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NEW GYMNOSPERM WOOD FOSSILS, A SEED-OVULE STRUCTURE, AND A NEW GENERIC AFFINITY TO *CEDROXYLON CANOASENSE* RAU FROM THE PERMIAN AND TRIASSIC–JURASSIC OF SOUTHERN BRAZIL

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ABSTRACT – Two new species of gymnosperm wood from the Triassic–Jurassic of Brazil are here described [*Lobatoxylon kaokense* Kräusel and *Chapmanoxylon jamuriense* (Maheswari) Pant & Singh], and a new age and generic affinity are proposed for *Cedroxylon canoasense* Rau. To the latter, originally considered as Triassic, an early Permian age is proposed based on its lithological relationships and the location of its discovery. Additionally, a seed-ovule structure linked to *Kaokoxylon zalesskyi* (Sahni) Maheswari wood materials, is illustrated and analyzed. All materials were identified in the sedimentary rocks exposed in the central E-W belt (Central Depression) of the State of Rio Grande do Sul, South Brazil, where is exposed the Gondwana Sequence of Paraná Basin. The new wood taxa here described increase the number of known genera in the Triassic–Jurassic of southern Brazil. Nevertheless, the arboreal vegetation of gymnosperms remains impoverished when compared with that present in the Permian deposits. Survivors from the Permian–Triassic extinction, they show that new and more evolved types were capable to explore and adapt to the new landscapes resulting from the environmental changes that affected the interior continental areas of Western Gondwana.

Keywords: fossil woods, seed-ovule, Gymnosperms, Ginkgophyta, Permian, Triassic–Jurassic.

RESUMO – Duas novas espécies de lenhos gimnospérmicos do Triássico–Jurássico do sul do Brasil são aqui descritas [*Lobatoxylon kaokense* Kräusel e *Chapmanoxylon jamuriense* (Maheswari) Pant & Singh], e uma nova afinidade genérica é proposta para *Cedroxylon canoasense* Rau. Esta última forma, originalmente considerada como Triássica, por suas relações litológicas e local do achado é aqui proposta como referente ao Eopermiano. Além disto, uma semente identificada junto a fragmentos de lenho de *Kaokoxylon zalesskyi* (Sahni) Maheswari, é ilustrada e analisada. No conjunto o material lenhoso foi identificado na faixa central de sentido E-W do Rio Grande do Sul (Depressão Central), onde afloram as litologias da Sequência Gondwana da Bacia do Paraná. As duas novas formas aqui descritas ampliam o número de táxons lenhosos conhecidos para o Triássico–Jurássico no sul do Brasil, apesar de atestar uma vegetação arbórea de gimnospermas mais empobrecida, quando comparada com aquela conhecida para o Permiano. Sobreviventes da Extinção Permo–Triássica demonstram, por outro lado, que novos tipos mais evoluídos foram capazes de explorar e se adaptar às novas paisagens resultantes das mudanças ambientais e climáticas que afetaram as áreas do interior do Gondwana Ocidental.

Palavras-chave: lenhos, óvulo-semente, Gimnospermas, Ginkgophyta, Permiano, Triássico–Jurássico.

INTRODUCTION

A huge amount of gymnosperm petrified fossil woods (Beltrão, 1965; Santos & Moreira, 1987; Guerra-Sommer & Scherer, 2002) were known since the XIX century in the State of Rio Grande do Sul (Ave-Lallemant, 1880; Isabelle, 1883), mainly concentrate in the Central Depression area (Figure 1). The fossil woods remains were in general found in the fluvial channel deposits included in the Santa Maria (Middle–Upper Triassic) and Caturrita (Upper Triassic–Lower Jurassic) formations, which corresponds to the Gondwana I and II sequences of Paraná Basin from Milani *et al.* (1998, 2007). Their occurrence become more impressive in the youngest levels of Caturrita Formation (**CF**), leading Faccini *et al.* (2003) to propose an informal stratigraphic unit, the "Mata Sandstones", separated from CF by a time gap (Figure 2).

In it, a real petrified forest, was detected in westernmost outcrops, in the surroundings of the cities of Mata and São Pedro do Sul (Figure 1).

Zerfass *et al.* (2003, 2004) included all those Mesozoic strata in the Santa Maria Supersequence, a second order succession, with three second orders sequences (Santa Maria 1, 2, and 3). From that, the last two correspond to the “Middle–Upper Triassic sequences” from Faccini & Paim (2001). The permineralized woods appears in the top of Santa Maria 2 sequence (**SM2**), and are still more abundant and diverse at SM3 (= “Mata sandstones”), from where came part of the herein described wood pieces. Initially considered restricted to the Upper Triassic, recent contributions that analyze the conchostracan faunas and dinosaurs ichnites, allow to confirm that Lower Jurassic rocks occurs at least in SM3 (Barboni & Dutra, 2013; Soares *et al.*, 2014; Rohn *et al.*, 2014; Jenisch *et al.*, 2017).

However, conifer fossil woods are a minor component of the basal SM2, where leaf assemblages of pteridosperms and Ginkgophyta dominate (Guerra-Sommer & Cazzullo-Klepzig, 2000; Barboni & Dutra, 2015), accompanied by a characteristic tetrapod fauna of Carnian age (Zerfass *et al.*, 2003).

Previously known fossil wood materials

The petrified woods of upper SM2 and of SM3 are represented by fragmentary to entire trunks, which varies between 70–100 cm in diameter, and can reach more than 12 m long (Figures 3A–C), most of them reworked and found dispersed in Quaternary soils. A list of the described material is furnished in Table 1.

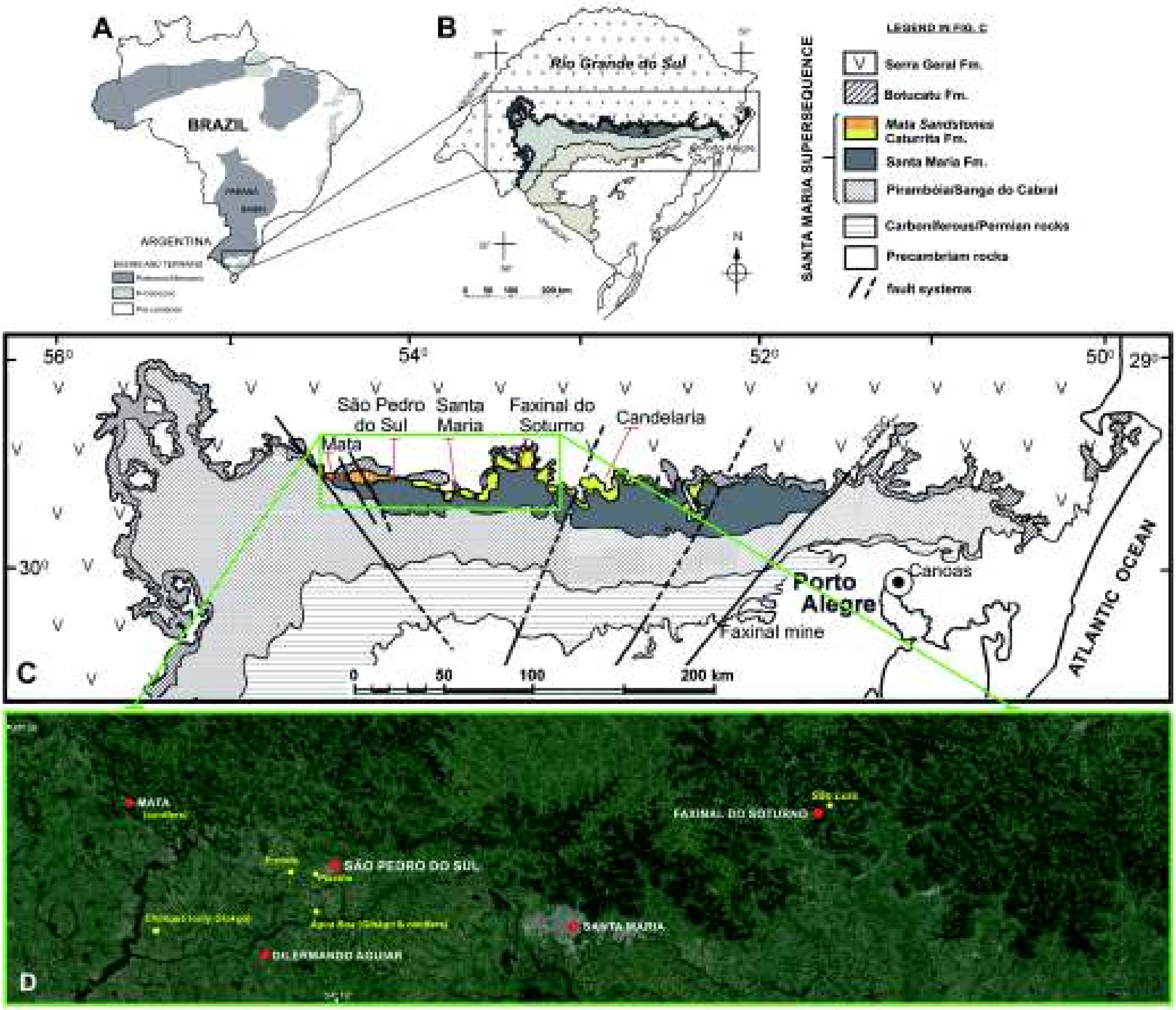

Figure 1. A, Location of the main Paleozoic and Mesozoic intracratonic basins in Brazil; **B**, State of Rio Grande do Sul and the broad E-W belt (Central Depression) that exposes the Permian and Triassic deposits of Paraná Basin are exposed; **C**, detail of B, highlightening the distribution of the sedimentary units of the Santa Maria Supersequence from Zerfass *et al.* (2003), its correlate lithostratigraphic units and the main local places with Triassic and Jurassic fossils; **D**, detail of the localities (red) and outcrops (yellow) were permineralized fossil woods were found (original picture from Gloogle Earth). See Table 1 to the proposed ages and taxa. A–C, modified from Faccini *et al.* (2003).

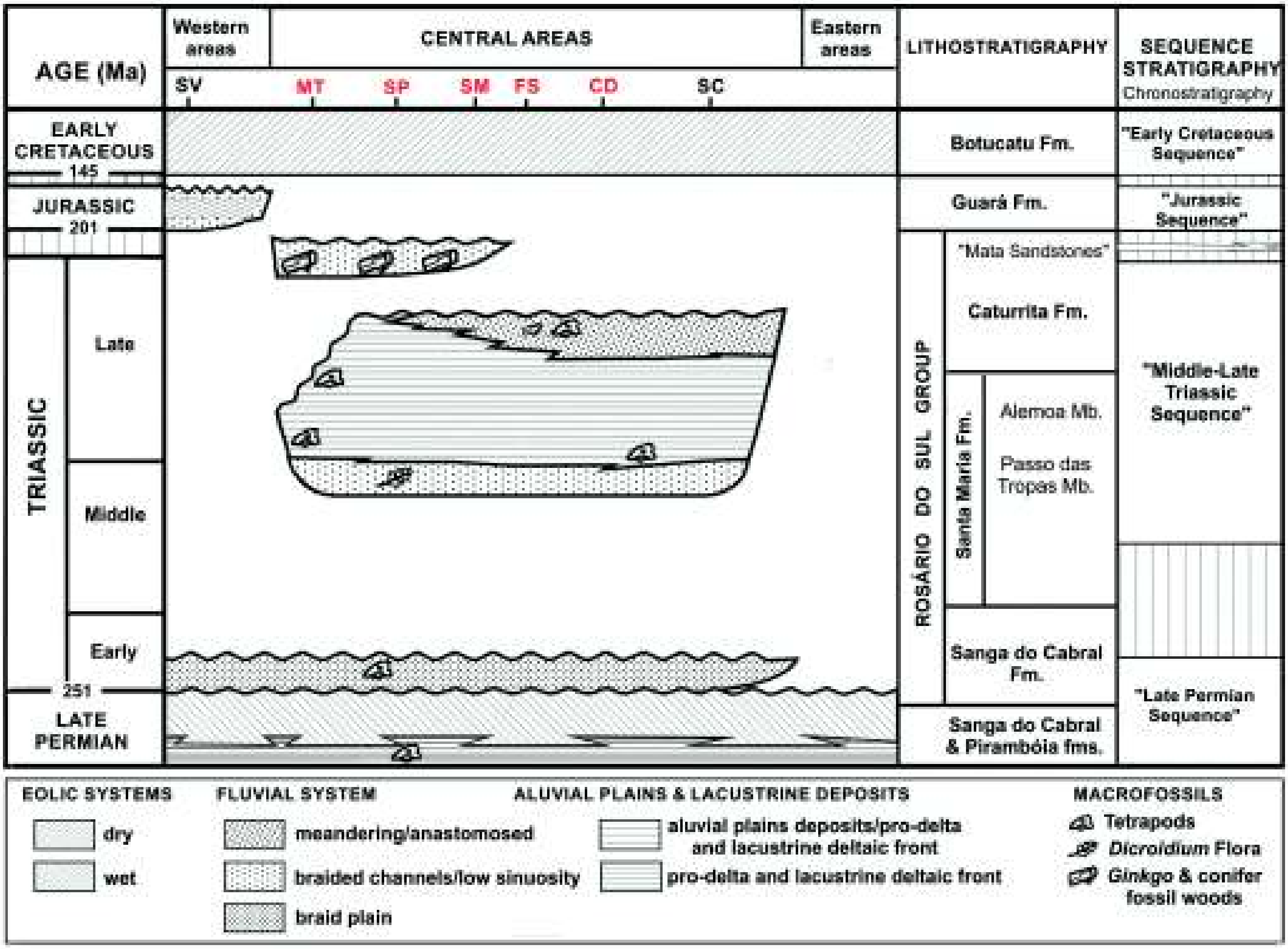

Figure 2. Chronological, lithological and sequential stratigraphic chart proposed by Faccini & Paim (2001) for the Mesozoic of Rio Grande do Sul. The location of the lithostratigraphic units, depositional structures and ages are actualized in accord with the newly described fossil assemblages (see text). The red letters indicate the localities with fossil wood occurrences. Ages from Cohen *et al.* (2013, updated). **Abbreviations: SV**, São Vicente do Sul; **MT**, Mata; **SP**, São Pedro do Sul; **SM**, Santa Maria, **FS**, Faxinal do Soturno; **CD**, Candelária; **SC**, Santa Cruz do Sul.

Table 1. Previously described wood taxa of Caturrita and Santa Maria formations in Rio Grande do Sul. In bold, the new ages proposed for the sedimentary succession contain the fossil woods by the data herein commented. **Abbreviations: Tr**, Late Triassic; **J**, Early Jurassic; **SPS**, São Pedro do Sul; **FS**, Faxinal do Soturno. **Symbol: ?**, reflect an uncertain age or source of the sample.

