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Charcoalified *Agathoxylon*-type wood with preserved secondary phloem from the lower Permian of the Brazilian Parana Basin

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ABSTRACT

For the first time, secondary phloem tissue of *Agathoxylon* Hartig (sensu Rößler et al. 2014) is described from Permian charcoalified wood remains. Large (up to 13.4 × 21.8 cm), highly compressed, charred logs and branches were collected from the lower and upper boundaries of a tonstein bed (U/Pb age 291 ± 1.3 Ma) interlayered in a Sakmarian coal seam in the Faxinal Coalfield, Rio Grande do Sul, Brazil (Rio Bonito Formation). Small pieces were sampled with a dissecting knife and needles, mounted on standard stubs, gold-coated, and photographed under a scanning electron microscope. The phloem tissue is composed of thin-walled sieve cells, thick-walled fibers, and axial and radial uniseriate parenchyma. The extraordinary preservation shows sieve cells with pores grouped in conspicuous sieve areas occurring on lateral cell walls. Sieve cells are inferred to be arranged in tangential layers alternating with mixed rows of fibers and scarce parenchyma. Conclusions are drawn about preservation conditions involving cyclic environmental dryness and possible affinities with pteridosperms and cordaitaleans.

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1. Introduction

Land plants underwent a rapid diversification after the emergence of conductive tissue approximately 400 million years ago (Niklas, 1997), and the knowledge of the evolution of the vascular tissue through geologic time comes predominantly from secondary xylem (Taylor, 1990). Even though bifacial vascular cambium yielding both secondary xylem and secondary phloem is already present in the Devonian (Raven and Andrews, 2010), for a long time, contributions to phloem phylogeny were mainly based on inferences from extant groups due to its rarity in the fossil record (Van Bel, 1999).

The preservation of phloem tissue is influenced by its generally insubstantial production by the cambium, the thin-walled structure of the conducting cells, and physical instability on account of the functional hydrostatic pressure to which they are subjected, favoring the collapse of the sieve cells following damage (Esau et al., 1953; Smoot and Taylor, 1978; Taylor, 1990; Beck, 2005). Furthermore, Paleozoic stems are in most cases decorticated, precluding secondary phloem observation (Decombeix et al., 2014).

The charcoalification process can potentially preserve most cellular structures three-dimensionally (Lupia, 1995), but the resultant material is brittle and susceptible to breakage from transport and compression; additionally, the fire temperature can either preserve or destroy delicate tissues (Scott, 2010). According to Hather (2000), during a wildfire, the phloem tissue can deteriorate or solidify, generating a formless mass of glassy charred tissue. However, good preservation occurs if the plant tissues have been slowly dried prior to charring. Specific environmental conditions are thus required to yield informative charcoalified plant material.

The present study documents the occurrence of charcoalified *Agathoxylon*-type wood and describes the organically associated secondary phloem tissue from large, exceptionally well-preserved specimens resulting from autochthonous/hypautochthonous charcoal input to Permian peat (Degani-Schmidt et al., 2015). Conclusions about the preservation conditions are drawn and anatomical affinities are briefly discussed based on xylem and phloem features.

2. Geologic and paleontological context

The study area comprises the Faxinal Coalfield, an opencast coal mine located at the southeastern outcrop belt of the Rio Bonito Formation of the Paraná Basin, southern Brazil (Fig. 1A, 30°15′52.6″S, 51°41′53.8″W).

The top coal seam S interlayers with a tonstein bed (Plate I, 1, 2) dated at 291 ± 1.3 Ma (radiometric age after Simas et al., 2012) thus being of late Sakmarian age (Cohen et al., 2013; updated 2015) (Fig. 1B, C). The tonstein occurs throughout the coal seam area (1.6 km^2) and contains abundant compressed plant organs of the *Glossopteris* Flora (Plate I, 3).

