

Canoinhas Outcrop, State of Santa Catarina

Unique Record of the Permian Conifer *Krauselcladus* from the Paraná Basin

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Unique Record of the Permian Conifer Krauselcladus from the Paraná Basin

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The Canoinhas outcrop (in state of Santa Catarina) represents a peculiar palaeontological and palaeoenvironmental record from the Guadalupian at the Paraná Basin, and its type section is really meaningful in terms of lithologies of the upper part of the Teresina Formation (Passa Dois Group), including a great number of very well preserved lithofacies which are hardly ever found all joined at the same location. It corresponds to the type locality of the unique conifer branches known at this time interval in the Brazilian portion of Gondwanaland. The conifers described as *Krauselcladus canoinhensis* pointed by its exceptional morphological and anatomical preservation, presenting xeromorphic features that reinforce the previous understandings about the climatic context relatively dry at the Paraná Basin. There are also teeth and scales of fishes concentrated in bone beds, and bivalve shells in carbonates or coquinas well mixed with abundant permineralized microphylls, and rare lycophyte stems. The depositional environment of the formation was probably a large shallow water body influenced by storms without evident connection with the ocean and marked by climatic oscillations. The Canoinhas outcrop is presented here as an important palaeontological and palaeoenvironmental site which has a huge historic evolutive meaning for recording the gradual climatic context of drought at the western Gondwana regions (including the Paraná Basin) from the end of the Early Permian.

Key words: Canoinhas outcrop, Teresina Formation, Paraná Basin, *Krauselcladus*, Coniferales, Guadalupian.

INTRODUCTION

The Canoinhas outcrop, in state of Santa Catarina, described here provides a concrete example of the upper portion of the lithostratigraphic unit known as the Teresina Formation, a unit comprising part of the Passa Dois Group of the Paraná Basin (Schneider *et al.*, 1974; Rohn, 1994, 1997; Rohn & Lavina, 1993; Milani, 1997).

The intracratonic Paraná Basin includes a vast region in the eastern central part of the South American continent and consists of a magmatic sedimentary package documenting the temporal interval between the Late Ordovician and the Late Cretaceous during the evolution of Gondwana (Milani, 1997). The Brazilian part of this large basin involves more than a million square kilometers, with the western portion encompassing parts of the states of São Paulo, Paraná, Santa Catarina and Rio Grande do Sul (Milani, 1997).

The Canoinhas outcrop represents a distinctive palaeontological and palaeoenvironmental register of the Paraná Basin during the Guadalupian (Middle Permian). It is the type locality of the only conifer branches known for this time interval in the Brazilian Gondwanaland (Yoshida 1968, 1970; Rohn *et al.* 1997; Fanton *et al.* 2006). These are exceptionally well preserved morphologically and anatomically. Since

fossil conifer records in other Gondwanan basins of the Middle and Upper Permian are also relatively rare, the Canoinhas fossils are especially important in their contribution to our knowledge about the evolutionary history of the conifers.

The outcrop is also lithologically quite representative of the upper part of the Teresina Formation; it includes a large number of well preserved lithofacies, which is difficult to find in a single location elsewhere. In addition to the conifer-bearing layer, the outcrop includes bone beds concentrating the teeth and scales of fishes, as well as coquinas composed of fragmented mollusc shells and permineralized microphylls and stems of lycophytes.

Part of the outcrop containing the fossil conifers has already been damaged by the paving of highway from Canoinhas to Porto União, and it may be totally destroyed if additional lanes are added to the highway or the shoulders are widened. Therefore, protective measures should be instituted to preserve this unique geologic site.

LOCATION

The Canoinhas outcrop (26°11'59.8" S and 50°25'58.8" W) is located in the western part of the state of Santa Catarina, approximately 6 km to the southeast of the main interchange in the municipality

of Canoinhas, along highway BR 280 (Fig. 1). The outcrop has been cut from east to west by the highway at km 242. The rocks containing the fossil conifers are located along the southern edge of the roadway, practically on a level with the asphalt. The northern part of the outcrop constitutes an abandoned quarry (Fig. 2) from which material for the maintenance of the local roads of the region was extracted.