Taxa	Age	Outcrop/Locality	References
Rhexoxylon brasiliensis (Corystosp.)	Tr	near SPS (not precise)	Herbst & Lutz, 1988
Araucarioxylon spp. (conifer)	Tr/J?	Cerro da Ermida, SPS	Minello (1994b)
Baieroxylon cicatricum (Ginkgoaceae)	Tr	Chiniquá/Agua Boa, SPS	Minello (1994b)/Bardola *et al*. (2009)
Sommerxylon spiralosus (Taxaceae)	J	São Luis outcrop, FS	Pires & Guerra-Sommer (2004)
Kaokoxylon zalesskyi (conifer)	J	São Luis outcrop, FS	Crisafulli & Dutra (2009)
Agathoxylon africanum (conifer)	J?	Soturno River, FS	Crisafulli *et al*. (2016)
Chapmanoxylon jamuriense (conifer)	J?	unknow, SPS	this work
Chapmanoxylon sp. cf. *C. jamuriense*	J?	Soturno river, FS	Crisafulli *et al*. (2016)
Megaporoxylon kaokense (conifer)	J?	Soturno river, FS	Crisafulli *et al*. (2016)
Lobatoxylon kaokense (conifer)	J?	unknow, SPS	this work

Few specimens were found *in situ* (*sensu* Martínez & Santonja, 1994) and until now, they are exclusive from the areas of Mata and São Pedro do Sul. The reworked materials were for a long time found during agricultural activities, and most of them were sliced, polished and sold to scientific institutions and collectors. In Mata, however, they were catalogued and placed on floors and walls of different buildings, public parks, and squares (Figures 3A–C), a strategy of Priest Daniel Cargnin, an amateur paleontologist, to guarantee its preservation near the source area. Today these material are maintained in the field areas where occur (like in the Paleobotanical Garden of Mata) or housed in the regional museums. Those of São Pedro do Sul are also exposed in the Main Square (Figure 3D) and, when detected in the original levels (Figure 3E), allow to confirm its relation with the fluvial sandbars of CF. They are aligned in relation to the sandstone dunes (Figures 3E–F) in a preferential NNE direction, the same of the main river flow of CF.

On other side, in the more southern Água Boa and Chiniquá expositions (Figure 1), they are exclusive by the conjunct occurrence of conifers (mainly related with the Araucariaceae) and Ginkgophyta (Bardola *et al*., 2010), and thus support the older ages proposed by the stratigraphic models. In spite of the wealth of specimens in the whole region and the studies made (Pires & Guerra-Sommer, 2004; Bardola *et al*., 2009, 2010; Crisafulli *et al.*, 2009, 2016), their description is still far from providing a complete understanding of its diversity.

The pioneer work with fossil woods of the Paraná Basin was made by Rau (1933), a German specialist in coal mines prospection. Based on the anatomical features preserved in some charcoalified fragments, he nominated the new species *Cedroxylon canoasense*. In its notes, he indicates that it was found in a well 6 m deep, made in white clay deposits (the "tabatinga bermeja" for Rau), near the city of Canoas (Figure 1), and associated by him with the Triassic Santa Maria Formation (=basal SM2). However, the absence of Triassic levels in the region allow to infer that Rau´s material actually come from Permian units, and specifically, from the Rio Bonito Formation, distinguished by its white mudstones (with kaolinite), and charcoal lenses (Jasper *et al.*, 2011) in the Paraná basin sedimentary column. Additionally, Degani-Schmidt & Guerra-Sommer (2016), indicate the presence of *Agathoxylon*-type of wood at the Faxinal coal-mine. The specimen of Rau (1933) seems to be lost, but based in the original diagnosis and its poor illustrations, is herein proposed that represents a form of *Agathoxylon* (*Dadoxylon*) Hartig. Taking this into account, the first work with a taxonomic focus with the Triassic xyloflora of Rio Grande do Sul was that of Herbst & Lutz (1988). Based on samples from the Walter Ilha Museum in São Pedro do Sul, they described and proposed a new genus and species, *Rhexoxylon brasiliensis*, linked to the Corystospermales. Later, Minello (1994a), working in the Ermida outcrop, and based in the anatomy of a secondary xylem, proposed a relationship of this permineralized woods with *Araucarioxylon* (=*Agathoxylon*), what was afterwards confirmed by Guerra-Sommer *et al*. (1999).

Pires & Guerra-Sommer (2004), working with parautochtonous materials of the surroundings of Faxinal do Soturno county (São Luis outcrop, Figure 1), described the new genus and species *Sommerxylon spiralosus*, considered related to the Taxaceae. In the same levels, Crisafulli & Dutra (2009) studied an autochtonous conifer wood (with roots *in situ*), and considered it, by the anatomical features, comparable to *Kaokoxylon zalesskyi* (Sahni) Maheswari. Both materials come from the basal levels of a lake deposit, deposited over massive crevasse splay fine sands deposits, and together represents the younger levels of CF in the area.

Bardola *et al.* (2009) described a Ginkgophyta wood (*Baieroxylon cicatricum* Prasad & Lele) found at Chiniquá outcrop and associated to a tetrapod fauna characteristic of the Santa Maria Formation (Table 1). Other works also focused the taphonomic process involved in the fossil wood permineralization by silica minerals (Bolzon & Guerra-Sommer, 1994; Minello, 1993, 1994a, b) and in the applying of growth rings to confirm the seasonal conditions of the paleoclimate (Bolzon, 1993; Alves *et al*., 2005; Pires *et al.*, 2005).

MATERIAL AND METHODS

The two new conifer woods herein described are based on specimens identified in the fossil collection of the Paleontological Museum Walter Ilha, at São Pedro do Sul, and result from collections made in the 1960 decade. They are kept at the Museum under the acronym **CPWI** (field number CPV E1). One ovule and seed, tridimensionally preserved, found linked to a lignified portion (cone axis?) in the same beds that contain the *K. zalesskyi* wood remains (Crisafulli & Dutra, 2009) is also herein described.

Thin sections (transversal, longitudinal radial and tangential) have been prepared in the usual way. The anatomical nomenclature is based on García Esteban *et al*. (2002), and the terminology in the descriptions, is that from the list of microscopic features used by IAWA (2004). To the taxonomic treatment and description of araucaria related reproductive structures, the nomenclature proposed by Stockey (1978) and Stockey & Taylor (1978) was used. A minimum of 25 measurements was made, quoting the media, and minimum and maximum values in parentheses. The specimen described as "conifer seed" from the São Luis locality is kept at the Paleobotanical Collection of the Universidade do Vale do Rio dos Sinos (**UNISINOS**), in the city of São Leopoldo, Rio Grande do Sul, under the acronym **ULVG**-8352.

The original specimen of *Cedroxylon canoasense* Rau seems to be lost, but Philippe & Thevenard (1996) quote some slides found at the Humboldt Museum of Natural Sciences in Berlin (MNB collection numbers: 25/6r-359) which apparently belong to it (see below for more data). Although badly preserved, we assume here that they correspond to Rau's species.

Figure 3. The distinct Lower Mesozoic big woods of the Caturrita Formation (Mata Sandstones) in the western area of central Rio Grande do Sul. **A**–**B**, large stems lying near the church and in the main square at the city of Mata; **C**, detail of a path paved with polished fossil wood pieces in Mata; **D**, fossil wood stems exposed in the main square of the São Pedro do Sul Municipality; **E**, organized disposition of big stems over the margins of BR 290 highway at Piscina outcrop (Paleobotanical Monument), São Pedro do Sul, and an *in situ* fossil woods (**arrow**) in the sand bar deposits (scale bar 50 cm). **F**, detail of the wood remains horizontal and multidirectionally orientated, in the mid-channel bar deposits of Piscina outcrop, characterized by intense bioturbation (arrows). Scale bar in figures E-F = 1 m.

SYSTEMATIC PALEONTOLOGY

Division TRACHEOPHYTA Sinnott, 1935 ex Cavalier-Smith, 1998
Class SPERMATOPSIDA Serbet & Rothwell, 1995
Order CONIFERALES Engler, 1897
Family *incertae sedis*

Lobatoxylon Kräusel, 1956

Type species: *Lobatoxylon pedroi* (Zeiller) Kräusel, 1956.

Lobatoxylon kaokense Kräusel, 1956
(Figures 4–5)

1956 *Lobatoxylon kaokense* Kräusel, 37: 447–453, tab. 2, fig. 10; tab. 4, fig., 17; tab., 5 figs. 18–21.
2001 *Lobatoxylon kaokense* Kräusel, *in*: Lutz *et al.*, p. 123–125, fig. 5, tab. 1.

Material. CPWI 713 (field number CPV E1 067); slides CPWI 713a,b,c., São Pedro do Sul, Rio Grande do Sul, Brazil.
Description. Rounded slice of silicified wood about 13 x 9 cm in diameter, preserving a 4- lobulated heterogeneous, compact, nontabicated pith, primary xylem, and secondary xylem, but not the cortex (Figures 4, 5A–B). Parenchyma cells are rounded, their radial and tangential average diameters are 30 x 33 (23 x 35; 30 x 38) µm. Secretory circular cells, isolated or in groups, are present (Figures 5B–C). Scarce sclerenchymatous polygonal cells are also observed. Primary xylem with cuneiform projections, endarch protoxylem (Figure 5C). Growth rings present. Secondary xylem picnoxylic; tracheids are quadrangular in traverse section. An average of six (4–8) cells separate the radii (Figure 5D). In a longitudinal radial section, tracheids with uniseriate, circular, contiguous, biseriate and triseriate bordered pits (Figures 4, 5E–F). Cross fields with 4–6 araucarioid pits; in longitudinal tangential section radii are uni- and partially biseriate, averaging four to ten cells high (Figure 4).
Discussion. Some authors, like Berthelin *et al.* (2004) and Merlotti & Kurzawe (2011) still use the generic epithet *Trigonomyelon* Walton for *Lobatoxylon* Kräusel, but as shown by Lutz *et al.* (2001), who made a synthesis about it based on the arguments provided by Kräusel (1956), the latter name should be used. The four-lobulated pith and the pitting type of the longitudinal radial tracheidal walls of the secondary xylem allows to assimilate this specimen to the South African *L. kaokense* Kräusel and separate it from the other species recorded to this genus in the Permian, of Brazil: *L. pedroi* (Zeiller), originally named as *Dadoxylon pedroi* by Zeiller (1895), *w*hich was made the type species of the genus; from India: *L. raniganjense* (Maheshwari,1967; Prasad, 1986) and that from the Upper Triassic of India and Chile: *L. kamthiensis* (Prasad) Lutz, Crisafulli & Herbst (*in* Lutz *et al.*, 2001). The distinctive characters are the absence of secretory canals in the pith, the hexagonal pits on the radial tracheidal walls and the presence of triseriate pits and sclerenchymatic cells in the pith, all absent in *L. kamthiensis*. The species *L. pedroi* is different because in *L. kaokense* the trilobite pith and its secretory canals is absent, and has a higher number of pits (4–6) in its fields, distinct from the 1–2 pits from *L. pedroi.*

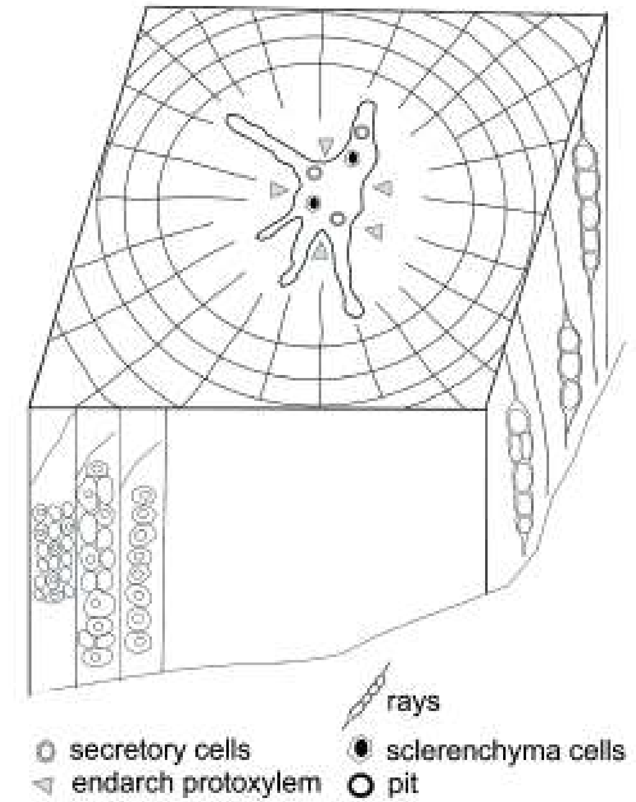

Figure 4. *Lobatoxylon kaokense* Kräusel. Block diagram showing wood characters in transversal, radial and tangential longitudinal section.

Chapmanoxylon Pant & Singh, 1987

Type species. *Chapmanoxylon jamuriense* (Maheshwari) Pant & Singh, 1987.

Chapmanoxylon jamuriense (Maheshwari) Pant & Singh, 1987
(Figure 6)

1966 *Dadoxylon jamuriense* Maheshwari, 13(2):148, lám. 1, fig. 1–5, lám. 2, fig 6.
1972 *Damudoxylon jamuriense* (Maheshwari) Maheshwari, 138: 11.
1987 *Chapmanoxylon jamuriense* (Maheshwari) Pant & Singh, 203, p. 21, tab. 3.
2008 *Chapmanoxylon jamuriense* (Maheshwari) Pant & Singh, *in*: Crisafulli & Herbst, 5: 739-740, fig 3.1–4 and 4.1–2.
2009 *Chapmanoxylon jamuriense* (Maheshwari) Pant & Singh, in Crisafulli *et al.*, 5:7–8, figs. 5D–G, 6A–E.
2012 *Chapmanoxylon jamuriense* (Maheshwari) Pant & Singh, in: Leiva Veron *et al.*, 8:71, figs. 3C–D.

