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Oligocene – Miocene Angiosperm Fossil Site at the Boa Vista Basin, Paraíba State, Northeast Brazil

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Abstract

The Boa Vista Basin consists of a half-graben controlled by the extensional reactivation of the Serra do Monte Shear Zone, situated within the Transversal Zone, Alto Moxotó Domain of the Borborema Province. The basin was filled by a volcanic-sedimentary sequence characterized by basaltic flows, lacustrine bentonitic clays, and fluvial sandstones and conglomerates of the Campos Novos Formation. The age of the overlying basalts indicates the Oligocene-Miocene boundary. The palynomorph association observed in the Campos Novos Formation presents a preliminary age from the upper Eocene to the lower Oligocene. We identified the fossil material in the sandstones and bentonitic clays. The massive lithic arkosic sandstones present planar and trough cross-bedding and include pieces of silicified wood up to 2 m in length. The bentonitic clays present greenish, light brown, and dark brown colors, with fossil remains identified at the levels of greenish and light brown bentonitic clays in the Juá II and Bravo mines. About 200 specimens of leaves, fruits, and wood fragments were collected at these site, associated with ichnofossils in vertical and horizontal tubes. Among the numerous and varied leaf remains preserved as impressions, Fabaceae, Annonaceae, Lauraceae, Burseraceae, Anacardiaceae, Myrtaceae, and Malvales types dominate. The set attests to a tropical to subtropical flora, similar to elements that grow in the coastal areas of the state of Paraíba today. Some morphotypes are also characteristic of drier regions of Central Brazil. This set has preferential affinities with globally dry and locally humid environments. It seems to have a good relation with the more arid phases that accompanied the global temperature drop intervals at the Oligocene-Miocene boundary, supporting the geological age data.

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1. Introduction

This study presents an angiosperm fossil site identified from collection activities in open-pit bentonite mines of Juá II and Bravo, located on the eastern edge of the Boa Vista Basin. The dissemination of this paleontological site aims to stimulate the continuation of research in the area, which is highly vulnerable, and to highlight the importance and potential for telling the story of the Cenozoic in the region. The Boa Vista Basin (BVB) is located in the municipality of Boa Vista, in the state of Paraiba, covering an estimated area of 25 km², including volcanic rocks. The basin occurs over the Precambrian rocks of the Transversal Zone, Northeast of the Borborema Province, and its deposition is bounded to the south and southeast by the reactivated portion of the Serra do Monte shear zone (Figure 1). This site presents at least 24 taxa, including a new species, belonging to seven botanical families with taxonomy, phylogeny, and affinities with fossil floras known for the Cenozoic in tropical basins and with modern analogous floras.