HISTORICAL OVERVIEW

The seminal palaeontological study of Yoshida (1968) provided a systematic report of the conifer fossils in the Canoinhas outcrop, and a new genus (*Krauselcladus*) was identified, with two species proposed. The type-locality, however, was described as belonging to the "Estrada Nova Formation". Nowadays, however, this stratigraphic unit is generally known as the Teresina Formation (Schneider *et al.* 1974; Rohn, 1994, 1997; Rohn & Lavina, 1993; Milani, 1997).

Rohn (1994) analyzed the environmental evolution of the Paraná Basin in the eastern part of Santa Catarina and Paraná and mapped the columnar section of the Canoinhas outcrop. She described the lithology, provide a preliminary palaeontological description and, based on stratigraphic correlations, concluded that the outcrop must correspond to the upper part of the Teresina Formation. Rohn (1994) reported the presence both of the conifers and of bivalve coquinas, as well as microphylls and sparse stems of lycophytes. Later publications concerning the chronostratigraphic and palaeogeographic interpretation of the bivalve (Simões *et al.* 1997, Stollhofen *et al.* 2000) and plant fossils (Rohn *et al.* 1997; Rohn & Rösler, 2000) gave rise to new discussions about the possible age of these records and the environment of their deposition.

Fanton *et al.* (2004, 2005, 2006) reinvestigated the morphological characteristics of the *Krauselcladus* conifers and pointed out new anatomical data, concluding that all of the Canoinhas branches could be classified as belonging to the single species *K. canoinhensis* Yoshida, and the diagnosis was emended. Various taphonomic interpretations of the layer containing the abundant conifer branches were suggested in an attempt to explain the specific event in the depositional history of the Paraná basin.

SITE DESCRIPTION

Geology

The Canoinhas outcrop (Fig. 2) corresponds to the upper portion of the Teresina Formation (Rohn, 1994, 1997). As denominated by Gordon Jr. (1947)

and modified by Schneider *et al.* (1974), the Teresina Formation is defined as the lithostratigraphic unit located between the Serra alta and Rio do Rasto formations, which, together with the Irati Formation, constitutes the Passa Dois Group in the central and southern part of the Paraná Basin. As the basin progresses to the northeast, this formation gradually decreases in thickness and gives way to the reddish color generally considered characteristic of the Corumbataí Formation in the state of São Paulo (Rohn, 1994).

Some 40 meters of the upper the Teresina Formation are exposed in the Canoinhas outcrop, with 14 meters along the southern edge of the highway, and the rest constituting an abandoned quarry along the northern edge (Rohn, 1994; Rohn *et al.* 1997; Fanton *et al.* 2006). The complete columnar section of the outcrop is presented in Figure 3.

The base of the outcrop along the southern edge consists of thin interlaminated shales and very-fine grained calciferous sandstones with wavy bedding and bioturbation. They are intercalated with bivalve-bearing oobiosparites and, wave cross-laminated very fine calciferous sandstones, in part including thin mud intercalations, flaser and wavy bedding, as well as parallel lamination and mud cracks (Fig. 3). After a short covered interval, the succession presents fine-grained heterolithic rocks with wavy bedding, mud cracks and thin rippled fine-grained sandstones. Above this is a light grey very fine-grained calciferous sandstone in which the branches of the conifer *Krauselcladus canoinhensis* (Fig. 3) are found. The branches are abundant in various horizons of the sandstone and are exceptionally well preserved (Fig. 4.A). This bed is practically on a level with the asphalt.

On the other side of the highway, at a distance of a hundred meters, the stratigraphic profile of the abandoned quarry reveals mostly interlaminated mudstones and fine-grained sandstones with wavy bedding (Fig. 3). Fine sandstones with wave cross lamination are common. Some parts of the section show cyclic gradually coarsening-upward successions, suggesting changes in depth of depositional environment from deeper to shallower water, with greater storm wave influence at the top of the succession.