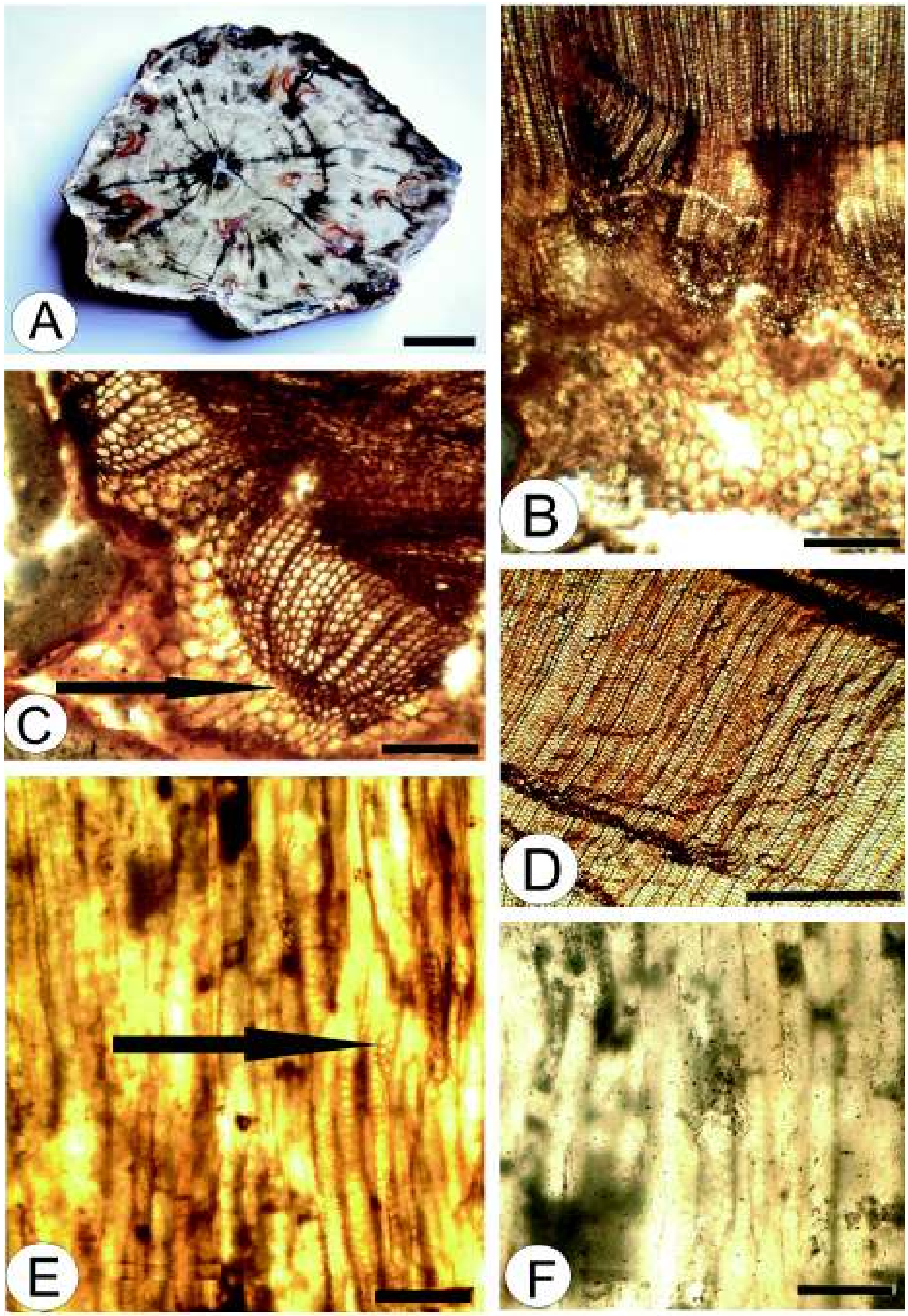

Figure 5. *Lobatoxylon kaokense* Kräusel. **A**–**D**, transverse sections (CPWI 713a): **A**, general aspect of the wood (CPWI 713); **B**, parenchimatic pith, primary xylem with wedge-shaped projections and pycnoxilic secondary xylem; **C**, detail of B: arrow indicates the protoxylem; **D**, secondary xylem with growth rings. **E**–**F**, Longitudinal radial section (CPWI 713 b), showing pits on the tracheidal walls: **E**, uniseriate pits; arrow indicates biseriate, alternate pits. **F**, uniseriate and triseriate pits. Scale bars: A = 5 cm; B = 150 µm; C, E = 100 µm; D = 400 µm; F = 70 µm.

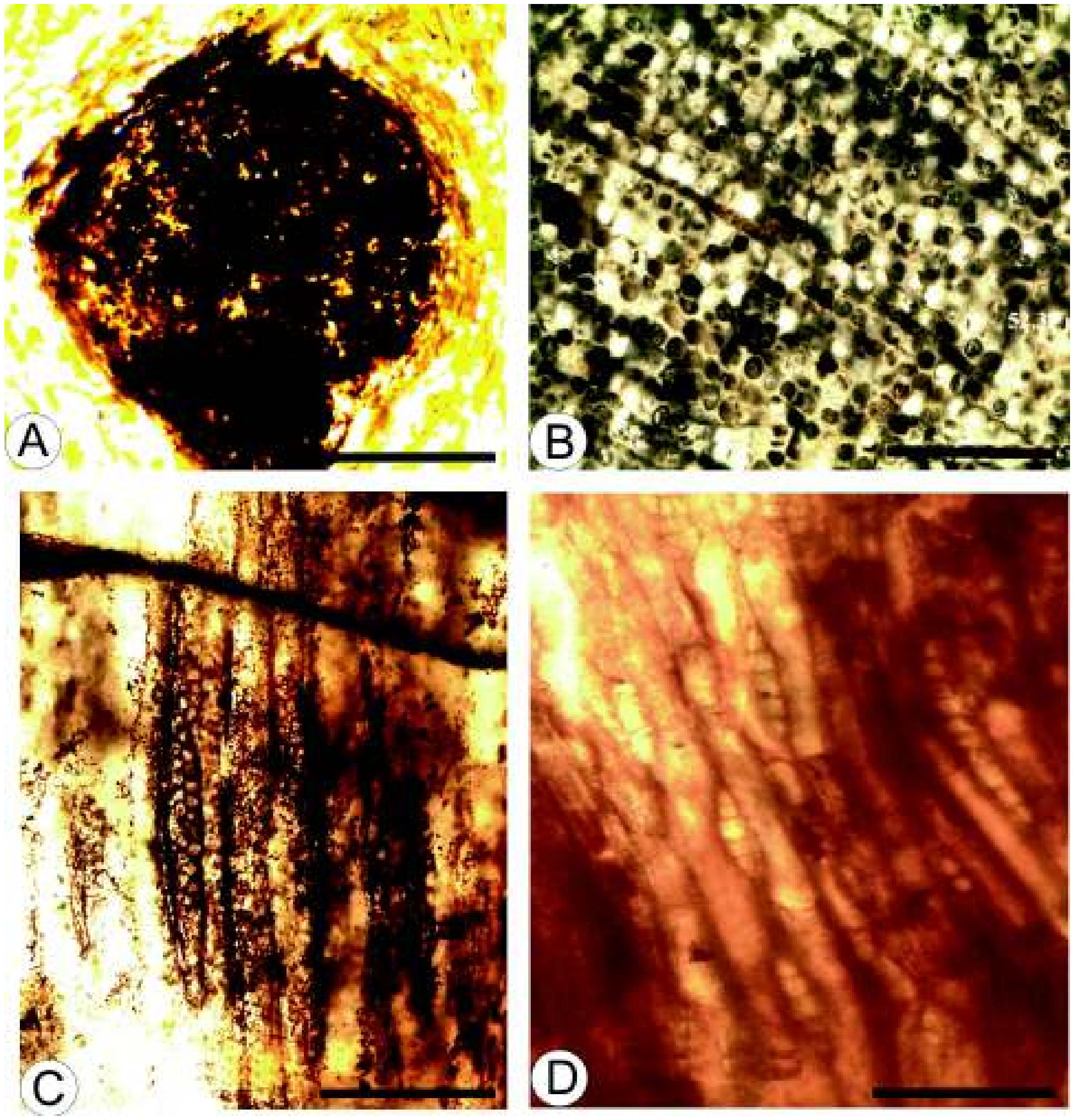

Figure 6. *Chapmanoxylon jamuriense* (Maheswari) Pant & Singh (CPWI 714). **A**, longitudinal tangential section of secondary xylem, with detail of transversal section of the pith of the trace (CPWI 714c); **B**, transversal section showing tracheids of secondary xylem with dark contents (CPWI 714a); **C**, longitudinal radial section of secondary xylem, showing biseriate, sub- opposite pits on the tracheidal walls (CPWI 714b); **D**, uniseriate and lower rays (CPWI 714c). Scale bars: A = 1 mm; B = 330 µm; C = 160 µm; D = 240 µm.

Material. CPWI 714 (original field number CPE1 091); slides CPWI 714 a,b,c. Walter Ilha Museum, São Pedro do Sul, Rio Grande do Sul, Brazil.

Description. Rounded slice of silicified wood, circa 8 cm thick and about 20 x 15 cm in diameter, preserving the pith, primary and secondary xylem, but without cortex. Pith circular, about 2.5 cm in diameter, homogeneous, compact, not tabicated and composed of rounded parenchyma cells in transverse section. Tangential and radial average diameters 55 x 63 (40 x 50; 50 x 60) µm. In the longitudinal radial section, they are rectangular. Primary xylem forming cuneiform projections; protoxylem endarch. Secondary xylem picnoxylic with marked growth rings and shearing zones (*sensu* Erasmus, 1976). In transversal section tracheids are rectangular; with radial and tangential average diameters of 42 x 33 (33 x 25; 48 x 33) µm; 6 (4–7) tracheid separate radii (Figure 6B). Radial walls of the secondary xylem cells with uni-to biseriate, circular, and contiguous to separate pits; the biseriate ones are alternate (Figure 6C). Cross fields with rounded pits. In longitudinal tangential section, the radial system is homogeneous. Radii are homocellular, uniseriate and low; average height is 5 (4–7) cells (Figure 6D).

Discussion. *Chapmanoxylon* is one of the few genera with a homogeneous pith and an araucarioid secondary xylem. The distribution of pits in the tracheids and cross fields, as well as the height of the non-articulate radii, justify the specific name of the present specimen. This species was also found in the Permian of Argentina (Solca Formation, Crisafulli & Herbst, 2008), Uruguay (Tres Islas Formation, Crisafulli *et al.*, 2009), Paraguay (Tacuary Formation, Leiva Verón *et al.*, 2012) and in the Permian Raniganj Formation of India (Pant & Singh, 1987). A specimen close to this species and referred as “*cfr.*” was found *in situ*, in levels of Caturrita Formation outcropping at the Rio Soturno terraces, near Faxinal do Soturno County (Crisafulli *et al*., 2016, Table 1).

Family ARAUCARIACEAE

Agathoxylon Hartig, 1948

Type species. *Agathoxylon cordaianum* Hartig, 1848.

Agathoxylon canoasense (Rau) Crisafulli nov. comb.
(Figure 7)

1933 *Cedroxylon canoasense* Rau, 68, figs. 1–3.
1949 *Xenoxylon canoasense* (Rau), Kräusel, *in*: Kräusel, 89: (part 3):188.
1996 *Xenoxylon canoasense* (Rau) Kräusel, *in*: Philippe & Thevenard, 91: 357.

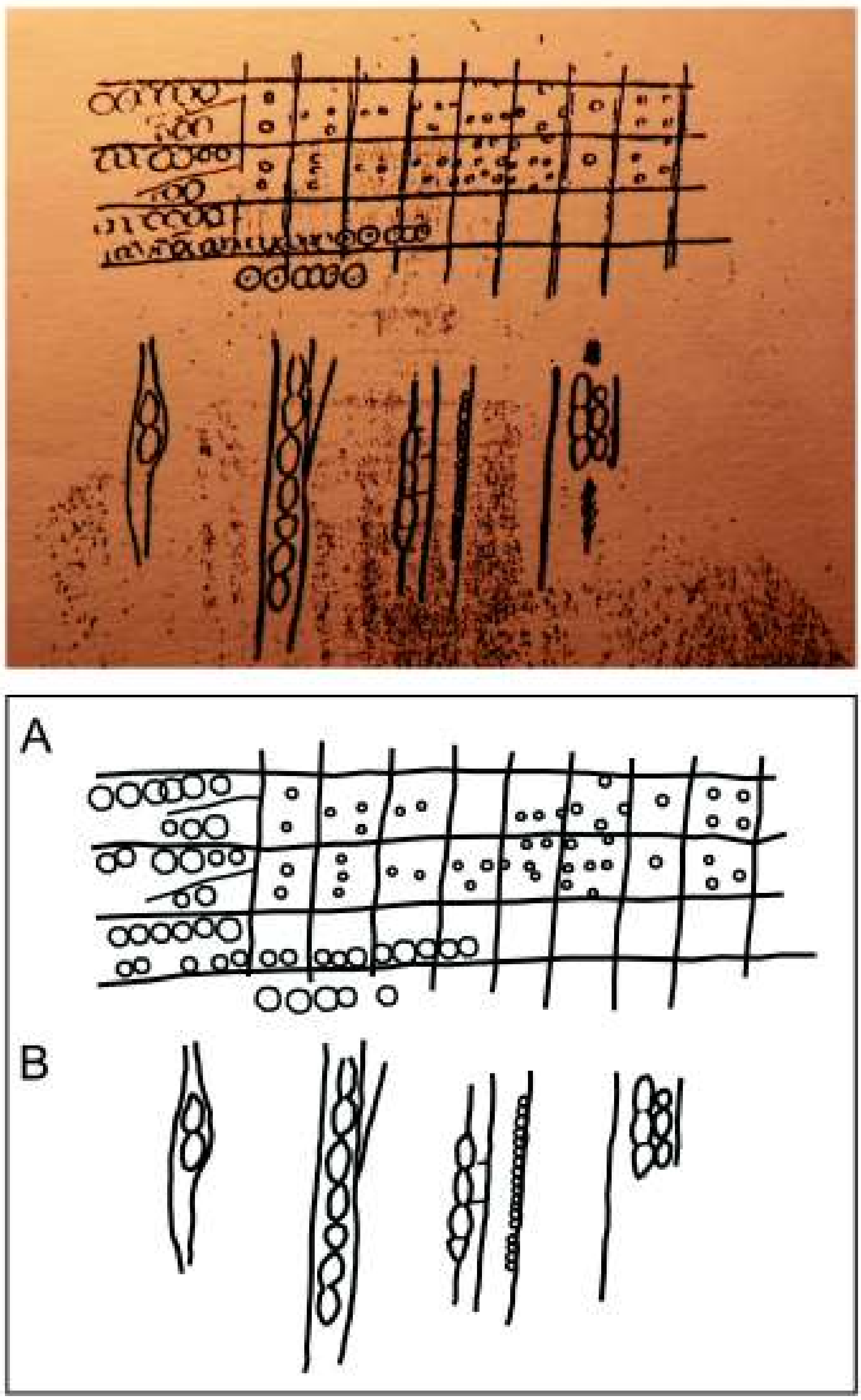

Figure 7. *Agathoxylon canoasense* (Rau) nov. comb., with the sketch from the original work of W. Rau (upper) and the more clear replica of it made by R. Herbst (low). **A**, longitudinal radial section of secondary xylem showing circular and contiguous uniseriate and biseriate, opposite, spaced pits, on the tracheidal walls and the arrangement of pits on the cross field. **B**, longitudinal tangential section showing uniseriate rays.

Diagnosis. Taken textually that from Rau (1933, p. 68): "Bordered pits uniseriate, rarely opposite. If biseriate, generally one row is on a different level or separated by fine tracheid-wall. Bordered pits flattened above and below and appear elliptic. There are slightly and greatly flattened pits. But circular ones are also seen in the rows and peculiarly if isolated. There are no hexagonal or polygonal pits. Diameter of the bordered pits 9–15 µm. Lenght of the markraysells (*) 21–28 µm. Breath of the markraysells 14–21 µm. In tangential slices the markrays are uniseriate, only rarely biseriate. Resin canals or cells do not exist. Growth rings perspicuous on the transversal slice. Pits of the markrays are small (abietinoid ?Prof. Zimmermann)" (*): *markraysells* and *markrays* are original spellings.

Comments. Kräusel (1949, part 3, p. 188) proposed a new combination of this species with the genus *Xenoxylon* based only on the poor quality of the photographs and Rau's sketches (herein redrawn in its proper vertical orientation), but left it as "doubtful forms". From the description and the few illustrations given by the author and our interpretation, it seems clear that this species can be included more accurately in *Agathoxylon* Hartig in its present modern definition (Rößler *et al*., 2014). The genus *Cedroxylon* initially proposed by Rau (1933) has a somewhat complicated history, as it has been used in several ways and with different meanings and further, the original diagnosis is not too clear, making of it a nice imbroglio. Bamford & Philippe (2001) and Philippe & Bamford (2008) reviewed the history of this genus and finally recommended not to use the generic name *Cedroxylon* Kraus, at least for the "Gondwanic area". It is out of our scope here to analyze this matter in detail, and thus it is felt that the generic name *Cedroxylon* can confidently be eliminated from the list of woods present in the Triassic of southern Brazil. On the other hand, Philippe & Thevenard (1996) showed that the genus *Xenoxylon* Gothan, used by Kräusel (1949) for Rau's specimen, seems to be exclusive to the boreal hemisphere, and also established that the species "*X. canoasense*" doubtfully belongs to it. In that paper, the authors cite the finding of some slides (numbered 25/6r-359) in the MNB (Berlin, see above) which seem to be original ones from Rau (1933). Philippe (*in litt*. 23-01-2016) from his early notes quotes about them: "radial pitting uniseriate, poorly preserved, possibly araucarian; cross fields not preserved". Thus, it seems we are certain in our assignment to *Agathoxylon*. From the evidence available (photographs and sketches by Rau & Philippe's data) most characters indicate this genus, except by the apparent "xenoxyloid" pitting in his photograph (Rau, 1933, fig.1), a character that does not appear in the mentioned slides.