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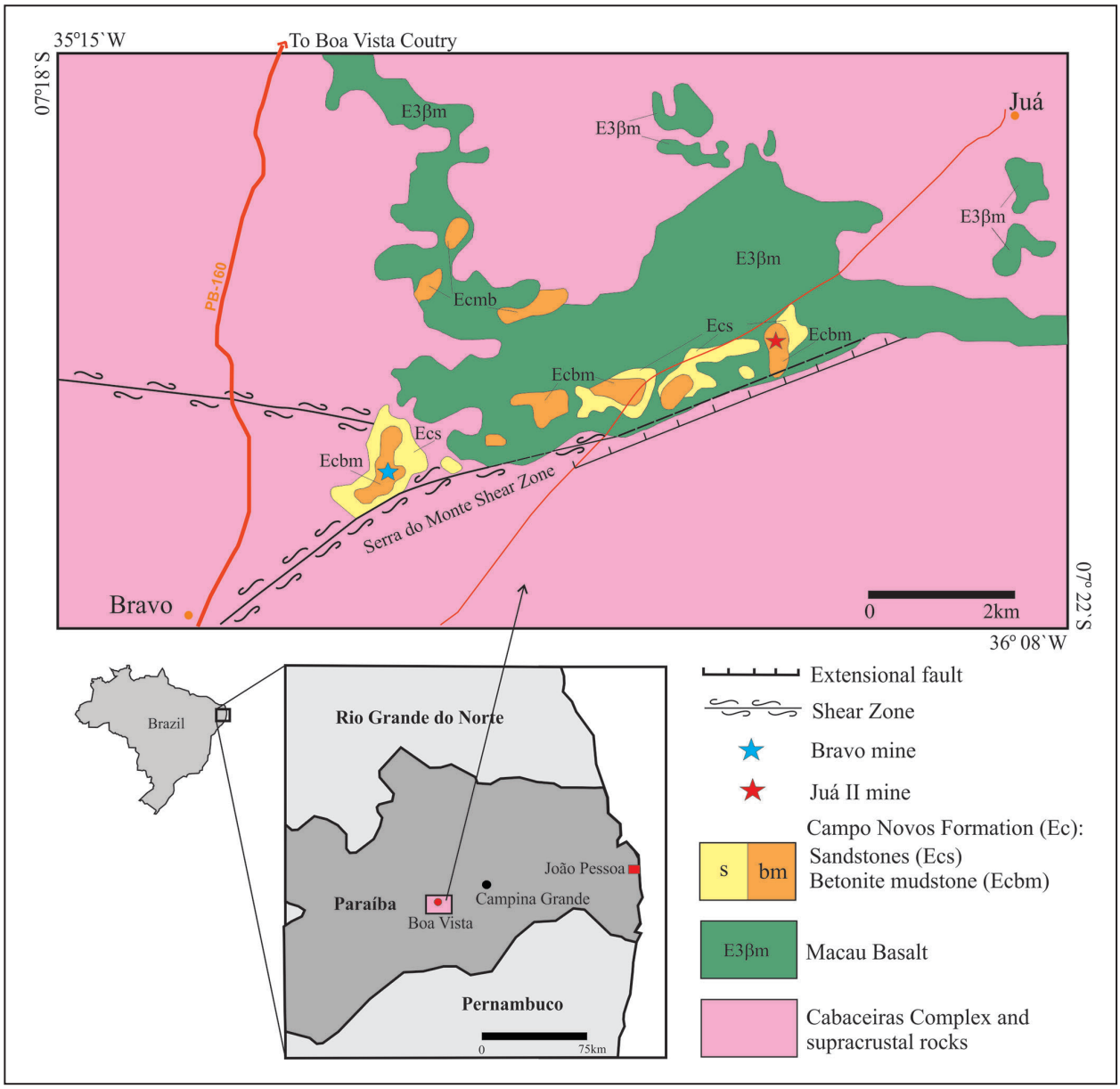

Figure 1. Location map of the Boa Vista Basin and the fossil sites of the Juá II and Bravo Mines.

2. Geological setting

The Boa Vista Basin consists of a half-graben (Figure 2), filled with a sequence of volcanic-sedimentary and sedimentary rocks. The structural control is driven by a system of interconnected extensional faults and dip-slip normal faults with NE-SW directions, related to the extensional reactivation of the Serra do Monte shear zone in the southern and southeastern parts (Souza et al. 2005; Lages 2017). This basin rests on rocks from the Alto Moxotó Domain (Zona Transversal, Borborema Province), represented in the area by migmatized orthogneisses from the Cabaceiras Complex and supracrustal rocks, as highlighted by Caldasso (1965), Barbosa and Souza (1999a), Souza et al. (2005), and Lages (2017).

The Boa Vista Basin is filled with a volcanic-sedimentary sequence, characterized by flows of olivine basalts, lapilli tuffs considered as part of the Macau Formation, from the Macau-Queimadas alignment, similar to the basalts occurring in the Macau-RN region (Souza et al. 2005), and sedimentary deposits of fluvio-lacustrine origin, formalized as the Campos Novos Formation (Holder Neto and Silva 1974). The volcanic rocks occur as irregular flows approximately 30 km in extent and E-W/WSW-ENE direction and are divided into lower and upper flows. The lower flows are massive and composed of vesicular to scoriaceous olivine basalts, invariably altered in sharp contact with the basement. The upper flow consists of olivine basalt, which caps the sediments of the Campos Novos Formation. They have textures of pillow lavas of various sizes and shapes, fragmented vitreous edges forming hyaloclastites, lapilli breccias between the pillows occurring as intrusions in aerial and sub-aquatic conditions, and whose rapid cooling is indicated by the fine grain of the flows. Effusive, glassy, aphanitic, commonly vesicular to pumiceous rocks, and pyroclastic varieties (lapillites) can be observed in the capping of the Juá II mine (Barbosa and Souza 1999a,b; Petta and Barbosa 2003; Lages 2017). The volcanic rocks are basalts