At the base of the northern exposure is a layer of oosparite; in the middle portion are abundant clastic dikes (possible the result of seismic activity during the Permian) and bone beds composed of fish teeth and scales. In the upper portion is a coquina composed of more or less fragmented bivalve shells as *Pinzonella neotropica* and *cf. Jacquesia elongata* (Rohn & Penatti, 1993; Rohn *et al.* 1995a,b) which includes abundant microphylls and rare stems of lycophytes (*?Lycopodiopsis derbyi*), permineralized with silica (Fig. 4. C,D).

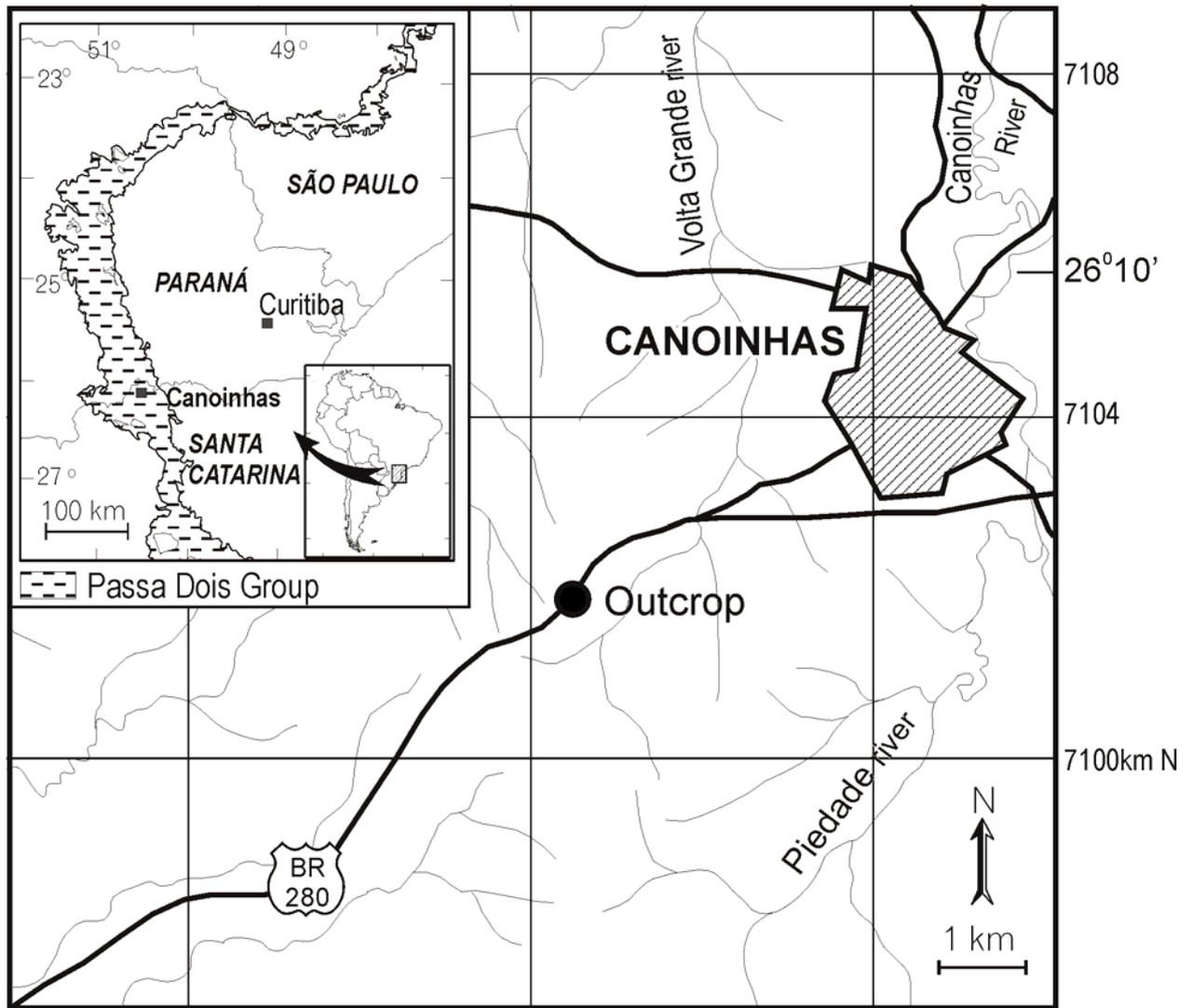


Figure 1. Map showing location of Canoinhas outcrop (circle), in the state of Santa Catarina in the south of Brazil (modified from Fanton *et al.* 2006).



Figure 2. View of Canoinhas outcrop on northern side of highway BR 280.