Agathoxylon, viz. *A. africanum* (Bamford) Kurzawe & Merlotti, has been described in detail from Permian levels of southern Brazil (Kurzawe & Merlotti, 2010) and also to the Upper Triassic–Jurassic Caturrita Formation of Rio Grande do Sul, by Crisafulli *et al*. (2016). Many other specimens have been quoted as uncertain species of *Araucarioxylon* (Guerra-Sommer *et al*., 1999; Guerra-Sommer & Cazullo-Klepzig, 2000; Guerra-Sommer & Scherer, 2002), but are distinct from *A. canoasense*. A conservative position is maintained here in relation to the species, accepting that proposed by Rau (1933) until more and better material is available for comparisons.

A "conifer seed" in *Kaokoxylon zalesskyi* (Sahni) Maheswari
(Figures 8–9)

Comments. Replicas of ovules and seed, preserved in iron oxi-hydroxides, was detected on a sector of a *Kaokoxylon zalesskyi* (Sahni) Maheswari wood, also preserved by densely impregnated iron oxides. In the wood is maintained the pith, the cuneiform primary xylem and the picnoxylic secondary one (Figure 8A). The reproductive structures, with an oblong form, with 3.2 mm long x 0.8 wide, is inverted and adaxially inserted in one or perhaps two per scale (Figures 8B–C). The integument seems to be thick in texture, and the nucellus, micropylar part (narrow) and megagametophitic tissue are well developed (Figure 8E). In one portion of the stem, two nucellar cavities enclosed by a common integument was detected (Figure 8C). The integument seems to contain a sarcotesta and endotesta, although not very distinct. The nucellus may be differentiated from the integument, except in the chalazal area, and the megagametophitic tissue occupies all the space of the nucellar cavities. Part of the peduncle of this fructification is also preserved (Figures 8D–E; 9).

The specimen (ULVG 8532) originates from the same lacustrine laminated mudstones of São Luis outcrop (Caturrita Formation) where the *Kaokoxylon* species were detected and is housed at the Paleobotanical Collection of LaViGaea – MHGEO, UNISINOS (Figure 8A). Later, researchers from the Zoobotanical Foundation of Rio Grande do Sul identified in the same beds a still unstudied little "araucarioide" cone (2.5 cm in diameter), covered by a crust of iron-rich clay, which conserves its tridimensional morphology and the inserted seeds.

Other evidence of such kind of special and exceptional preservation of plant fossils in the Triassic and Jurassic beds of South Brazil were preliminarily informed (Dutra & Barboni, 2014) and are under study (Kerkhoff, 2017). This is aligned with the many announcements about similarly preserved plant fossils in other world deposits, most with correlate ages and preservation. They called the attention by its coincidence with signals of microbial activity as inductors of the iron deposits and favouring this unique preservation (*e.g.* Dunn *et al*., 1997; Bomfleur *et al*., 2007; Locatelli, 2014; Peterffy *et al*., 2016).

As already pointed by Crisafulli & Dutra (2011), the herein described seed characters allow a general comparison with those found in the Araucariaceae representatives, like that from the Jurassic Cerro Cuadrado Formation, Argentine Patagonia (Stockey, 1975, 1977, 1978; Stockey & Taylor, 1978), Rajmahal Series, India (*Araucarites mittrii* from Bohra & Sharma, 1980), and other genera of Coniferales *sensu lato* (*e.g. Nipaniostrobus* Rao, 1943), and *Sciadopitys* (Saiki, 1992), from the Cretaceous of Japan. With *A. mittrii* it shares the presence of two nucellar cavities found in some specimens. However, in the here studied ovule the shrunk or wavy zig-zag appearance of the nucellus in the micropylar

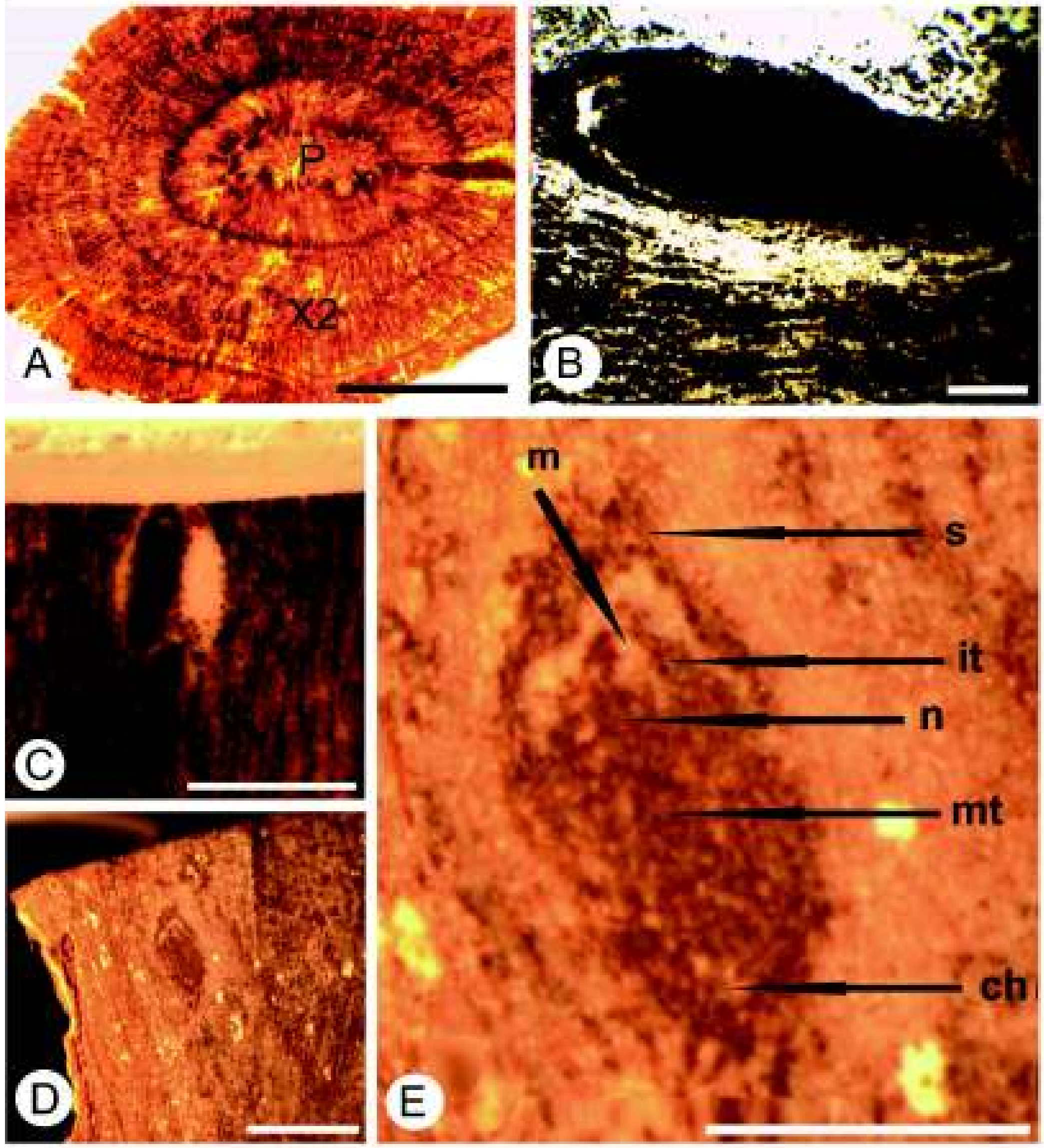

Figure 8. *Kaokoxylon zalesskyi* (Sahni) Maheswari (ULVG 8352) and associated seed. **A**, transversal section showing pith (**P**), wedge-shaped primary xylem (**X**) and picnoxylic secondary xylem (**X2**). Slide ULVG 8352a; **B**, longitudinal tangential section of secondary wood (ULVG 8352b), highlight the curving radial system which accompany the reproductive structure; **C**, longitudinal tangential section of secondary wood (ULVG 8352b), with the seed and an empty space left by another one; **D**, seed on the wood structure (ULVG 8352a); **E**, detail of D. **Abbreviations: s**, scale; **m**, micropyle; **it**, internal tegument; **mt**, megagametophytic tissue; **ch**, chalaza; **n**, nucella. Scale bars: A = 25 mm; B = 800 µm; C = 17 mm; D = 5 mm; E = 2.2 mm.

zones, characteristic of *A. mittrii* and *A. mirabilis* Spegazzini (Stockey, 1975, 1978), was not observed.

The herein detected reproductive structure and some features of the associated wood also suggest an affinity with the Jurassic petrified cone, *Pararaucaria patagonica* Wieland emend. Escapa, Rothwell, Stockey & Cúneo (Stockey, 1977; Stockey & Taylor, 1978; Escapa *et al.*, 2013), from Cerro Quadrado and Cañadon Calcáreo formations, to the cone axis of Araucariaceae from Stockey & Taylor (1978) and, in longitudinal section, with the ovules of *Mikasastrobus hokkaidoensis* Saiki & Kimura (1993) cones.

Taking all this data into account, it seems to be somewhat difficulties to establish whether these ovules were part of a definite "cone", or if they are attached to the wood as suggested by the surrounding tissues, where the tracheids seem to curve around the seed (Figures 8B–E). In any manner, and despite the poor state of preservation, the peculiar state of its preservation stimulates the detection of other similar occurrences.

FINAL REMARKS

The two new woods herein described from samples housed at the Walter Ilha Museum of São Pedro do Sul, help to enlarge the list of known gymnosperm wood taxa from the Triassic and Jurassic of Southern Brazil (Table 1). Therefore, an emphasis has to be put in describing more *in situ* material in order to make more clear the characteristics of the fossil

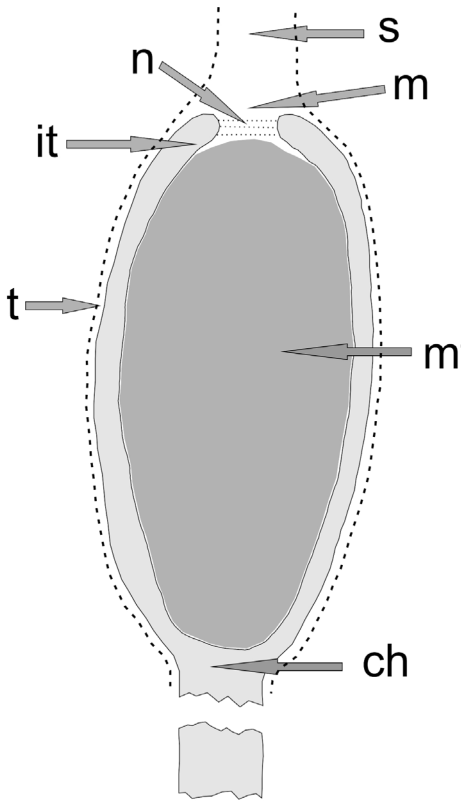

Figure 9. Sketch of the female reproductive structure. **Abbreviations** as in Figure 8.

forests” of Santa Maria and Caturrita formations.

To the CF, the present study attests for the first time, a more formal presentation of fertile organs linked to the Araucariaceae. Associated to the previous known female cone of *Williamsonia potyporanae*, also tridimensionally preserved and in the same mudstones facies of the São Luis outcrop (Barboni & Dutra, 2013), is possible to inferred a flora of bennettites and small woody araucarioid conifers (by the caliber of its autochtonous roots and stems), which growed over crevasse splay deposits or river channel margins and were covered by the less ephemeral waters of a confined lake (oxbow?) or alluvial plain, in epochs of increasing humidity. A similar context was proposed by Colombi & Parrish (2008) for the Valle de La Luna Member of the Ischigualasto Formation in northeastern Argentina. In the Ladinian–Carnian Santa Maria Formation, reproductive structures were known for a more long time, exhibiting relations with *Dicroidium* or its allied genus (*Pteruchus* and *Umkomasia* related forms) and with the Ginkgoaceae. Finally, the analysis made with the original material of *Cedroxylon* from Rau (1933), allow us to reject the presence of this genus in the list of taxa from Brazil, and still its relation with the Triassic assemblages.

All of them together, these findings expand our knowledge about the Mesozoic paleoxylotaphoflora of Brazil, and attest the radiation of the gymnosperms in the south-western interior areas of the Gondwana, under the influence of changing climates and environments. The data here discussed support a Middle–Late Triassic interval characterized by continuous landmasses and seasonal climates like proposed by Parrish (1993) and Preto *et al*. (2010) that allowed a uniform and dominant *Dicroidium* and Ginkgo flora to be distributed along the Gondwana. Between the end of Triassic and the Lower Jurassic (McElwain *et al*., 1999), despite the great extinction event worldwide detected, or because of it, this flora gave place to a more local and shrub size vegetation of conifers, which soon evolved to higher strata of wood forests adapted to the margins of low sinuosity rivers and to the crevasse splay deposits of the small rift basins resulting from extensional tectonic efforts (Zerfass *et al.*, 2004). In all those processes the here detected wood floras and its associated facies are an important tool for the paleoenvironmental reconstructions.

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TRIBUTE TO PE. DANIEL CARGNIN AND DR. RAFAEL HERBST

"Here in Mata I don't have catholics, lutherans, evangelics, black or whites, I have people" **(Pe. Daniel Cargnin)**

Dr. Rafael Herbst

We want to leave our homage to two lost persons in the last years that had a great significance in our lives and in the research with Paleobotany in Brazil, by their dedication and the splendid work made.

Father Daniel Cargnin (1930–2002), priest of Mata during 20 years and an amateur paleontologist, while carrying out his main mission of protecting the men soul, also was fascinated by the numerous occurrences of fossil woods in the city terrains. Then, he convinced the inhabitants of Mata and of the surroundings to use the fossil woods as an ornament in the streets, squares and buildings, in a way of preserving and protecting that wealth. His clairvoyance is attested by the words in the figure here shown, written by him at the end of the 1970`s, and more than this, by its big concern for humanity.

Dr. Rafael Herbst (1936–2017), despite being one of the greatest geologists and paleobotanist from Argentina, and having trained a great amount of young researchers in the study of fossil woods, was also a “globetrotter”, fond by the South American landscapes. During a long time he comes to Brazil, searching for comparative forms between the Triassic deposits of his and of our country. In one of these trips, a sample showed by Dr. Walter Ilha, director of the Museum, at São Pedro do Sul, allowed him to describe, with Alicia Lutz, the exclusive pteridosperm wood *Rhexoxylon brasiliensis* from the Paraná Basin deposits of Rio Grande do Sul, expanding our knowledge about of the “Dicroidium Flora”. This tribute to Pe. Cargnin was a desire of Dr. Herbst during the time off we were involved in the present work, and the herein made homage (with the plaque in the entrance of the Church of Mata) had been prepared by him.

