Palaeogeography, Palaeoclimatology, Palaeoecology 441 (2016) 627–652

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Palaeoclimatic and site-specific conditions in the early Permian fossil forest of Chemnitz—Sedimentological, geochemical and palaeobotanical evidence

Ludwig Luthardt [a,*], Ronny Rößler [a], Joerg 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

ARTICLE INFO

Article history:
Received 5 August 2015
Received in revised form 13 October 2015
Accepted 15 October 2015
Available online 26 October 2015

Keywords:
Fossil forest
T^0 assemblage
Palaeosol
Root systems
Seasonality
Precipitation

ABSTRACT

As significant indicators of deep-time palaeoclimate, a number of new palaeontological, pedological and geochemical characteristics are provided for the Chemnitz Fossil Lagerstätte to depict more precisely its environmental conditions. For the first time, several lines of evidence indicate that this fossil forest, instantaneously preserved by volcanic deposits, once received an annual precipitation of around 800–1100 mm, but grew on a nearly unweathered palaeosol. Although the composition of this rich and diverse T^0 assemblage suggests a hygrophilous, dense and multi-aged vegetation dominated by conservative lineages, the habitat was affected by environmental disturbances and pronounced seasonality. Repeated changes in local moisture availability are suggested by geochemical proxies, the co-occurrence to intergrowth of calcic and ferric glaebules in the palaeosol and developmental traits of perennial vegetational elements. Specific substrate adaptation is reflected by different root systems and cyclic growth interruptions recorded in the stems, branches and roots of long-lived woody plants. Many differentially adapted terrestrial animals complete the more comprehensive reconstruction of a late Sakmarian ecosystem and its climatic and preservational controls. Albeit spatially confined, this diverse *in-situ* record may contribute to understand wetland–dryland dynamics of sub-tropical Northern Hemisphere Pangaea.

1. Introduction

The most important witness of how ancient ecosystems react to climatic and environmental changes lies in the geological record. Of overall significance in this regard are fossil forests, especially if they represent *in-situ* records that reflect not only plant remains but also diverse animals, interactions between organisms and environmental characteristics. However, significant examples of such instantaneously preserved ecosystems are rare in the late Palaeozoic. Nevertheless, if thoroughly studied and understood they can provide a detailed picture of ancient living communities in the continental realm, and offer a high potential for understanding palaeoecological relationships (Césari et al., 2012; Gastaldo et al., 2004; Hinz et al., 2010; Opluštil et al., 2014; Wang et al., 2012). An ideal example with both a long study history (Cotta, 1832; Frenzel, 1759; Sterzel, 1875) and multi-focus ongoing research (Dietrich et al., 2013; Dunlop and Rößler, 2013; Feng et al., 2012; Matysová et al., 2010; Rößler et al., 2012a,b) is the Petrified Forest of Chemnitz. It represents an early Permian (latest Sakmarian) forest ecosystem developed on a distal braidplain and buried instantaneously by the deposition of volcanic ashes and flows. The rapid coverage by pyroclastics, due to a series of explosive volcanic eruptions, led to a three-dimensional record of the forest in growth position including its palaeosol, which classifies it as an outstanding T^0 assemblage (compare characteristics given in DiMichele and Falcon-Lang, 2011).

Historically, this fossil Lagerstätte has been well known since at least the early 18th century, due to prospecting activities for precious minerals. Although there exist some scientific descriptions from that time (Frenzel, 1759), the major motivation for collecting petrifactions was the utilisation as gemstones. The interest in its palaeobotanical significance has risen since the 19th century and continues today (e.g., Barthel, 1976; Cotta, 1832; Rößler, 2000, 2006; Sterzel, 1904). However, for a long time scientific descriptions were based on coincidental finds only, which occurred during construction works in the city of Chemnitz. On the basis of such material, research on specific fern or calamitean taxa has been carried out (Feng et al., 2012; Rößler, 2000; Rößler and Galtier, 2002a, b; Rößler and Noll, 2006, 2007, 2010). Additionally, during the last two decades geological research improved the general understanding of the basin development, its facies architecture, stratigraphic subdivision and interregional correlation (Eulenberger et al., 1995; Fischer, 1991; Schneider et al., 2012).