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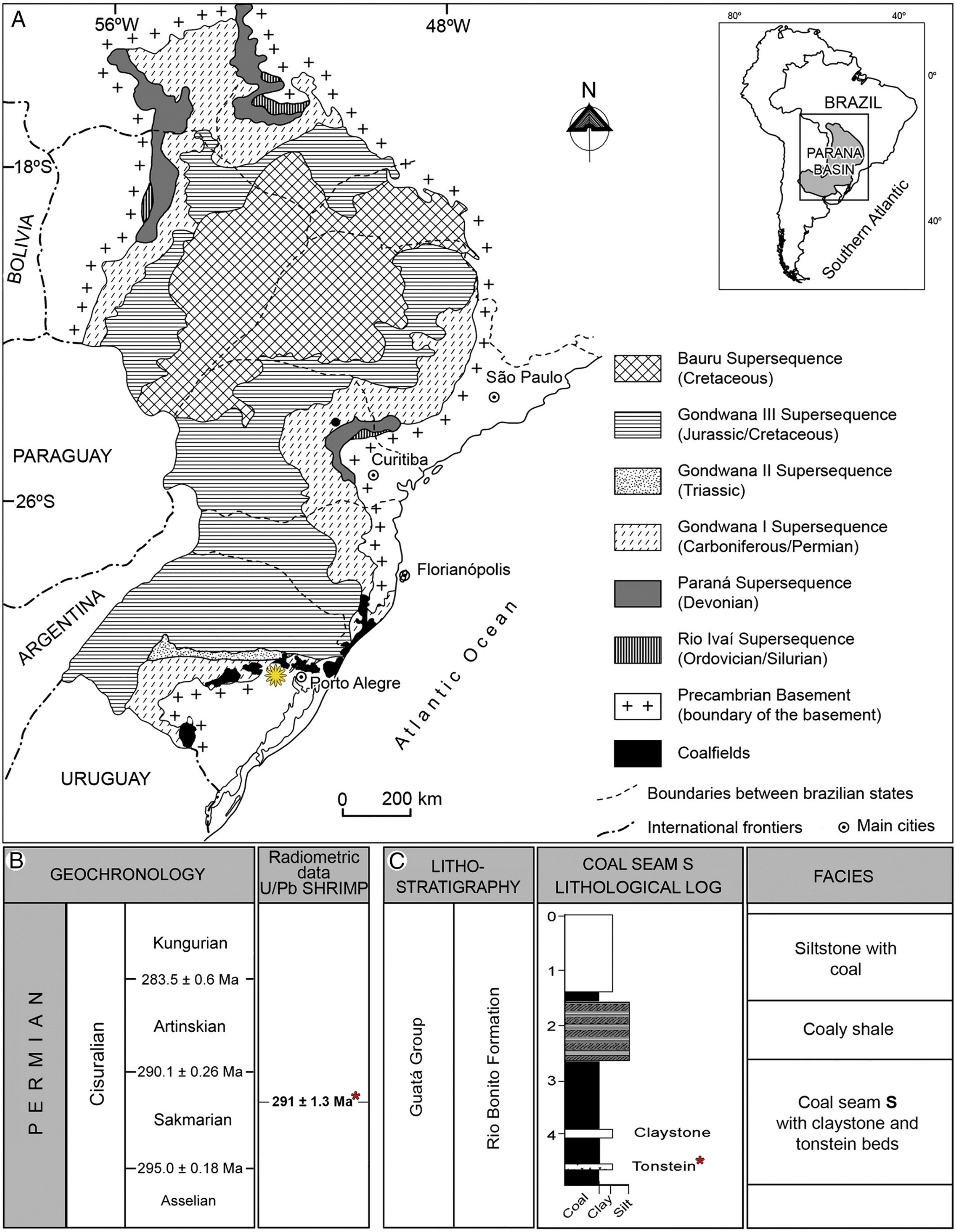

Fig. 1. Map and stratigraphic framework. A) Location map (modified from Santos et al., 2006); B) geochronology (after Cohen et al., 2013; updated 2015), and radiometric age (Simas et al., 2012); C) lithostratigraphy of the coal seam S and overlying layers (after Guerra-Sommer et al., 2008). *Radiometric age obtained through SHRIMP (Sensitive High Resolution Ion Microprobe) in zircons from the tonstein bed.

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