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NEW GYMNOSPERM WOOD FOSSILS, A SEED-OVULE STRUCTURE, AND A NEW GENERIC AFFINITY TO *CEDROXYLON CANOASENSE* RAU FROM THE PERMIAN AND TRIASSIC–JURASSIC OF SOUTHERN BRAZIL

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ABSTRACT – Two new species of gymnosperm wood from the Triassic–Jurassic of Brazil are here described [*Lobatoxylon kaokense* Kräusel and *Chapmanoxylon jamuriense* (Maheswari) Pant & Singh], and a new age and generic affinity are proposed for *Cedroxylon canoasense* Rau. To the latter, originally considered as Triassic, an early Permian age is proposed based on its lithological relationships and the location of its discovery. Additionally, a seed-ovule structure linked to *Kaokoxylon zalesskyi* (Sahni) Maheswari wood materials, is illustrated and analyzed. All materials were identified in the sedimentary rocks exposed in the central E-W belt (Central Depression) of the State of Rio Grande do Sul, South Brazil, where is exposed the Gondwana Sequence of Paraná Basin. The new wood taxa here described increase the number of known genera in the Triassic–Jurassic of southern Brazil. Nevertheless, the arboreal vegetation of gymnosperms remains impoverished when compared with that present in the Permian deposits. Survivors from the Permian–Triassic extinction, they show that new and more evolved types were capable to explore and adapt to the new landscapes resulting from the environmental changes that affected the interior continental areas of Western Gondwana.

Keywords: fossil woods, seed-ovule, Gymnosperms, Ginkgophyta, Permian, Triassic–Jurassic.

RESUMO – Duas novas espécies de lenhos gimnospérmicos do Triássico–Jurássico do sul do Brasil são aqui descritas [*Lobatoxylon kaokense* Kräusel e *Chapmanoxylon jamuriense* (Maheswari) Pant & Singh], e uma nova afinidade genérica é proposta para *Cedroxylon canoasense* Rau. Esta última forma, originalmente considerada como Triássica, por suas relações litológicas e local do achado é aqui proposta como referente ao Eopermiano. Além disto, uma semente identificada junto a fragmentos de lenho de *Kaokoxylon zalesskyi* (Sahni) Maheswari, é ilustrada e analisada. No conjunto o material lenhoso foi identificado na faixa central de sentido E-W do Rio Grande do Sul (Depressão Central), onde afloram as litologias da Sequência Gondwana da Bacia do Paraná. As duas novas formas aqui descritas ampliam o número de táxons lenhosos conhecidos para o Triássico–Jurássico no sul do Brasil, apesar de atestar uma vegetação arbórea de gimnospermas mais empobrecida, quando comparada com aquela conhecida para o Permiano. Sobreviventes da Extinção Permo–Triássica demonstram, por outro lado, que novos tipos mais evoluídos foram capazes de explorar e se adaptar às novas paisagens resultantes das mudanças ambientais e climáticas que afetaram as áreas do interior do Gondwana Ocidental.

Palavras-chave: lenhos, óvulo-semente, Gimnospermas, Ginkgophyta, Permiano, Triássico–Jurássico.

INTRODUCTION

A huge amount of gymnosperm petrified fossil woods (Beltrão, 1965; Santos & Moreira, 1987; Guerra-Sommer & Scherer, 2002) were known since the XIX century in the State of Rio Grande do Sul (Ave-Lallemant, 1880; Isabelle, 1883), mainly concentrate in the Central Depression area (Figure 1). The fossil woods remains were in general found in the fluvial channel deposits included in the Santa Maria (Middle–Upper Triassic) and Caturrita (Upper Triassic–Lower Jurassic) formations, which corresponds to the Gondwana I and II sequences of Paraná Basin from Milani *et al.* (1998, 2007). Their occurrence become more impressive in the youngest levels of Caturrita Formation (**CF**), leading Faccini *et al.* (2003) to propose an informal stratigraphic unit, the "Mata Sandstones", separated from CF by a time gap (Figure 2).

In it, a real petrified forest, was detected in westernmost outcrops, in the surroundings of the cities of Mata and São Pedro do Sul (Figure 1).

Zerfass *et al.* (2003, 2004) included all those Mesozoic strata in the Santa Maria Supersequence, a second order succession, with three second orders sequences (Santa Maria 1, 2, and 3). From that, the last two correspond to the "Middle–Upper Triassic sequences" from Faccini & Paim (2001). The permineralized woods appears in the top of Santa Maria 2 sequence (**SM2**), and are still more abundant and diverse at SM3 (= 'Mata sandstones'), from where came part of the herein described wood pieces. Initially considered restricted to the Upper Triassic, recent contributions that analyze the conchostracan faunas and dinosaurs ichnites, allow to confirm that Lower Jurassic rocks occurs at least in SM3 (Barboni & Dutra, 2013; Soares *et al*., 2014; Rohn *et al.*, 2014; Jenisch *et al*., 2017).

However, conifer fossil woods are a minor component of the basal SM2, where leaf assemblages of pteridosperms and Ginkgophyta dominate (Guerra-Sommer & Cazzullo-Klepzig, 2000; Barboni & Dutra, 2015), accompanied by a characteristic tetrapod fauna of Carnian age (Zerfass *et al*., 2003).

Previously known fossil wood materials

The petrified woods of upper SM2 and of SM3 are represented by fragmentary to entire trunks, which varies between 70–100 cm in diameter, and can reach more than 12 m long (Figures 3A–C), most of them reworked and found dispersed in Quaternary soils. A list of the described material is furnished in Table 1.

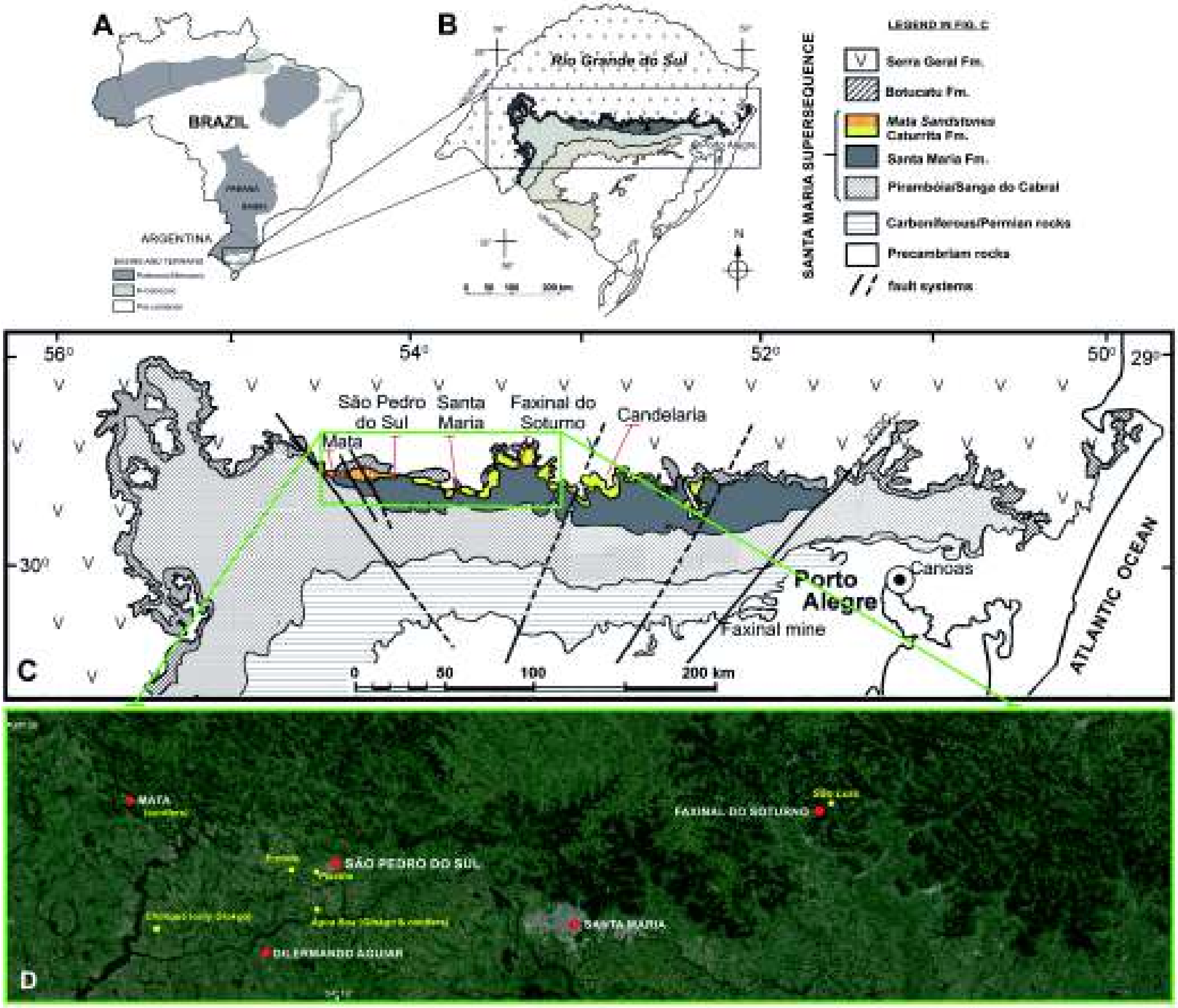

Figure 1. A, Location of the main Paleozoic and Mesozoic intracratonic basins in Brazil; **B**, State of Rio Grande do Sul and the broad E-W belt (Central Depression) that exposes the Permian and Triassic deposits of Paraná Basin are exposed; **C**, detail of B, highlightening the distribution of the sedimentary units of the Santa Maria Supersequence from Zerfass *et al*. (2003), its correlate lithostratigraphic units and the main local places with Triassic and Jurassic fossils; **D**, detail of the localities (red) and outcrops (yellow) were permineralized fossil woods were found (original picture from Gloogle Earth). See Table 1 to the proposed ages and taxa. A–C, modified from Faccini *et al.* (2003).

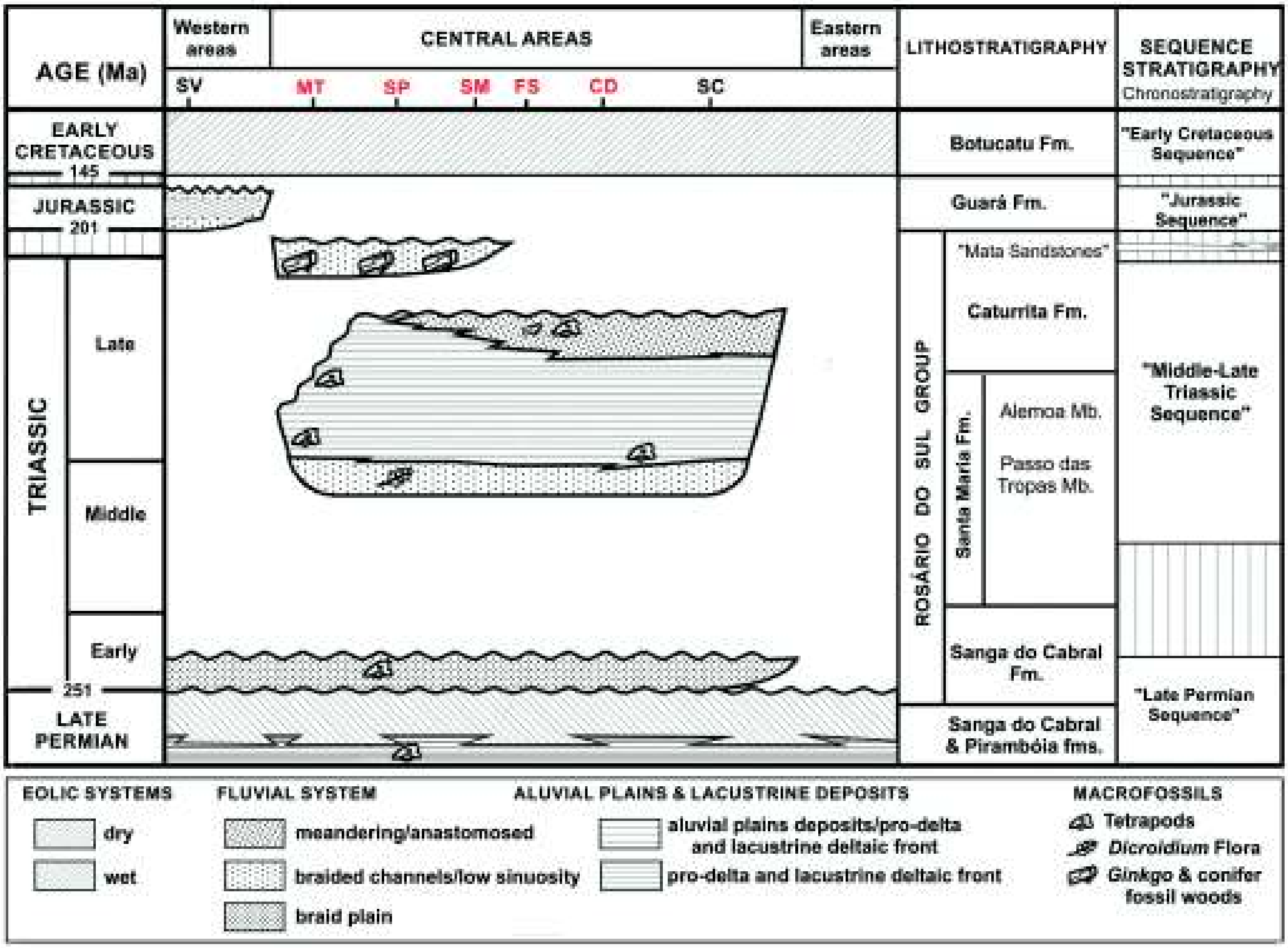

Figure 2. Chronological, lithological and sequential stratigraphic chart proposed by Faccini & Paim (2001) for the Mesozoic of Rio Grande do Sul. The location of the lithostratigraphic units, depositional structures and ages are actualized in accord with the newly described fossil assemblages (see text). The red letters indicate the localities with fossil wood occurrences. Ages from Cohen *et al.* (2013, updated). **Abbreviations: SV**, São Vicente do Sul; **MT**, Mata; **SP**, São Pedro do Sul; **SM**, Santa Maria, **FS**, Faxinal do Soturno; **CD**, Candelária; **SC**, Santa Cruz do Sul.

Table 1. Previously described wood taxa of Caturrita and Santa Maria formations in Rio Grande do Sul. In bold, the new ages proposed for the sedimentary succession contain the fossil woods by the data herein commented. **Abbreviations: Tr**, Late Triassic; **J**, Early Jurassic; **SPS**, São Pedro do Sul; **FS**, Faxinal do Soturno. **Symbol: ?**, reflect an uncertain age or source of the sample.