* Corresponding author.
E-mail addresses: luthardt@mailserver.tu-freiberg.de (L. Luthardt), roessler@naturkunde-chemnitz.de (R. Rößler), schneidj@geo.tu-freiberg.de (J.W. Schneider).

http://dx.doi.org/10.1016/j.palaeo.2015.10.015
0031-0182/

Between 2008 and 2011, a scientific excavation site at Chemnitz–Hilbersdorf delivered for the first time a more complete insight into a local taphocoenosis of this fossil forest. During this excavation, a vast amount of data was gathered offering potential for a detailed, albeit spatially confined, reconstruction of this ancient forest habitat (Kretzschmar et al., 2008; Rößler et al., 2008, 2009, 2010, 2012b). The fossil record comprises a comprehensive spectrum of plant and animal remains, more complete than ever documented before. Fifty-three upright-standing petrified trees, still anchored in the original substrate, were discovered together with a variety of parautochthonously embedded stems and twigs. A countless number of leaf adpressions and moulds were found preserved in one single horizon next to various arthropod remains or reptile and amphibian skeletons exhibiting even their former body outlines (Dunlop and Rößler, 2013; Feng et al., 2014; Rößler et al., 2012b).

Within a distance of approximately 2 km from the aforementioned locality, a second excavation site in Chemnitz–Sonnenberg was initiated in 2009 and finally set up in 2014 (Rößler and Merbitz, 2009). We aim to continue this excavation during the next years to verify the knowledge about the fossil forest ecosystem, especially regarding plant and animal diversity and spatial distribution, variation of site-specific environmental characteristics within a wider area and taphonomic differences correlated with different distances from the volcano.

Other late Palaeozoic T^0 assemblages, which show similar volcanic preservational backgrounds comprise peat-forming wetland communities that flourished in the Pennsylvanian palaeoequatorial tropics, in basinal settings, obviously under long-term stable environmental and climatic conditions (Opluštil et al., 2007, 2009). However, there is a growing awareness of ice-age-caused repetitive climatic oscillations resulting in seasonal dryness and floral change even in equatorial Pangaea (DiMichele, 2014; DiMichele and Phillips, 1996; Falcon-Lang et al., 2009; Montañez and Poulsen, 2013; Pfefferkorn et al., 2008; Roscher and Schneider, 2006). In Cathaysia, conditions maintaining extended peat-forming communities, continued into to the Permian (Wang et al., 2012). On the contrary, early Permian ecosystems in Euramerica and northern Gondwana were increasingly forced by environmental and ecological dynamics (Capretz and Rohn, 2013; DiMichele et al., 2006, 2007, 2011; Galtier and Broutin, 2008; Kerp, 1996; Looy et al., 2014; Ricardi-Branco, 2008; Rößler, 2006; Tabor and Poulsen, 2008), which are documented by changing plant communities and their migration routes, changes in dominance patterns of sedimentary facies and palaeosols at different spatial and temporal scales.

In Chemnitz we have a wetland flora on mineral soil that was captured in a red-bed environment, which is commonly occupied by mesophilous to xerophilious plants (Schneider et al., 2012). This spatially restricted fossil Lagerstätte is ecologically far from the widely distributed peat-forming swamps that are most frequently documented from the Middle Pennsylvanian to the earliest Permian (e.g., DiMichele et al., 2002; Greb et al., 2003; Opluštil et al., 2009; Wagner, 1989; Wang et al., 2012). On the other hand, it has little in common with the typical extrabasinal or upland occurrences (Cridland and Morris, 1963; Falcon-Lang and Bashforth, 2004; Kerp, 1996; Pfefferkorn, 1980). This still inadequately understood occurrence of plants that usually characterise conservative peat-forming communities, show an overall absence of typical extrabasinal elements.