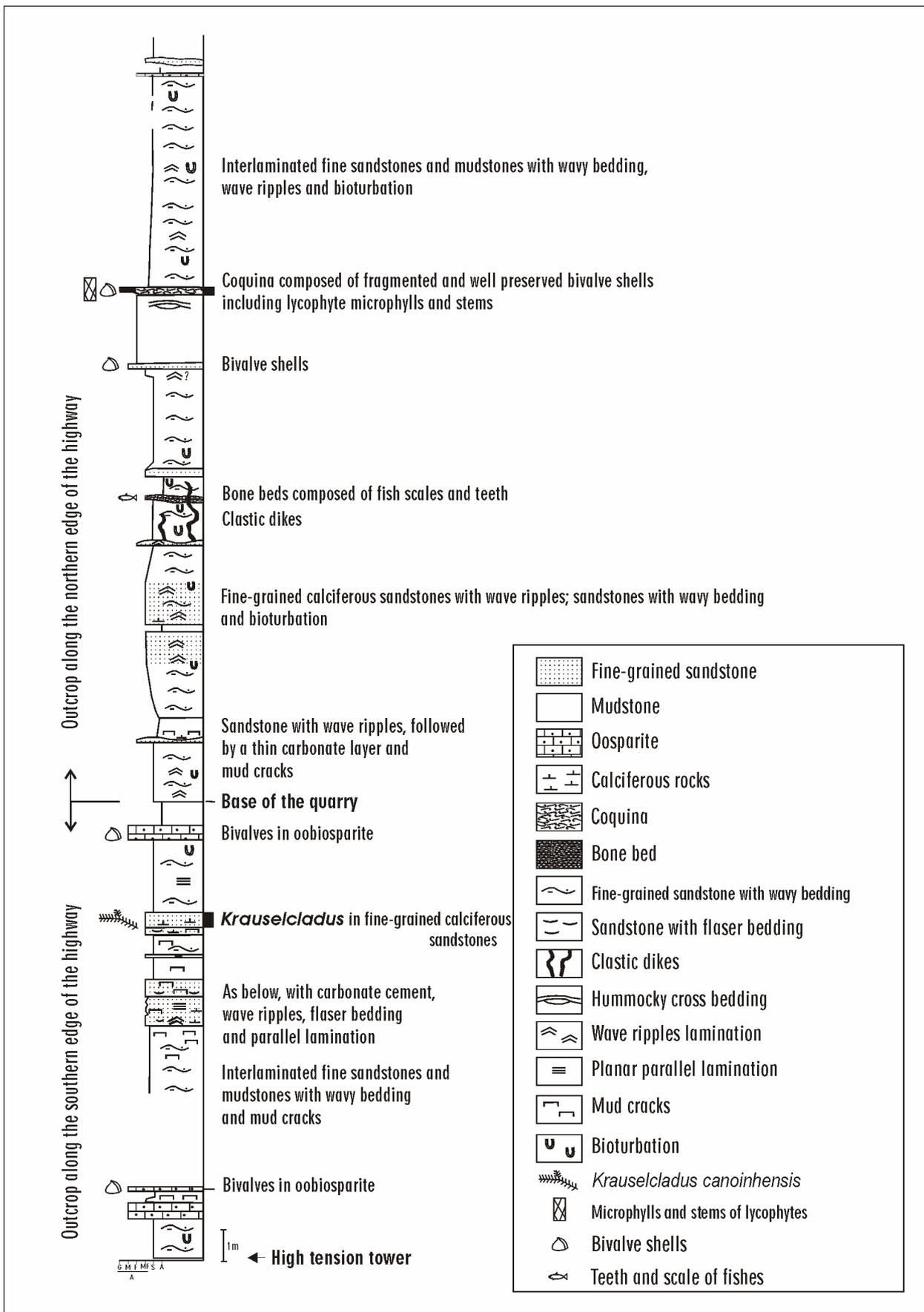


Figure 3. Columnar section of Canoinhas outcrop (modified from Fanton *et al.* 2006).

According to some authors (Schneider *et al.* 1974; Milani, 1997), the Passa Dois Group records a long

marine regression and a consequent continentalization of the Paraná Basin, revealing the transition from

marine to continental conditions. Various authors have posited a shallow marine environment with tidal flats for the deposition of the Teresina and Corumbataí formations (Schneider *et al.* 1974; Petri & Coimbra, 1982; Souza *et al.* 1991), whereas Lavina (1991) and Rohn (1994) discard the influence of tides, as well as any direct connection between the ocean and this large shallow epicontinental sea. The lack of evidence for a marine connection during the deposition of the Teresina Formation has been corroborated by recent studies which reaffirm the endemic nature of the bivalve molluscs found in this formation (Simões *et al.* 1998; Mello, 1999).

During the gradual dryness increment of the Paraná Basin region, cyclic oscillations between drier and wetter conditions must have occurred. These climatic oscillations probably influenced variations in water level and its salinity (Rohn, 1994; Fanton *et al.* 2006; Meglhoratti, 2006). It has also been suggested that the genesis of the carbonates in the Teresina Formation has been related to the drier climatic conditions, when the supply of siliciclasts was reduced and the water had probably become saltier, more alkaline, and shallower (Rohn, 1994; Meglhoratti, 2006).

