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The Presence of Callipterids in the Permian of Northeastern Brazil: Stratigraphic and Phytogeographical Implications

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Abstract This is the first record of callipterids, *sensu stricto*, in South America, Western Gondwana. Previously, they were known only from the palaeoequatorial belt, including the Euroamerican (North America and Europe), northernmost African, and Cathaysian (northern China, Southeast Asia, and the Malay Archipelago) regions, or from north of Pangaea (Siberia), during the latest Carboniferous–late Permian interval. In the present study, fossils were collected from sediments from the middle–upper Pedra de Fogo Formation, part of the Permian of the Parnaíba Basin in eastern Maranhão State, northeastern Brazil. The material recovered can be attributed to the callipterid genus *Rhachiphyllum*, and specifically to the species *Rhachiphyllum schenkii* (Heyer) Kerp. In addition, we found an *Autunia*-like fructification, corroborating a peltasperm affinity. The presence of *R. schenkii* could be indicative of an early Permian age for the Pedra de Fogo Formation since this species has a short and well-determined stratigraphic range in Europe. Palaeogeographically, the above-mentioned species found in association with fern genus *Pecopteris* suggests a migration corridor running from central Europe and northern South America during Permian times.

Keywords Callipterids · Permian · Western Gondwana · Pedra de Fogo Formation · Northeastern Brazil

As part of the research project entitled “Permo–Triassic vertebrates from Paraná and Parnaíba basins: phylogeny and stratigraphic correlations”, financed by the Foundation for Research Support of the São Paulo State (FAPESP), fieldwork was

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conducted prospecting for and collecting fossils from sediments of the Pedra de Fogo Formation, part of the Permian of the Basin of Parnaíba, in the eastern part of Maranhão State. We visited several localities in the counties of Pastos Bons, Nova Iorque, São Domingos do Azeitão, and Benedito Leite, searching for macrofossils (vertebrates, invertebrates, and plants). At a locality informally named “Costela” in the municipality of New York, fronds were collected in a silty mudstone lens, found beneath a thick bed of limestone. These fronds are attributable to the group of peltasperm callipterids and to pteridophytes, both preserved as impressions. The fern fronds were classified into the morphogenus *Pecopteris* (Brongn.) Sternb., based on their digitiform pinnules with pinnate venation, whereas the peltasperm fronds could be included in *Rhachiphyllum* Kerp, a callipterid morphogenus characterized by the occurrence of intercalary and pinnatifid pinnules showing alethopteroid venation (Kerp 1988). Besides the sterile fronds, fragments of reproductive structures were also found, similar to *Autunia* Krasser emend. Kerp, and which definitively confirm the presence of the callipterid group in this association. The sterile specimens closely resemble those classified as the species *Rhachiphyllum schenkii* (Heyer) Kerp, which is also found in association with pecopterid ferns in the *Pecopteris* Horizon from the Nahe Group of the Saar-Nahe Basin, in the lower Permian of Germany (Kerp 1988).

Stratigraphically, the callipterid and fern fronds are positioned in the middle member of the Pedra de Fogo Formation, according to Faria Jr. and Truckenbrodt (1980), who established the regional stratigraphic framework for this unit. The age of the Pedra de Fogo Formation has been a subject of disagreement in recent years. Initially, the palynological content was considered as indicative of an early Permian age (Petri and Fulfaro 1983). However, a recent analysis dated the upper part of the unit as late Permian (Dino et al. 2002). Controversial ages have come from the vertebrate studies. The temnospondyli arqueosaurid *Prionosuchus plummeri* (Price 1948) was considered as evidence for a Cisuralian age (Petri and Fulfaro 1983), though more recently, Cox and Hutchinson (1991) interpreted that its very long snout would be more typical of the Lopingian (late Permian). Plant fossils from the overlying Motuca Formation can be also useful in the discussion on the ages of these units. The genus *Grammatopteris*, recently reported at the base of the Motuca Formation, has been found registered only in the earliest Cisuralian of Germany and France (Rößler and Galtier 2002). *Tietea*, the most abundant plant genus in the Parnaíba Basin, is a taxon established in the Paraná Basin and typically found in the Corumbataí and Teresina formations, dated to the earliest of the Guadalupian (Tavares and Rohn 2009). However, recently, the genus has been found as fossil logs in the reworked “Facies Ibicatu” of the Formation Tatuí in the Paraná Basin (Chahud and Petri 2009), the age of which must be Cisuralian (early Permian).

The species *R. schenkii* (Heyer) Kerp has been assigned in central Europe to the Moscovian (late Carboniferous) to Rotliegendes (early Permian) interval (Kerp 1988). Taking into account the above-mentioned probable fossil ages, the presence of this species is suggestive of an earliest Cisuralian age for the upper third of the Pedra de Fogo Formation.

This record corresponds to the first evidence of callipterids *sensu stricto* in South America, previously known only from the palaeoequatorial belt, including the Euroamerican (North America and Europe), northernmost African, and Cathaysian (northern China, Southeast Asia, and the Malay Archipelago) regions, or from northern Pangaea (Siberia), during the latest Carboniferous–late Permian interval (Booi et al. 2009). Palaeogeographically, even situated in tropical palaeolatitudes, the occurrence of peltasperms, represented by callipterids, in northeastern Brazil is the southernmost record in Gondwana of this group. This is of great palaeobiogeographical importance, because these are considered to be closely related to *Corytospermales*, a group that dominated the Gondwana Flora *Dicroidium* during the Triassic (Hamad et al. 2008).

Finally, the presence of *R. schenkii* (Heyer) Kerp found in association with the fern genus *Pecopteris* suggests a migration corridor running from central Europe and northern South America during earliest Permian times, as a similar association is present in the *Pecopteris* Horizon from the Nahe Group of the Saar-Nahe Basin (Kerp 1988). Traditionally, northeastern Brazil is regarded as having been located in a semiarid subtropical belt distributed along the northern part of Western Gondwana (Rees et al. 2002), notably based on the record of carbonates in the Permian Pedra de Fogo Formation. The occurrence of similar climatic conditions between northeastern South America and western tropical Pangaea (North America and Europe) throughout the late Carboniferous–early Permian interval (Montañez et al. 2007) could be the best explanation to understand the geographical distribution of *R. schenkii* (Heyer) Kerp. In conclusion, this species was probably adapted to these semiarid (seasonally dry) climates since the latest Carboniferous, which enabled its expansion/migration to the distant terrains of northeastern South America.

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