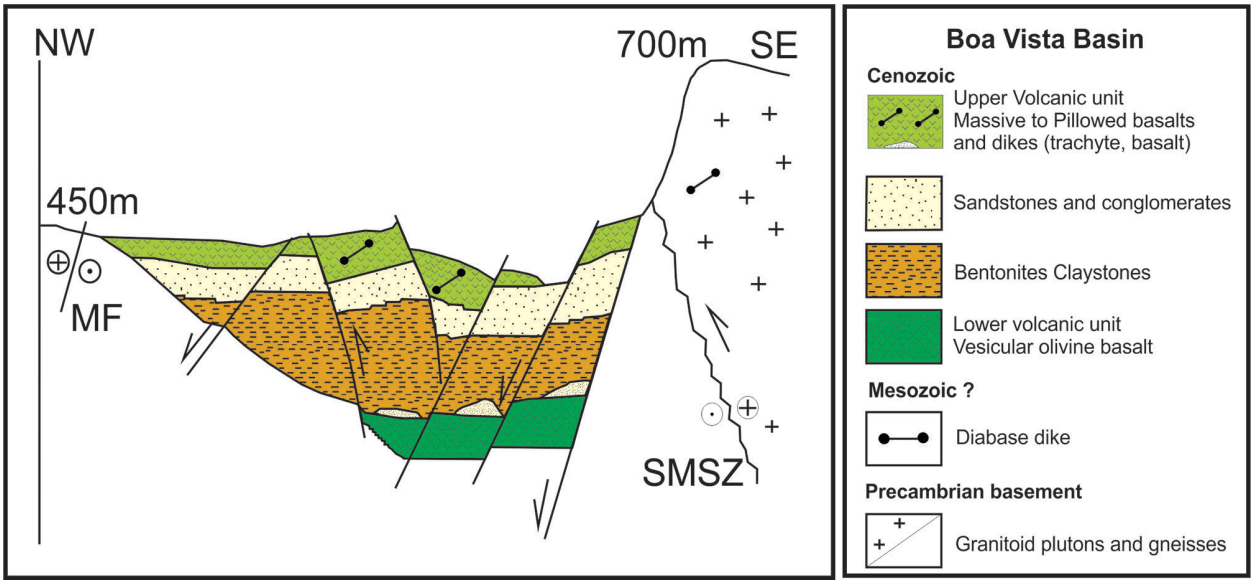

Figure 2. Schematic section of the Boa Vista Basin, NW-SE direction. Legend: The main faults are SMSZ, Serra do Monte Shear Zone, and MF, main fault (modified from Souza et al. 2005).

and basaltic andesites of ferro-tholeiitic affinity enriched in light rare earth elements and potassium poor (Souza et al. 2005; Lages 2017). The ages of these rocks were discussed by Souza et al. (2005), who synthesized the geochronology of the Macau-Queimadas alignment, indicating K-Ar ages ranging from 13 to 42 Ma, with ages in the BVB around 30 ± 6 Ma and 24-25 Ma, leading the authors to assume an Oligocene-Miocene age. Souza et al. (2013) dated the lower and upper basalts in the Boa Vista Basin at 27.3 ± 0.8 Ma and 25 ±1.3 Ma to 22.5 ± 0.2 Ma, respectively, using the 40Ar/39Ar technique.

The Campos Novos Formation comprises layers of bentonitic clays, friable or silicified sandstones, and clast-supported conglomerates. The bentonitic clays are fossiliferous, with color variations (brown, green, dark brown) according to the chemical composition of the clay minerals, and are interpreted as originating from the alteration of pyroclastic materials (ashes and tuffs) in a lacustrine environment (Barbosa and Souza 1999a). The friable or silicified sandstones of fluvial origin are predominantly composed of quartz, feldspars, and volcanic-clastic fragments, sometimes fossiliferous. These sandstones can be massive or with planar and through cross-bedding. The clast-supported conglomerates are polymictic, contain mainly quartz and volcanic rock grains, and occur in basal sections related to fluvial channels (Caldasso 1965; Caldasso and Andrade 1979; Barbosa and Souza 1999a; Dias et al. 2004; Lages 2017). In the palynological study by Roesner et al. (2004) of the bentonitic clays, the palynofacies were described, consisting essentially of amorphous organic matter, with an indication of restricted sedimentary input. The authors also suggest an age range from the upper Eocene to the lower Oligocene based on palynological association.