The Teresina Formation lacks good index fossils and up to the present no volcanic intrusions have been found which would make precise absolute dating possible. However, some important radiometric dates are available for the Irati Formation and indirectly for the Rio do Rasto Formation. In his review of the palynostratigraphy of the Carboniferous-Permian interval of the Paraná Basin, Souza (2006) reported that the bentonites interbedded in the Irati Formation (resulting from the alteration of volcanic ashes) had an approximate age of 278.4 ± 2.2 Ma, corresponding approximately to the end of the Artinskian. Stollhofen *et al.* (2000) revealed that the volcanic ashes located slightly above the last occurrences of bivalves in the Gai-As Formation (correlating with the bivalves in the lower portion of the Rio do Rasto Formation) were dated to 265 ± 2.5 Ma, which is approximately equivalent to the middle of the Guadalupian (beginning of the Capitanian). These data make it possible to locate the upper portion of the Teresina Formation as probably belonging to the Lower Guadalupian (Roadian).

Palaeontology: The conifer *Krauselcladus canoinhensis*

The genus *Krauselcladus* Yoshida *emend* Fanton *et al.* is the only conifer formally recognized in the Brazilian portion of Gondwana which can be attributed to the Guadalupian (Middle Permian). This genus has been found exclusively in the Canoinhas outcrop; it was described by Yoshida (1970), who originally proposed

two species, *K. canoinhensis* Yoshida e *K. catarinensis* Yoshida.

The fossils of this conifer are preserved as compressions/carbonifications (Fig. 4. A) and generally have a well preserved cuticle, which makes the anatomic analysis of the epidermis of the leaves possible. A reinvestigation of the morphological characteristics and the description of new anatomical data led to the conclusion that the two originally proposed species (Yoshida 1970) are actually only *Krauselcladus canoinhensis*. Moreover, the presence of esquizogenous resin ducts suggested that the fossils belong to the Coniferales Order (Fanton *et al.* 2006).