In order to clarify these contradictions and improve the palaeoecological model of this site we carried out additional investigations and analyses focusing on both palaeontology and geochemistry. We tried to exclude, as much as possible, any taphonomic effects that resulted from the volcanic type of entombment, which sometimes modified the preservation of fossil material. This contribution provides new results that enable us to interpret abiotic and biotic influences on the environment and to recognise some variation at the habitat spatial scale. The general aim to reconstruct this ecosystem can only be achieved by the combination of different perspectives. These include the understanding of taphonomic influences during the emplacement of pyroclastics, palaeobotanical investigations focusing on the three-dimensionally preserved plants, the appreciation of various interactions between individual organisms in the habitat, as well as local environmental constraints related to superordinated palaeoclimatic conditions. To restrain the scope of this contribution particular attention was paid to largely independent lines of evidence, which were traced by means of (1) geochemical proxies of the sedimentary basement, (2) pedogenetic features of the palaeosol, (3) the morphology, anatomy and community structure of floral elements, (4) diverse invertebrate and vertebrate animals and their mutual habitat preferences, and (5) interactions between plants, animals and microorganisms. We aim to integrate data derived from these individual lines of research in order to develop a better understanding and a more appropriate reconstruction of the whole ecosystem. This integrated approach will permit us to use this spatially constrained ecological study to understand aspects of the depositional system on a basin-wide scale, given that any small-scale site, although reflective of local conditions, also will bear a strong overprint from regional climate and sedimentary conditions.

2. Geological setting

The Petrified Forest is located in the town Chemnitz (Saxony, SE-Germany), situated in the eastern part of the early Permian Chemnitz Basin (Fig. 1A). The basin is bordered by the Granulite Massif in the North and the Erzgebirge Mountains in the South. It overlies different Carboniferous coal-bearing basin structures and metamorphic units of the Variscan basement and shows an extension of 70 × 30 km in SW–NE orientation. The basin fill consists of continental red beds and intercalated pyroclastics of early Permian (Asselian to Artinskian) and middle to late Permian (Capitanian to Wuchiapingian) age. These are overlain by late Permian (Wuchiapingian to Lopingian) marine and sabhka deposits of Zechstein Sea transgressions, as well as lowermost Triassic deposits (Legler and Schneider, 2008; Schneider et al., 2012). Up to six sedimentary megacycles can be distinguished in the continental deposits of the Chemnitz Basin, which are grouped into four formations (Fig. 2), exhibiting an overall thickness of approximately 1550 m.

2.1. Leukersdorf Formation

Representing an 800 m thick red-bed sequence of predominantly alluvial origin, the Leukersdorf Formation is characterised by three fining-up mesocycles, which are, in case of the first cycle completed by the 25 m thick lacustrine–palustrine grey sediments of the Rottluff Horizon, restricted to the eastern part of the basin, as well as by the basin-wide lacustrine Reinsdorf Carbonate Horizon (Fig. 2). There are some major pyroclastic marker horizons, e.g., the Chemnitz Tuff in the first cycle and in the third cycle the Zeisigwald Tuff, hosting the Chemnitz Fossil Forest. The dominant lithofacies type is fine-grained alluvial red beds, which interfinger with coarse clastics of semi-arid type alluvial fans from the basin margins. The ichnofauna of these “wet” red beds is dominated, and in contrast to the dry-playa red beds, characterised by infaunal burrows of the *Scoyenia* and *Planolites montanus* types (Schneider et al., 2012). Frequently, rhizolith-bearing, less mature vertic to calcic palaeosols occur, which are further diagnostic features of wet red beds (Schneider et al., 2010) The sparse floral record is restricted to minor relicts of meso- to xerophilous plants (“walchians”) typical for this kind of late Pennsylvanian to early Permian red beds.

The Reinsdorf Carbonate Horizon consists of one to five 0.30–0.50 m thick carbonate layers having a nearly basin-wide extent. The individual carbonate layers are intercalated with red-coloured fine clastics and coarse fluvial channel and sheetflood deposits of a braidplain system. The carbonates predominantly appear as homogenous micrites. In the urban area of Chemnitz they are described as laminated microbial-mat limestones and massive or partly finely laminated dolosparites, which frequently bear intraclasts and bioclasts. The microfaunal assemblage is quite diverse encompassing common gastropods and ostracods as