3. Materials and Methods

The fossil content discussed in this work was partly collected during field activities for the geological mapping project of the Boqueirão Sheet (Lages and Marinho 2012) by the Geological Survey of Brazil (SGB-CPRM) and partly during two expeditions (2011 and 2012) jointly conducted by the SGB-CPRM and the Life and Earth History Laboratory (LaViGaea) of the University of Vale do Rio dos Sinos (UNISINOS). There are 201 samples from the basal levels of the bentonitic clay layers of the Juá II Mine (UTM coordinates 812024/9187673) and the Bravo Mine (UTM coordinates 807649/9189873). Paniz (2015) and Dutra et al. (2023) described the identifications and diagnoses. The specimens are deposited in the Life and Earth History Laboratory (LaViGaea) collection at the University of Vale do Rio dos Sinos (UNISINOS).

4. History of paleontological studies

Paleontological research in the Boa Vista Basin is recent, with the earliest works mentioning the occurrence of fossil specimens without analysis or diagnosis. Caldasso (1965) published the first article describing the presence of fossilized trunks in a life position, with preserved roots in the basal layers of the Campos Novas Formation. Petta and Barbosa (2003) cited fossils such as leaf impressions, fish, and fragments of silicified wood. Barbosa and Souza (1999a) identified ichnofossils (tubes) and silicified woods. A palynological study highlighted a predominantly pollen association, with rare spores and absence of dinoflagellate cysts, where species such as *Margocolporites vanwijhei, Retitricolporites americana (?), Retitricolporites amapaensis, Retitricolporites quadrosi, Retitricolporites guianensis, Retitricolporites amazonensis, Verrucatosporites cf. V. usmensis, Perfotricolpites digitatus, Scabraperiporites nativensis, Monocolpites sp., Echiperiporites estelae, Echiperiporites akanthos, Monoporites annulatus, and Proxapertites spp.*, also occur *Cicatricosisporites spp.* and *Botryococcus spp* are notable (Roesner et al. 2004).

The geological mapping conducted by the Geological Survey of Brazil systematically collected the fossiliferous content found during field activities for identification, including fossil specimens of leaf impressions and fruits, characterizing the first occurrence of an angiosperm flora in the basin (Moura et al. 2008). The occurrence of a taphoflora composed of leaves, leaflets, fruits, and flower fragments

of a monocotyledon, with a predominance of families such as Fabaceae, followed by Lauraceae, Annonaceae, Burseaceae, Anacardiaceae, Myrtaceae, and Malvaceae was described by Paniz (2015). Dutra et al. (2023) described a new genus and a new species for the family Fabaceae (Detarioideae), with well-preserved tissues that allowed attribution to *Goniorrhachisinoxylon sergioarchangelskii*, also identifying a seasonal climate (possibly monsoons) for the late Oligocene, in the Northeast region of Brazil.

5. The Fossil Site of Juá II Mine and Bravo Mine

Researchers of the Geological Survey of Brazil collected the fossil occurrences described in this work at the Juá II Mine and the Bravo Mine (Figure 3). The geology of these fossil sites is represented by the siliciclastic sediments of the Campos Novos Formation, characterized by pelitic, arenaceous, and conglomeratic facies (Table 1) of a fluvial-lacustrine system, capped by basalt flows.

The pelitic facies are represented by bentonitic clays (Bm), which occur as massive and hardened, with colors varying from green, light brown to dark brown, where the color reveals the variation in the chemical composition of the clay minerals, such as illite, montmorillonite, smectite, and kaolinite. The most important specimens of plant fossils in the basin were collected in these facies. The green bentonitic clays, with an approximate thickness of 9m, contain few fossils preserved in molds and impressions. The lighter brown clays have an average thickness of 30m and present many plant fossils (leaves, fruits, flowers, and fragments of wood and roots in life position) and some ichnofossils. No fossil content was identified in the dark brown bentonitic clay, considered the main mineral deposit of bentonite (Figure 4). The pelitic layers (bentonitic clays) are interpreted as originating from the deposition in a lacustrine environment by volcaniclastic material in suspension.