Morphologically, the species *Krauselcladus canoinhensis* is represented by abundant sterile compound branches with four orders of branching; they are densely covered with simple sessile bifaciate leaves, with a decurrent base, spirally attached along the axis. Two basic morphotypes of leaves are found: linear (either straight or falcate) and lobed (bi- or multilobed), both having a conspicuous central vein. An artistic reconstitution assuming a tree-sized plant, as well as a detail of the morphology of the branches, is presented in Figure 4. A,B.

Anatomically, the presence of thick cuticles, abundant pits in the thick walls of the epidermal cells, sunken stomata and the resin ducts are considered xeromorphic structural adaptations resulting from a hydrologically deficient habitat, such as that associated with seasonal winds. Relatively dry conditions are also suggested by other evidence in the Teresina Formation (Rohn, 1994, 1997).

Taphonomically, the fact that the only known fossil branches of the conifer *Krauselcladus* have been found in the Canoinhas outcrop may be the result of an exceptional situation in the context of the broader depositional environment of the Teresina Formation (Rohn & Lavina, 1993; Fanton *et al.* 2006). The excellent preservation of the cuticles during the carbonification process suggests rapid burial of the branches in an aquatic environment. Considering that these conifers probably grew far away from the coast in an area with a limited water supply, it seems possible that the respective communities may have been spread closer to the epicontinental sea or retreated from it as a function of the rise and fall of the water level during periods of climatic oscillation. A long phase of frequent subaerial exposure due to drier conditions may have led to the approximation of the conifer communities to the basin. Under the influence of one or more strong storms, the conifer branches may have been stripped from the trees and quickly transported and deposited. In this way, the xerophilous elements did not necessarily suffer long transportation to the basin, which would explain the exceptionally good state of preservation (Fanton *et al.* 2006).

