapman, 1994; Schweingruber, 1996; Schweingruber et al., 2006). Both internal and external factors influence growth of plants likewise and superimpose higher-ranked climatic signals. The distinction between different factors is one of the major limitations in both dendrochronology and dendroecology (Schweingruber, 1996).

Annual tree-ring formation has been questioned in tropical systems for a long time. However, this phenomenon was demonstrated in

* Corresponding author at: Museum für Naturkunde Chemnitz, Moritzstraße 20, D-09111 Chemnitz, Germany.
E-mail address: luthardt@mailserver.tu-freiberg.de (L. Luthardt).

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