The arenaceous facies are represented by arkosic to lithic arkose sandstones with planar cross-bedded (Sp), trough cross-bedded (St), and massive (Sm), according to the classification of fluvial lithofacies by Miall (1996). These facies locally occur in discordant, erosive contact with the Bm facies. In this facies, silicified wood up to 2m in length was identified, some in life position (Figure 5). Finally, the facies of clast-supported conglomerates (Gcm) occur as massive (Table 1) and are associated with the massive sandstones in fluvial channels (Figure 6).

In the Juá II Mine, basalts with pillow lava structures were described (Figure 7), massive and sometimes with vesicular to pumice aspects, isotropic in appearance and with a fine grain, dark gray showing rounded pockets sometimes filled with carbonates. Under the microscope, they display diabasic to ophitic textures with the mineral plagioclase (46%), augite (44%), and olivine (<1%), primary and secondary opaque minerals (7%) and secondary carbonates fill the vesicles (2%). Chemically, they belong to a subalkaline (low-potassium tholeiitic) suite with low concentrations of Zr, Sr, Ni, Nb, and MgO, containing normative olivine+hypersthene or quartz+hypersthene (Lages 2017).

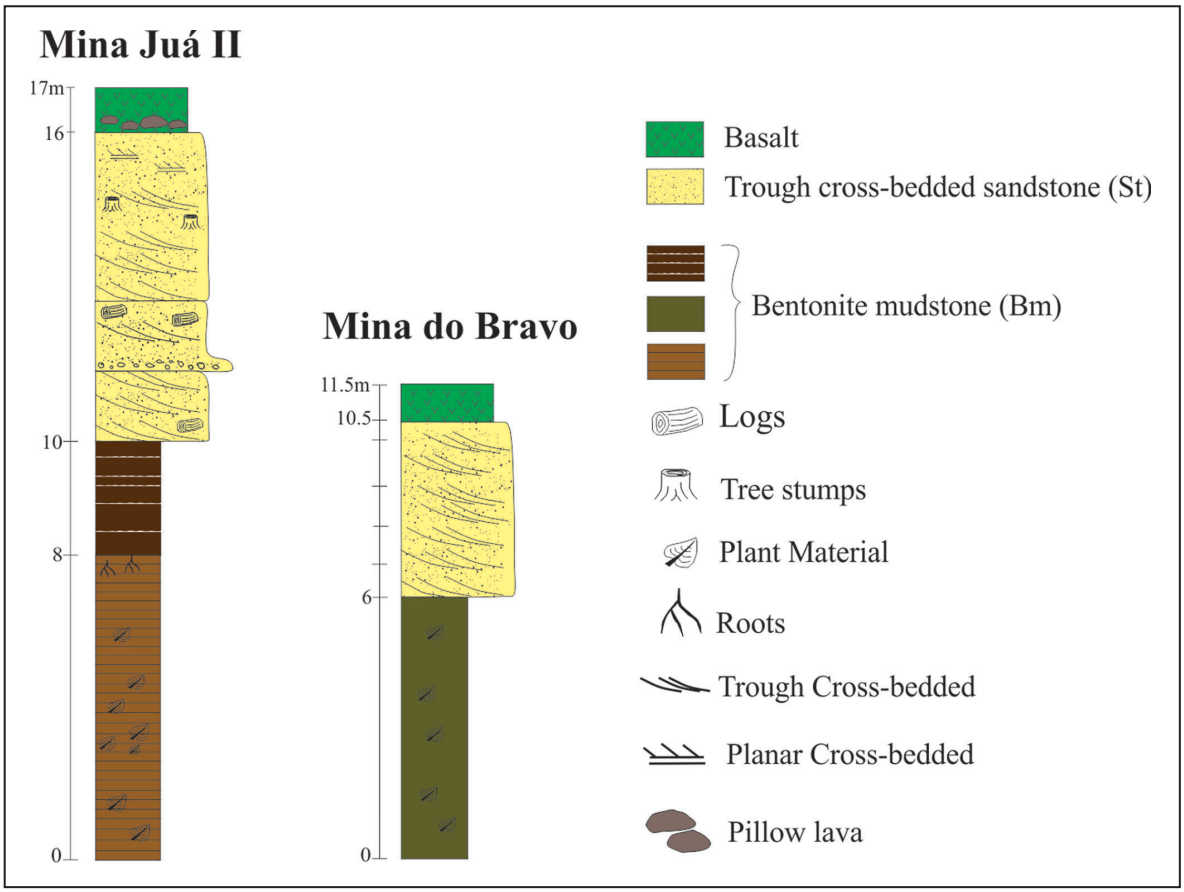

Figure 3. Composite profile of the Juá II Mine and Bravo Mine.