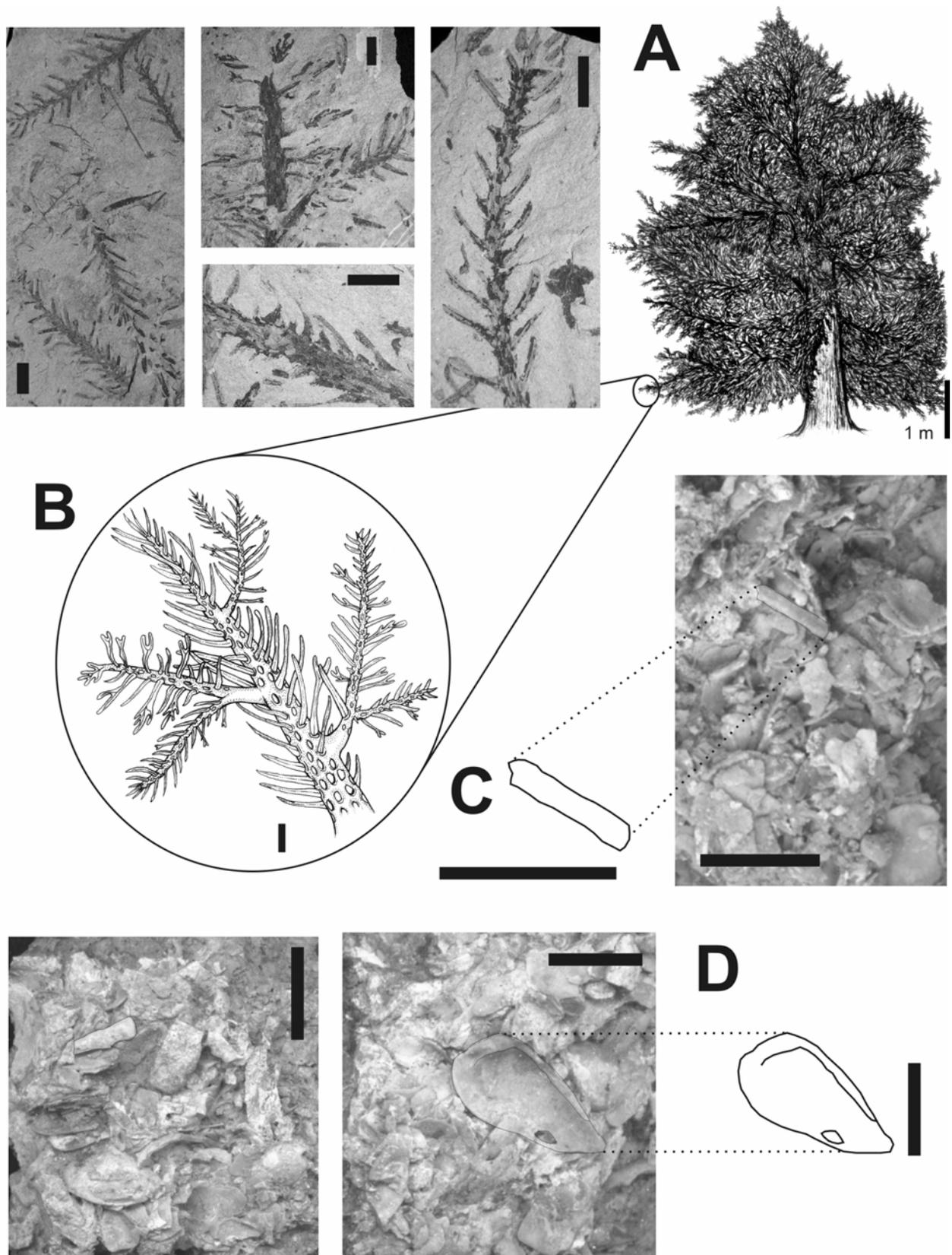


Figure 4. Fossils of the Canoinhas outcrop. **A-B:** Conifer *Krauselcladus canoinhensis*. **A.** Branch compressions and artistic reconstruction. **B.** Detail of branch with heteromorphic leaves. **C-D:** Silicified coquinas. **C.** Microphylls (?*Lycopodiopsis derbyi*). **D.** Bivalve shell fragments (*Pinzonella neotropica*, cf. *Jacquesia elongata*). Scale bars = 10 mm. (**A-B:** modified from Fanton *et al.* 2006).

PROTECTIVE MEASURES

The location of the outcrop on a federal highway means that the conservation of the site depends on the action of the public organs responsible for the management of this stretch of road (DNIT/SC and DEINFRA/SUPRE Norte). The data of these organs suggest that this section of the highway is reasonably well kept up; It consists of a two-lane highway with a lowered shoulder in some places; moreover, traffic of slow trucks transporting heavy containers and logs along the highway is very intense.

Given the intense truck traffic along this stretch of highway, it is highly probable that the government will propose the construction of additional lanes. In this case it will be necessary to orient the competent authorities so that the gravel and other residue left after construction will not be discarded beside the roadway in a place where they will cover the fossiliferous deposits. In order to guarantee the preservation of this fossil site, any such additions should be made to the north, so that the definitive loss of this natural patrimony can be avoided.

Moreover, the outcrop has not been marked in any way, and no information about the fossils is available to the general public. The long-term residents of the area are aware of the existence of the fossils, but the detached conifer branches have been interpreted as spikes of wheat which fell from a truck when it turned over on the highway. According to the comments of some of these residents, many samples of the fossils were carried off to private homes as souvenirs.

It is thus suggested that informative signs be installed along the relevant portion of the highway, and that a parking area be cleared on the northern side of the highway for vehicles, so that the touristic-educative potential of the outcrop can be exploited. The installation of attractive panels in a language accessible to the public at large is recommended, and these should provide information about the fossils to be found in the location, including an explanation of the probable environment in which the plants lived and the importance of these fossils today. Such an initiative should help preserve the site by involving the population in its welfare. It is recommended that an area of a few square meters where the actual fossils are concentrated be fenced off to avoid depredation and collection of the last fossil-containing rocks.

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