Taxa	Age	Outcrop/Locality	References
Rhexoxylon brasiliensis (Corystosp.)	Tr	near SPS (not precise)	Herbst & Lutz, 1988
"Araucarioxylon" spp. (conifer)	Tr/J?	Cerro da Ermida, SPS	Minello (1994b)
Baieroxylon cicatricum (Ginkgoaceae)	Tr	Chiniquá/Agua Boa, SPS	Minello (1994b)/Bardola *et al*. (2009)
Sommerxylon spiralosus (Taxaceae)	J	São Luis outcrop, FS	Pires & Guerra-Sommer (2004)
Kaokoxylon zalesskyi (conifer)	J	São Luis outcrop, FS	Crisafulli & Dutra (2009)
Agathoxylon africanum (conifer)	J?	Soturno River, FS	Crisafulli *et al*. (2016)
Chapmanoxylon jamuriense (conifer)	J?	unknow, SPS	this work
Chapmanoxylon sp. cf. *C. jamuriense*	J?	Soturno river, FS	Crisafulli *et al*. (2016)
Megaporoxylon kaokense (conifer)	J?	Soturno river, FS	Crisafulli *et al*. (2016)
Lobatoxylon kaokense (conifer)	J?	unknow, SPS	this work

Few specimens were found *in situ* (*sensu* Martínez & Santonja, 1994) and until now, they are exclusive from the areas of Mata and São Pedro do Sul. The reworked materials were for a long time found during agricultural activities, and most of them were sliced, polished and sold to scientific institutions and collectors. In Mata, however, they were catalogued and placed on floors and walls of different buildings, public parks, and squares (Figures 3A–C), a strategy of Priest Daniel Cargnin, an amateur paleontologist, to guarantee its preservation near the source area. Today these material are maintained in the field areas where occur (like in the Paleobotanical Garden of Mata) or housed in the regional museums. Those of São Pedro do Sul are also exposed in the Main Square (Figure 3D) and, when detected in the original levels (Figure 3E), allow to confirm its relation with the fluvial sandbars of CF. They are aligned in relation to the sandstone dunes (Figures 3E–F) in a preferential NNE direction, the same of the main river flow of CF.

On other side, in the more southern Água Boa and Chiniquá expositions (Figure 1), they are exclusive by the conjunct occurrence of conifers (mainly related with the Araucariaceae) and Ginkgophyta (Bardola *et al*., 2010), and thus support the older ages proposed by the stratigraphic models. In spite of the wealth of specimens in the whole region and the studies made (Pires & Guerra-Sommer, 2004; Bardola *et al*., 2009, 2010; Crisafulli *et al.*, 2009, 2016), their description is still far from providing a complete understanding of its diversity.

The pioneer work with fossil woods of the Paraná Basin was made by Rau (1933), a German specialist in coal mines prospection. Based on the anatomical features preserved in some charcoalified fragments, he nominated the new species *Cedroxylon canoasense*. In its notes, he indicates that it was found in a well 6 m deep, made in white clay deposits (the "tabatinga bermeja" for Rau), near the city of Canoas (Figure 1), and associated by him with the Triassic Santa Maria Formation (=basal SM2). However, the absence of Triassic levels in the region allow to infer that Rau´s material actually come from Permian units, and specifically, from the Rio Bonito Formation, distinguished by its white mudstones (with kaolinite), and charcoal lenses (Jasper *et al.*, 2011) in the Paraná basin sedimentary column. Additionally, Degani-Schmidt & Guerra-Sommer (2016), indicate the presence of *Agathoxylon*-type of wood at the Faxinal coal-mine. The specimen of Rau (1933) seems to be lost, but based in the original diagnosis and its poor illustrations, is herein proposed that represents a form of *Agathoxylon* (*Dadoxylon*) Hartig. Taking this into account, the first work with a taxonomic focus with the Triassic xyloflora of Rio Grande do Sul was that of Herbst & Lutz (1988). Based on samples from the Walter Ilha Museum in São Pedro do Sul, they described and proposed a new genus and species, *Rhexoxylon brasiliensis*, linked to the Corystospermales. Later, Minello (1994a), working in the Ermida outcrop, and based in the anatomy of a secondary xylem, proposed a relationship of this permineralized woods with *Araucarioxylon* (=*Agathoxylon*), what was afterwards confirmed by Guerra-Sommer *et al*. (1999).

Pires & Guerra-Sommer (2004), working with parautochtonous materials of the surroundings of Faxinal do Soturno county (São Luis outcrop, Figure 1), described the new genus and species *Sommerxylon spiralosus*, considered related to the Taxaceae. In the same levels, Crisafulli & Dutra (2009) studied an autochtonous conifer wood (with roots *in situ*), and considered it, by the anatomical features, comparable to *Kaokoxylon zalesskyi* (Sahni) Maheswari. Both materials come from the basal levels of a lake deposit, deposited over massive crevasse splay fine sands deposits, and together represents the younger levels of CF in the area.

Bardola *et al.* (2009) described a Ginkgophyta wood (*Baieroxylon cicatricum* Prasad & Lele) found at Chiniquá outcrop and associated to a tetrapod fauna characteristic of the Santa Maria Formation (Table 1). Other works also focused the taphonomic process involved in the fossil wood permineralization by silica minerals (Bolzon & Guerra-Sommer, 1994; Minello, 1993, 1994a, b) and in the applying of growth rings to confirm the seasonal conditions of the paleoclimate (Bolzon, 1993; Alves *et al*., 2005; Pires *et al.*, 2005).

MATERIAL AND METHODS

The two new conifer woods herein described are based on specimens identified in the fossil collection of the Paleontological Museum Walter Ilha, at São Pedro do Sul, and result from collections made in the 1960 decade. They are kept at the Museum under the acronym **CPWI** (field number CPV E1). One ovule and seed, tridimensionally preserved, found linked to a lignified portion (cone axis?) in the same beds that contain the *K. zalesskyi* wood remains (Crisafulli & Dutra, 2009) is also herein described.

Thin sections (transversal, longitudinal radial and tangential) have been prepared in the usual way. The anatomical nomenclature is based on García Esteban *et al*. (2002), and the terminology in the descriptions, is that from the list of microscopic features used by IAWA (2004). To the taxonomic treatment and description of araucaria related reproductive structures, the nomenclature proposed by Stockey (1978) and Stockey & Taylor (1978) was used. A minimum of 25 measurements was made, quoting the media, and minimum and maximum values in parentheses. The specimen described as "conifer seed" from the São Luis locality is kept at the Paleobotanical Collection of the Universidade do Vale do Rio dos Sinos (**UNISINOS**), in the city of São Leopoldo, Rio Grande do Sul, under the acronym **ULVG**-8352.

The original specimen of *Cedroxylon canoasense* Rau seems to be lost, but Philippe & Thevenard (1996) quote some slides found at the Humboldt Museum of Natural Sciences in Berlin (MNB collection numbers: 25/6r-359) which apparently belong to it (see below for more data). Although badly preserved, we assume here that they correspond to Rau's species.

Figure 3. The distinct Lower Mesozoic big woods of the Caturrita Formation ("Mata Sandstones") in the western area of central Rio Grande do Sul. **A**–**B**, large stems lying near the church and in the main square at the city of Mata; **C**, detail of a path paved with polished fossil wood pieces in Mata; **D**, fossil wood stems exposed in the main square of the São Pedro do Sul Municipality; **E**, organized disposition of big stems over the margins of BR 290 highway at Piscina outcrop (Paleobotanical Monument), São Pedro do Sul, and an *in situ* fossil woods (**arrow**) in the sand bar deposits (scale bar 50 cm). **F**, detail of the wood remains horizontal and multidirectionally orientated, in the mid-channel bar deposits of Piscina outcrop, characterized by intense bioturbation (arrows). Scale bar in figures E-F = 1 m.

SYSTEMATIC PALEONTOLOGY

Division TRACHEOPHYTA Sinnott, 1935 ex Cavalier-Smith, 1998
Class SPERMATOPSIDA Serbet & Rothwell, 1995
Order CONIFERALES Engler, 1897
Family *incertae sedis*

Lobatoxylon Kräusel, 1956

Type species: *Lobatoxylon pedroi* (Zeiller) Kräusel, 1956.

Lobatoxylon kaokense Kräusel, 1956
(Figures 4–5)

1956 *Lobatoxylon kaokense* Kräusel, 37: 447–453, tab. 2, fig. 10; tab. 4, fig., 17; tab., 5 figs. 18–21.
2001 *Lobatoxylon kaokense* Kräusel, *in*: Lutz *et al*., p. 123–125, fig. 5, tab. 1.

Material. CPWI 713 (field number CPV E1 067); slides CPWI 713a,b,c., São Pedro do Sul, Rio Grande do Sul, Brazil.
Description. Rounded slice of silicified wood about 13 x 9 cm in diameter, preserving a 4- lobulated heterogeneous, compact, nontabicated pith, primary xylem, and secondary xylem, but not the cortex (Figures 4, 5A–B). Parenchyma cells are rounded, their radial and tangential average diameters are 30 x 33 (23 x 35; 30 x 38) µm. Secretory circular cells, isolated or in groups, are present (Figures 5B–C). Scarce sclerenchymatous polygonal cells are also observed. Primary xylem with cuneiform projections, endarch protoxylem (Figure 5C). Growth rings present. Secondary xylem picnoxylic; tracheids are quadrangular in traverse section. An average of six (4–8) cells separate the radii (Figure 5D). In a longitudinal radial section, tracheids with uniseriate, circular, contiguous, biseriate and triseriate bordered pits (Figures 4, 5E–F). Cross fields with 4–6 araucarioid pits; in longitudinal tangential section radii are uni- and partially biseriate, averaging four to ten cells high (Figure 4).
Discussion. Some authors, like Berthelin *et al*. (2004) and Merlotti & Kurzawe (2011) still use the generic epithet *Trigonomyelon* Walton for *Lobatoxylon* Kräusel, but as shown by Lutz *et al.* (2001), who made a synthesis about it based on the arguments provided by Kräusel (1956), the latter name should be used. The four-lobulated pith and the pitting type of the longitudinal radial tracheidal walls of the secondary xylem allows to assimilate this specimen to the South African *L. kaokense* Kräusel and separate it from the other species recorded to this genus in the Permian, of Brazil: *L. pedroi* (Zeiller), originally named as *Dadoxylon pedroi* by Zeiller (1895), *w*hich was made the type species of the genus; from India: *L. raniganjense* (Maheshwari,1967; Prasad, 1986) and that from the Upper Triassic of India and Chile: *L. kamthiensis* (Prasad) Lutz, Crisafulli & Herbst (*in* Lutz *et al*., 2001). The distinctive characters are the absence of secretory canals in the pith, the hexagonal pits on the radial tracheidal walls and the presence of triseriate pits and sclerenchymatic cells in the pith, all absent in *L. kamthiensis*. The species *L. pedroi* is different because in *L. kaokense* the trilobite pith and its secretory canals is absent, and has a higher number of pits (4–6) in its fields, distinct from the 1–2 pits from *L. pedroi.*

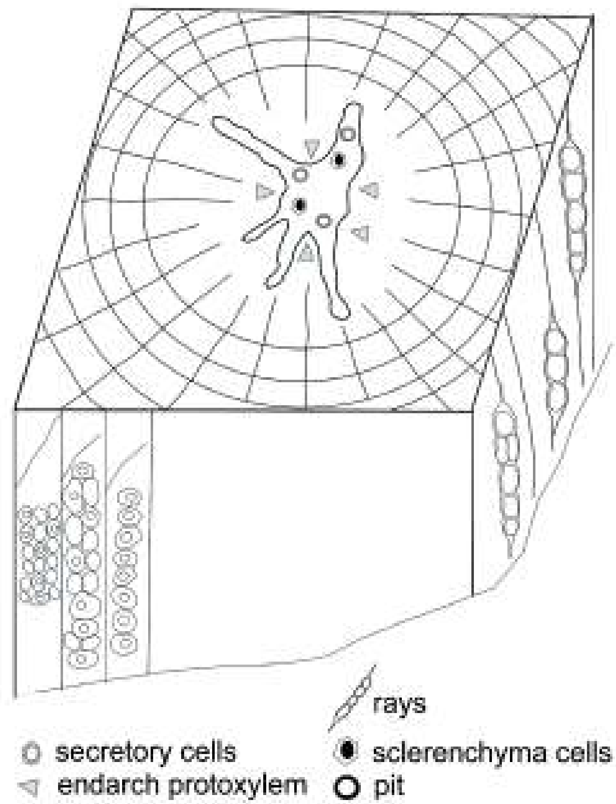

Figure 4. *Lobatoxylon kaokense* Kräusel. Block diagram showing wood characters in transversal, radial and tangential longitudinal section.

Chapmanoxylon Pant & Singh, 1987

Type species. *Chapmanoxylon jamuriense* (Maheshwari) Pant & Singh, 1987.

Chapmanoxylon jamuriense (Maheshwari) Pant & Singh, 1987
(Figure 6)

1966 *Dadoxylon jamuriense* Maheshwari, 13(2):148, lám. 1, fig. 1–5, lám. 2, fig 6.
1972 *Damudoxylon jamuriense* (Maheshwari) Maheshwari, 138: 11.
1987 *Chapmanoxylon jamuriense* (Maheshwari) Pant & Singh, 203, p. 21, tab. 3.
2008 *Chapmanoxylon jamuriense* (Maheshwari) Pant & Singh, *in*: Crisafulli & Herbst, 5: 739-740, fig 3.1–4 and 4.1–2.
2009 *Chapmanoxylon jamuriense* (Maheshwari) Pant & Singh, in Crisafulli *et al*., 5:7–8, figs. 5D–G, 6A–E.
2012 *Chapmanoxylon jamuriense* (Maheshwari) Pant & Singh, in: Leiva Veron *et al*., 8:71, figs. 3C–D.

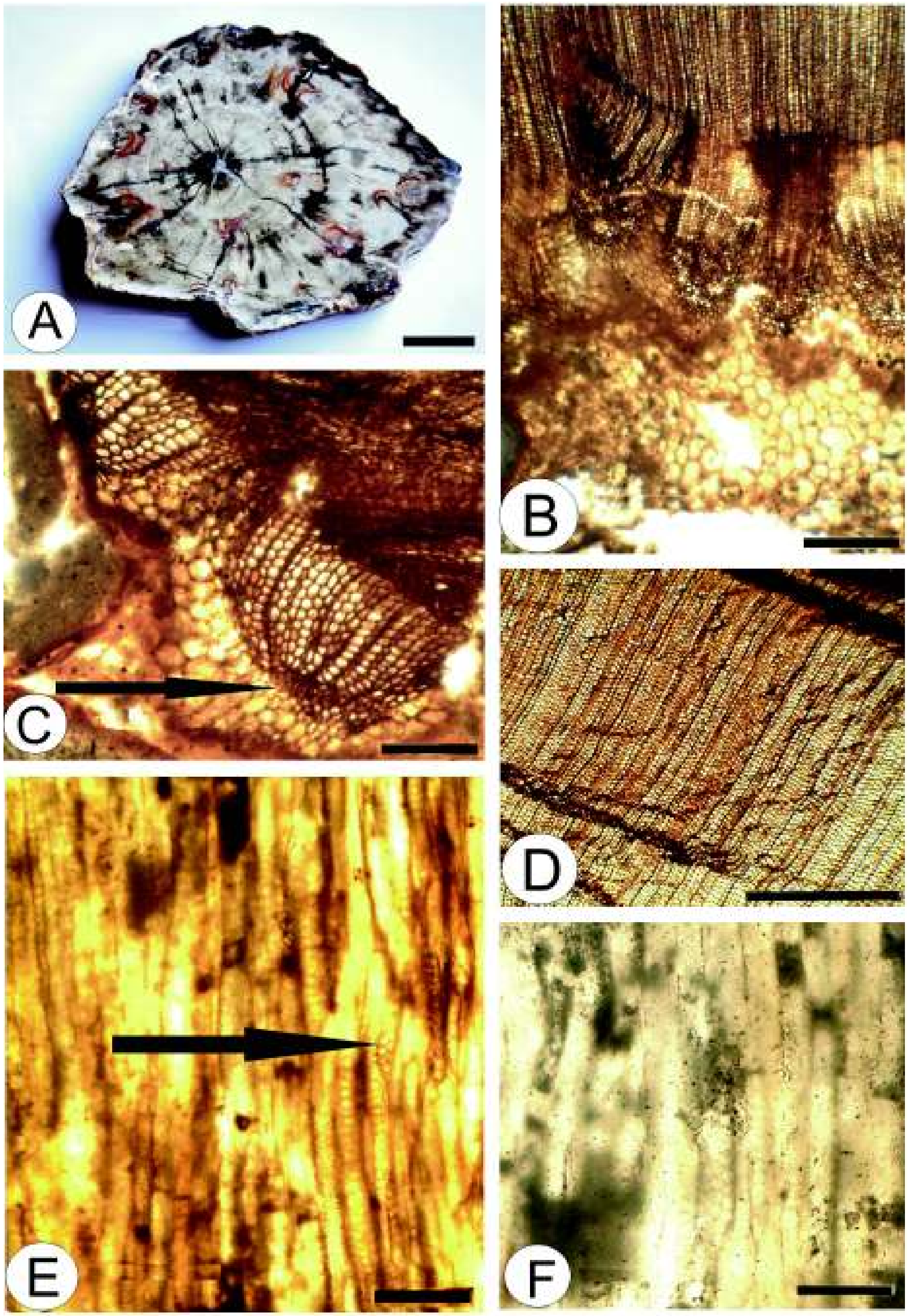

Figure 5. *Lobatoxylon kaokense* Kräusel. **A**–**D**, transverse sections (CPWI 713a): **A**, general aspect of the wood (CPWI 713); **B**, parenchimatic pith, primary xylem with wedge-shaped projections and pycnoxilic secondary xylem; **C**, detail of B: arrow indicates the protoxylem; **D**, secondary xylem with growth rings. **E**–**F**, Longitudinal radial section (CPWI 713 b), showing pits on the tracheidal walls: **E**, uniseriate pits; arrow indicates biseriate, alternate pits. **F**, uniseriate and triseriate pits. Scale bars: A = 5 cm; B = 150 µm; C, E = 100 µm; D = 400 µm; F = 70 µm.

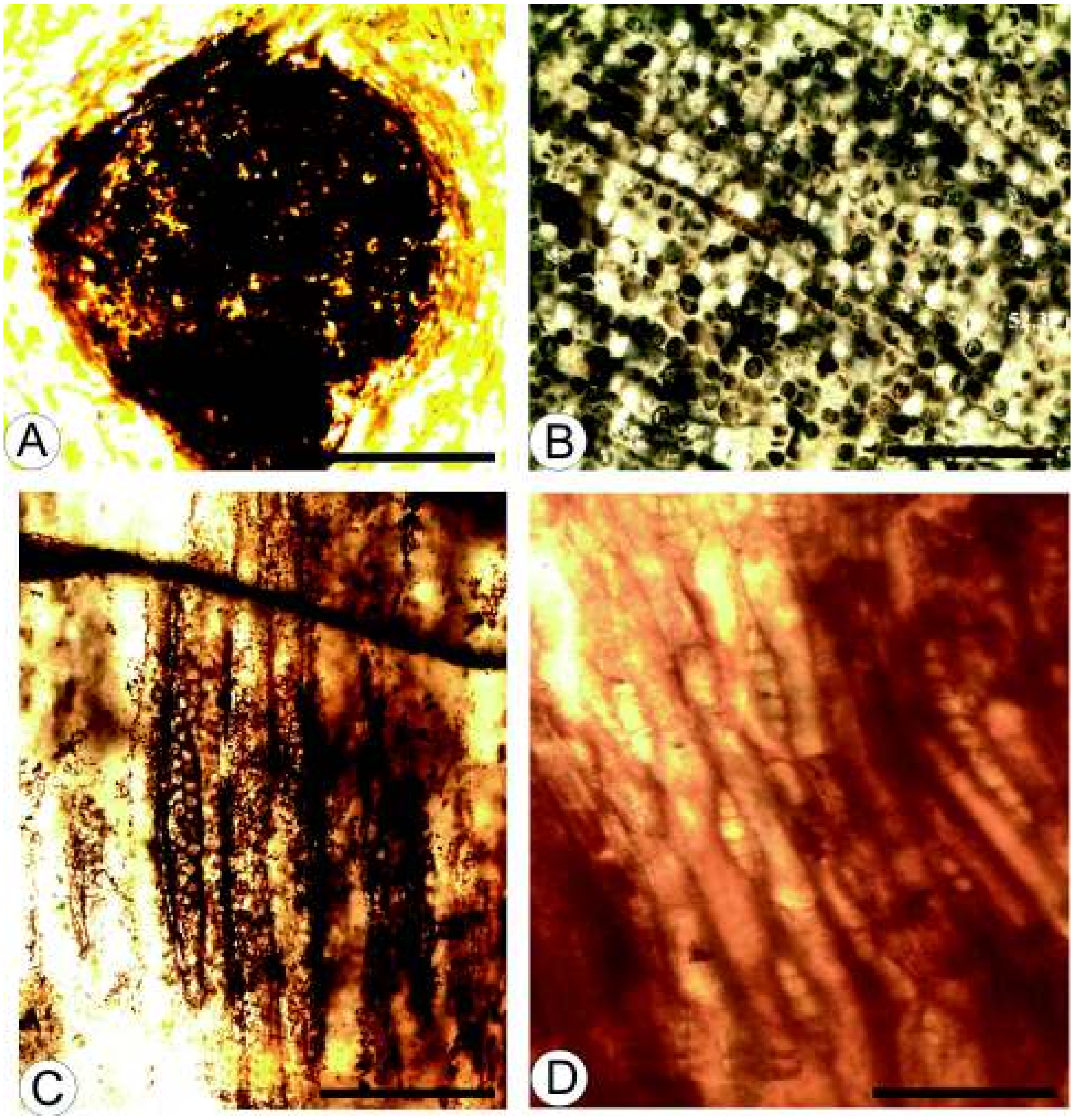

Figure 6. *Chapmanoxylon jamuriense* (Maheswari) Pant & Singh (CPWI 714). **A**, longitudinal tangential section of secondary xylem, with detail of transversal section of the pith of the trace (CPWI 714c); **B**, transversal section showing tracheids of secondary xylem with dark contents (CPWI 714a); **C**, longitudinal radial section of secondary xylem, showing biseriate, sub- opposite pits on the tracheidal walls (CPWI 714b); **D**, uniseriate and lower rays (CPWI 714c). Scale bars: A = 1 mm; B = 330 µm; C = 160 µm; D = 240 µm.

Material. CPWI 714 (original field number CPE1 091); slides CPWI 714 a,b,c. Walter Ilha Museum, São Pedro do Sul, Rio Grande do Sul, Brazil.

Description. Rounded slice of silicified wood, circa 8 cm thick and about 20 x 15 cm in diameter, preserving the pith, primary and secondary xylem, but without cortex. Pith circular, about 2.5 cm in diameter, homogeneous, compact, not tabicated and composed of rounded parenchyma cells in transverse section. Tangential and radial average diameters 55 x 63 (40 x 50; 50 x 60) µm. In the longitudinal radial section, they are rectangular. Primary xylem forming cuneiform projections; protoxylem endarch. Secondary xylem picnoxylic with marked growth rings and shearing zones (*sensu* Erasmus, 1976). In transversal section tracheids are rectangular; with radial and tangential average diameters of 42 x 33 (33 x 25; 48 x 33) µm; 6 (4–7) tracheid separate radii (Figure 6B). Radial walls of the secondary xylem cells with uni-to biseriate, circular, and contiguous to separate pits; the biseriate ones are alternate (Figure 6C). Cross fields with rounded pits. In longitudinal tangential section, the radial system is homogeneous. Radii are homocellular, uniseriate and low; average height is 5 (4–7) cells (Figure 6D).

Discussion. *Chapmanoxylon* is one of the few genera with a homogeneous pith and an araucarioid secondary xylem. The distribution of pits in the tracheids and cross fields, as well as the height of the non-articulate radii, justify the specific name of the present specimen. This species was also found in the Permian of Argentina (Solca Formation, Crisafulli & Herbst, 2008), Uruguay (Tres Islas Formation, Crisafulli *et al.*, 2009), Paraguay (Tacuary Formation, Leiva Verón *et al.*, 2012) and in the Permian Raniganj Formation of India (Pant & Singh, 1987). A specimen close to this species and referred as "*cfr.*" was found *in situ*, in levels of Caturrita Formation outcropping at the Rio Soturno terraces, near Faxinal do Soturno County (Crisafulli *et al*., 2016, Table 1).

Family ARAUCARIACEAE

Agathoxylon Hartig, 1948

Type species. *Agathoxylon cordaianum* Hartig, 1848.

Agathoxylon canoasense (Rau) Crisafulli nov. comb.
(Figure 7)

1933 *Cedroxylon canoasense* Rau, 68, figs. 1–3.
1949 *Xenoxylon canoasense* (Rau), Kräusel, *in*: Kräusel, 89: (part 3):188.
1996 *Xenoxylon canoasense* (Rau) Kräusel, *in*: Philippe & Thevenard, 91: 357.

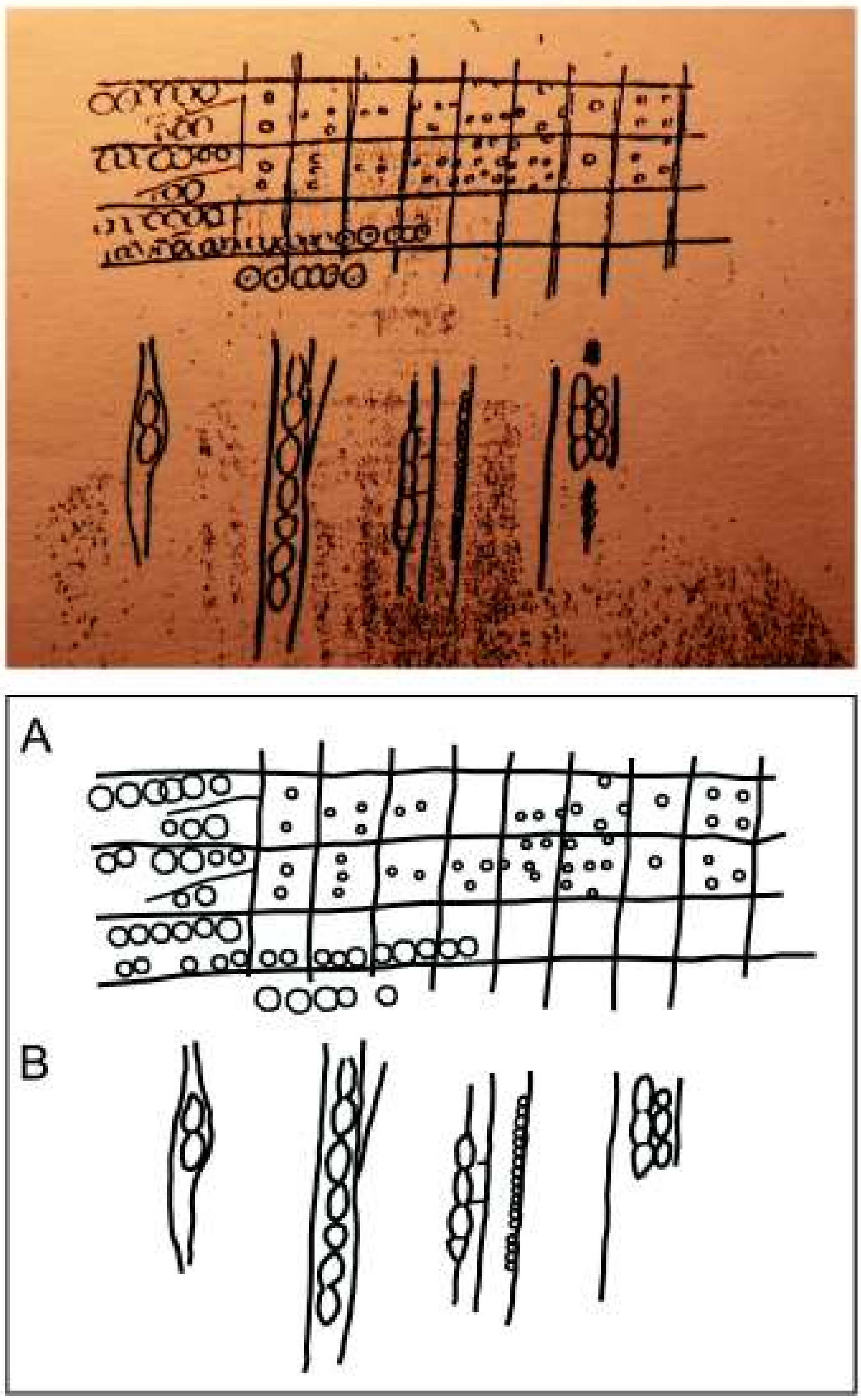

Figure 7. *Agathoxylon canoasense* (Rau) nov. comb., with the sketch from the original work of W. Rau (upper) and the more clear replica of it made by R. Herbst (low). **A**, longitudinal radial section of secondary xylem showing circular and contiguous uniseriate and biseriate, opposite, spaced pits, on the tracheidal walls and the arrangement of pits on the cross field. **B**, longitudinal tangential section showing uniseriate rays.

Diagnosis. Taken textually that from Rau (1933, p. 68): "Bordered pits uniseriate, rarely opposite. If biseriate, generally one row is on a different level or separated by fine tracheid-wall. Bordered pits flattened above and below and appear elliptic. There are slightly and greatly flattened pits. But circular ones are also seen in the rows and peculiarly if isolated. There are no hexagonal or polygonal pits. Diameter of the bordered pits 9–15 µm. Lenght of the markraysells (*) 21–28 µm. Breath of the markraysells 14–21 µm. In tangential slices the markrays are uniseriate, only rarely biseriate. Resin canals or cells do not exist. Growth rings perspicuous on the transversal slice. Pits of the markrays are small (abietinoid ?Prof. Zimmermann)". (*): *markraysells* and *markrays* are original spellings.

Comments. Kräusel (1949, part 3, p. 188) proposed a new combination of this species with the genus *Xenoxylon* based only on the poor quality of the photographs and Rau's sketches (herein redrawn in its proper vertical orientation), but left it as "doubtful forms". From the description and the few illustrations given by the author and our interpretation, it seems clear that this species can be included more accurately in *Agathoxylon* Hartig in its present modern definition (Rößler *et al*., 2014). The genus *Cedroxylon* initially proposed by Rau (1933) has a somewhat complicated history, as it has been used in several ways and with different meanings and further, the original diagnosis is not too clear, making of it a nice imbroglio. Bamford & Philippe (2001) and Philippe & Bamford (2008) reviewed the history of this genus and finally recommended not to use the generic name *Cedroxylon* Kraus, at least for the "Gondwanic area". It is out of our scope here to analyze this matter in detail, and thus it is felt that the generic name *Cedroxylon* can confidently be eliminated from the list of woods present in the Triassic of southern Brazil. On the other hand, Philippe & Thevenard (1996) showed that the genus *Xenoxylon* Gothan, used by Kräusel (1949) for Rau's specimen, seems to be exclusive to the boreal hemisphere, and also established that the species "*X. canoasense*" doubtfully belongs to it. In that paper, the authors cite the finding of some slides (numbered 25/6r-359) in the MNB (Berlin, see above) which seem to be original ones from Rau (1933). Philippe (*in litt*. 23-01-2016) from his early notes quotes about them: "radial pitting uniseriate, poorly preserved, possibly araucarian; cross fields not preserved". Thus, it seems we are certain in our assignment to *Agathoxylon*. From the evidence available (photographs and sketches by Rau & Philippe's data) most characters indicate this genus, except by the apparent "xenoxyloid" pitting in his photograph (Rau, 1933, fig.1), a character that does not appear in the mentioned slides.

Agathoxylon, viz. *A. africanum* (Bamford) Kurzawe & Merlotti, has been described in detail from Permian levels of southern Brazil (Kurzawe & Merlotti, 2010) and also to the Upper Triassic–Jurassic Caturrita Formation of Rio Grande do Sul, by Crisafulli *et al*. (2016). Many other specimens have been quoted as uncertain species of *Araucarioxylon* (Guerra-Sommer *et al*., 1999; Guerra-Sommer & Cazullo-Klepzig, 2000; Guerra-Sommer & Scherer, 2002), but are distinct from *A. canoasense*. A conservative position is maintained here in relation to the species, accepting that proposed by Rau (1933) until more and better material is available for comparisons.

A "conifer seed" in *Kaokoxylon zalesskyi* (Sahni) Maheswari
(Figures 8–9)

Comments. Replicas of ovules and seed, preserved in iron oxi-hydroxides, was detected on a sector of a *Kaokoxylon zalesskyi* (Sahni) Maheswari wood, also preserved by densely impregnated iron oxides. In the wood is maintained the pith, the cuneiform primary xylem and the picnoxylic secondary one (Figure 8A). The reproductive structures, with an oblong form, with 3.2 mm long x 0.8 wide, is inverted and adaxially inserted in one or perhaps two per scale (Figures 8B–C). The integument seems to be thick in texture, and the nucellus, micropylar part (narrow) and megagametophitic tissue are well developed (Figure 8E). In one portion of the stem, two nucellar cavities enclosed by a common integument was detected (Figure 8C). The integument seems to contain a sarcotesta and endotesta, although not very distinct. The nucellus may be differentiated from the integument, except in the chalazal area, and the megagametophitic tissue occupies all the space of the nucellar cavities. Part of the peduncle of this fructification is also preserved (Figures 8D–E; 9).

The specimen (ULVG 8532) originates from the same lacustrine laminated mudstones of São Luis outcrop (Caturrita Formation) where the *Kaokoxylon* species were detected and is housed at the Paleobotanical Collection of LaViGaea – MHGEO, UNISINOS (Figure 8A). Later, researchers from the Zoobotanical Foundation of Rio Grande do Sul identified in the same beds a still unstudied little "araucarioide" cone (2.5 cm in diameter), covered by a crust of iron-rich clay, which conserves its tridimensional morphology and the inserted seeds.

Other evidence of such kind of special and exceptional preservation of plant fossils in the Triassic and Jurassic beds of South Brazil were preliminarily informed (Dutra & Barboni, 2014) and are under study (Kerkhoff, 2017). This is aligned with the many announcements about similarly preserved plant fossils in other world deposits, most with correlate ages and preservation. They called the attention by its coincidence with signals of microbial activity as inductors of the iron deposits and favouring this unique preservation (*e.g.* Dunn *et al.*, 1997; Bomfleur *et al*., 2007; Locatelli, 2014; Peterffy *et al*., 2016).

As already pointed by Crisafulli & Dutra (2011), the herein described seed characters allow a general comparison with those found in the Araucariaceae representatives, like that from the Jurassic Cerro Cuadrado Formation, Argentine Patagonia (Stockey, 1975, 1977, 1978; Stockey & Taylor, 1978), Rajmahal Series, India (*Araucarites mittrii* from Bohra & Sharma, 1980), and other genera of Coniferales *sensu lato* (*e.g. Nipaniostrobus* Rao, 1943), and *Sciadopitys* (Saiki, 1992), from the Cretaceous of Japan. With *A. mittrii* it shares the presence of two nucellar cavities found in some specimens. However, in the here studied ovule the shrunk or wavy zig-zag appearance of the nucellus in the micropylar

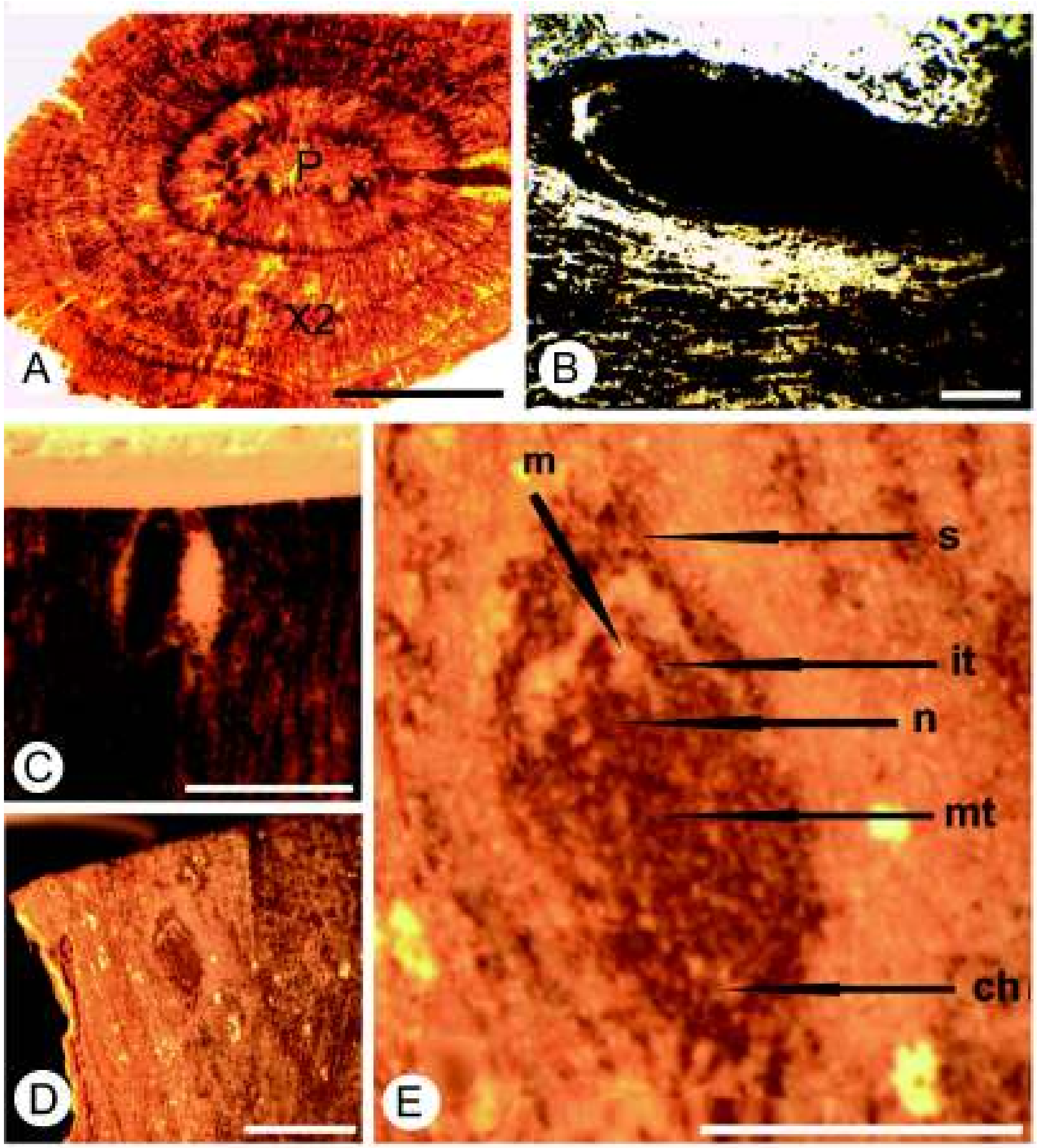

Figure 8. *Kaokoxylon zalesskyi* (Sahni) Maheswari (ULVG 8352) and associated seed. **A**, transversal section showing pith (**P**), wedge-shaped primary xylem (**X**) and picnoxylic secondary xylem (**X2**). Slide ULVG 8352a; **B**, longitudinal tangential section of secondary wood (ULVG 8352b), highlight the curving radial system which accompany the reproductive structure; **C**, longitudinal tangential section of secondary wood (ULVG 8352b), with the seed and an empty space left by another one; **D**, seed on the wood structure (ULVG 8352a); **E**, detail of D. **Abbreviations: s**, scale; **m**, micropyle; **it**, internal tegument; **mt**, megagametophytic tissue; **ch**, chalaza; **n**, nucella. Scale bars: A = 25 mm; B = 800 µm; C = 17 mm; D = 5 mm; E = 2.2 mm.

zones, characteristic of *A. mittrii* and *A. mirabilis* Spegazzini (Stockey, 1975, 1978), was not observed.

The herein detected reproductive structure and some features of the associated wood also suggest an affinity with the Jurassic petrified cone, *Pararaucaria patagonica* Wieland emend. Escapa, Rothwell, Stockey & Cúneo (Stockey, 1977; Stockey & Taylor, 1978; Escapa *et al.*, 2013), from Cerro Quadrado and Cañadon Calcáreo formations, to the cone axis of Araucariaceae from Stockey & Taylor (1978) and, in longitudinal section, with the ovules of *Mikasastrobus hokkaidoensis* Saiki & Kimura (1993) cones.

Taking all this data into account, it seems to be somewhat difficulties to establish whether these ovules were part of a definite "cone", or if they are attached to the wood as suggested by the surrounding tissues, where the tracheids seem to curve around the seed (Figures 8B–E). In any manner, and despite the poor state of preservation, the peculiar state of its preservation stimulates the detection of other similar occurrences.

FINAL REMARKS

The two new woods herein described from samples housed at the Walter Ilha Museum of São Pedro do Sul, help to enlarge the list of known gymnosperm wood taxa from the Triassic and Jurassic of Southern Brazil (Table 1). Therefore, an emphasis has to be put in describing more *in situ* material in order to make more clear the characteristics of the "fossil

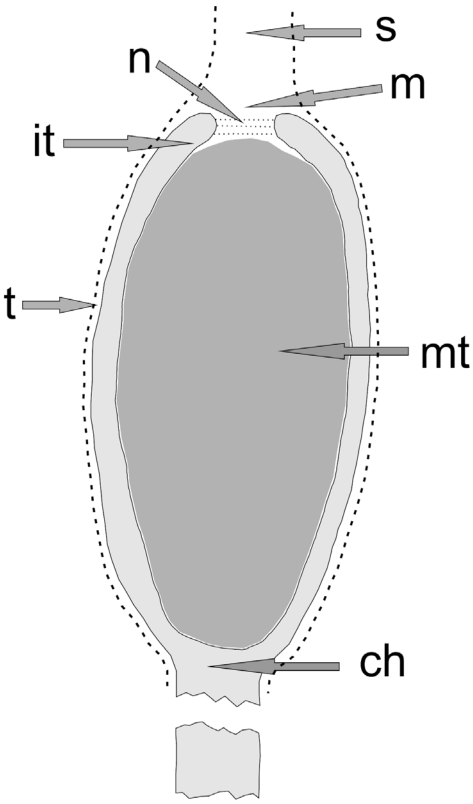

Figure 9. Sketch of the female reproductive structure. **Abbreviations** as in Figure 8.

forests" of Santa Maria and Caturrita formations.

To the CF, the present study attests for the first time, a more formal presentation of fertile organs linked to the Araucariaceae. Associated to the previous known female cone of *Williamsonia potyporanae*, also tridimensionally preserved and in the same mudstones facies of the São Luis outcrop (Barboni & Dutra, 2013), is possible to inferred a flora of bennettites and small woody araucarioid conifers (by the caliber of its autochtonous roots and stems), which growed over crevasse splay deposits or river channel margins and were covered by the less ephemeral waters of a confined lake (oxbow?) or alluvial plain, in epochs of increasing humidity. A similar context was proposed by Colombi & Parrish (2008) for the Valle de La Luna Member of the Ischigualasto Formation in northeastern Argentina. In the Ladinian–Carnian Santa Maria Formation, reproductive structures were known for a more long time, exhibiting relations with *Dicroidium* or its allied genus (*Pteruchus* and *Umkomasia* related forms) and with the Ginkgoaceae. Finally, the analysis made with the original material of *Cedroxylon* from Rau (1933), allow us to reject the presence of this genus in the list of taxa from Brazil, and still its relation with the Triassic assemblages.

All of them together, these findings expand our knowledge about the Mesozoic paleoxylotaphoflora of Brazil, and attest the radiation of the gymnosperms in the south-western interior areas of the Gondwana, under the influence of changing climates and environments. The data here discussed support a Middle–Late Triassic interval characterized by continuous landmasses and seasonal climates like proposed by Parrish (1993) and Preto *et al*. (2010) that allowed a uniform and dominant *Dicroidium* and Ginkgo flora to be distributed along the Gondwana. Between the end of Triassic and the Lower Jurassic (McElwain *et al*., 1999), despite the great extinction event worldwide detected, or because of it, this flora gave place to a more local and shrub size vegetation of conifers, which soon evolved to higher strata of wood forests adapted to the margins of low sinuosity rivers and to the crevasse splay deposits of the small rift basins resulting from extensional tectonic efforts (Zerfass *et al.*, 2004). In all those processes the here detected wood floras and its associated facies are an important tool for the paleoenvironmental reconstructions.

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TRIBUTE TO PE. DANIEL CARGNIN AND DR. RAFAEL HERBST

***"Here in Mata I don´t have catholics, lutherans, evangelics, black or whites, I have people"* (Pe. Daniel Cargnin)**

Dr. Rafael Herbst

We want to leave our homage to two lost persons in the last years that had a great significance in our lives and in the research with Paleobotany in Brazil, by their dedication and the splendid work made.

Father Daniel Cargnin (1930–2002), priest of Mata during 20 years and an amateur paleontologist, while carrying out his main mission of protecting the men soul, also was fascinated by the numerous occurrences of fossil woods in the city terrains. Then, he convinced the inhabitants of Mata and of the surroundings to use the fossil woods as an ornament in the streets, squares and buildings, in a way of preserving and protecting that wealth. His clairvoyance is attested by the words in the figure here shown, written by him at the end of the 1970`s, and more than this, by its big concern for humanity.

Dr. Rafael Herbst (1936–2017), despite being one of the greatest geologists and paleobotanist from Argentina, and having trained a great amount of young researchers in the study of fossil woods, was also a "globetrotter", fond by the South American landscapes. During a long time he comes to Brazil, searching for comparative forms between the Triassic deposits of his and of our country. In one of these trips, a sample showed by Dr. Walter Ilha, director of the Museum, at São Pedro do Sul, allowed him to describe, with Alicia Lutz, the exclusive pteridosperm wood *Rhexoxylon brasiliensis* from the Paraná Basin deposits of Rio Grande do Sul, expanding our knowledge about of the "Dicroidium Flora". This tribute to Pe. Cargnin was a desire of Dr. Herbst during the time off we were involved in the present work, and the herein made homage (with the plaque in the entrance of the Church of Mata) had been prepared by him.