Table 1. Classification of lithofacies (adapted from Miall 1996).

Facies code	Facies	Description	Interpretation
Gcm	Clast-supported gravel	Well-selected, ranging in size from pebbles to cobbles, polymicts also occur, containing clasts of quartz and volcanic rocks. Locally in contact with volcanic rocks and sometimes with sandstones	Pseudoplastic debris flow (turbulent flow)
Sp	Planar cross-bedded sandstone	Medium to coarse grains, gray in color, arkose to lithic arkose	Dunes of sandstone with straight crest (2D) of linguoid type
St	Trough cross-bedded sandstone	Fine to pebbly grain, gray in color, with pebbly layers, composed essentially of quartz	Dunes of sandstone with sinuous crest (3D) of linguoid type
Sm	Massive sandstone	Fine-grained, coarse, gray, composed of quartz and strongly silicified	Sediment gravity flow deposits
Bm	Betonite mudstone	Compact and hardened, with colors varying from slime green, light brown to dark brown. Levels of siliceous concretions are observed, locally oriented. Root marks between the layers.	Precipitation of suspended sediment caused by alteration of pyroclastic materials in a lake environment

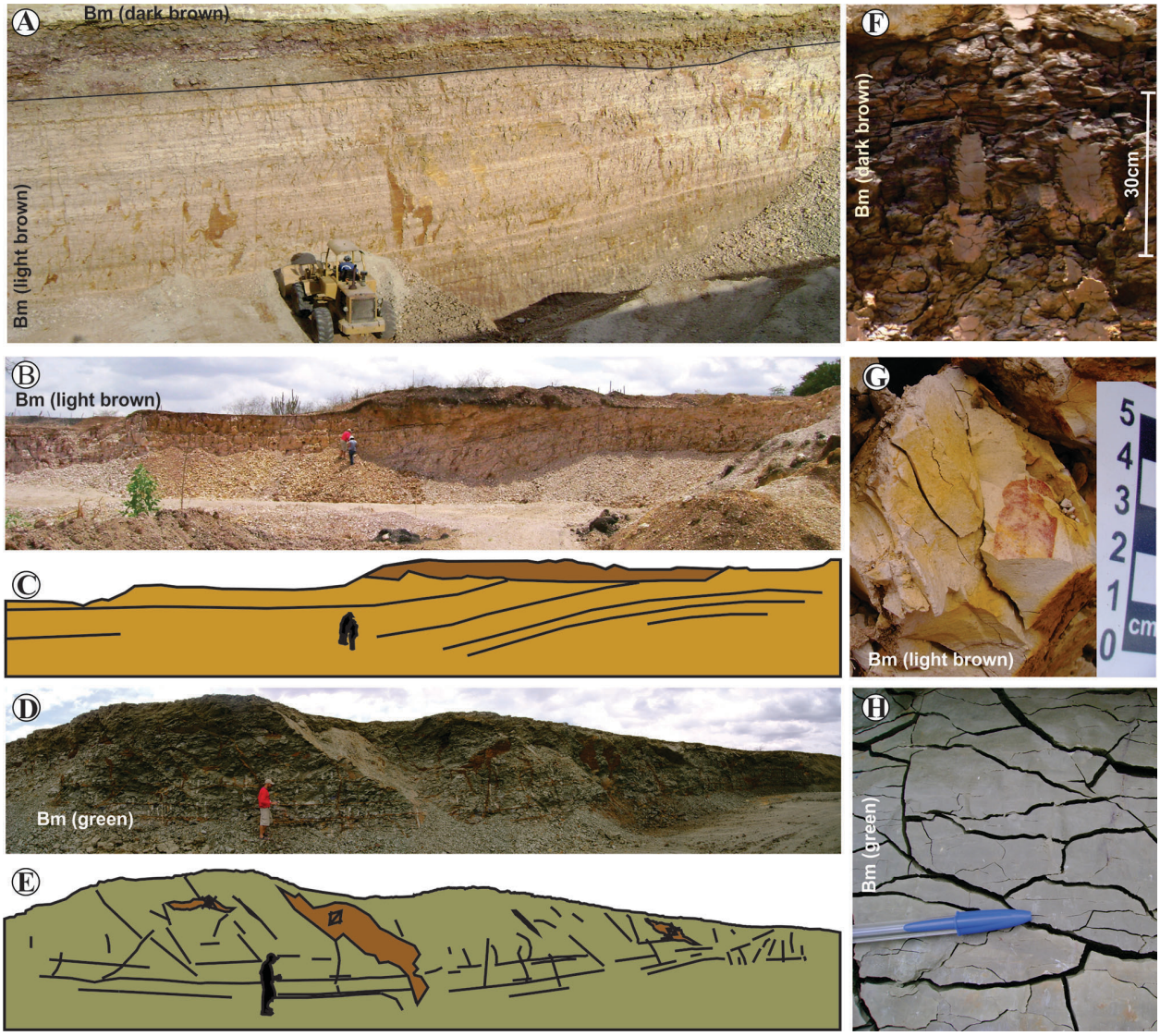

Figure 4. A) Relationship of the Bm facies, where the lighter brown presents extensive fossil material, and Bm dark brown lithofacies (top), these facies are absent of fossils. B) Light brown Bm facies, with a schematic drawing of the occurrence mode in C). D) Green Bm facies and E) its occurrence mode in the schematic drawing. F) Detail of the dark brown Bm facies. G) Detail of the light brown Bm facies. H) Detail of the green Bm facies.

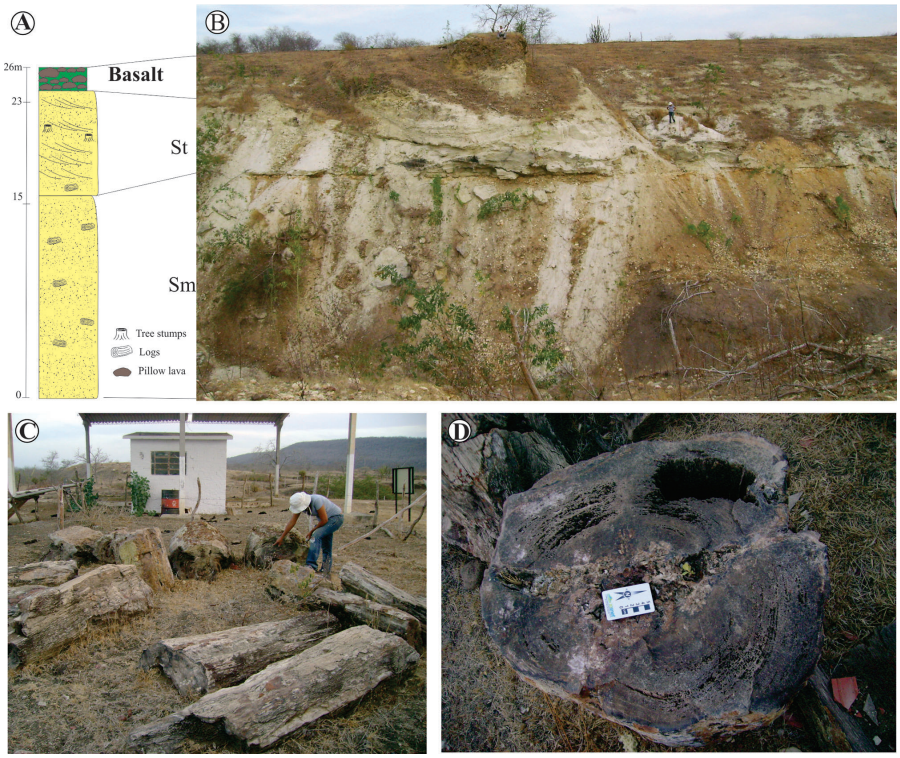

Figure 5. A) the Juá II mine pit's profile shows the presence of arenaceous facies containing fossil trunks. B) Outcrop with the relationship of the Sm and St lithofacies covered by the basalt flow. C) Fossil trunks collected and stored at the Juá II Mine. D) Detail of the fossil trunk.

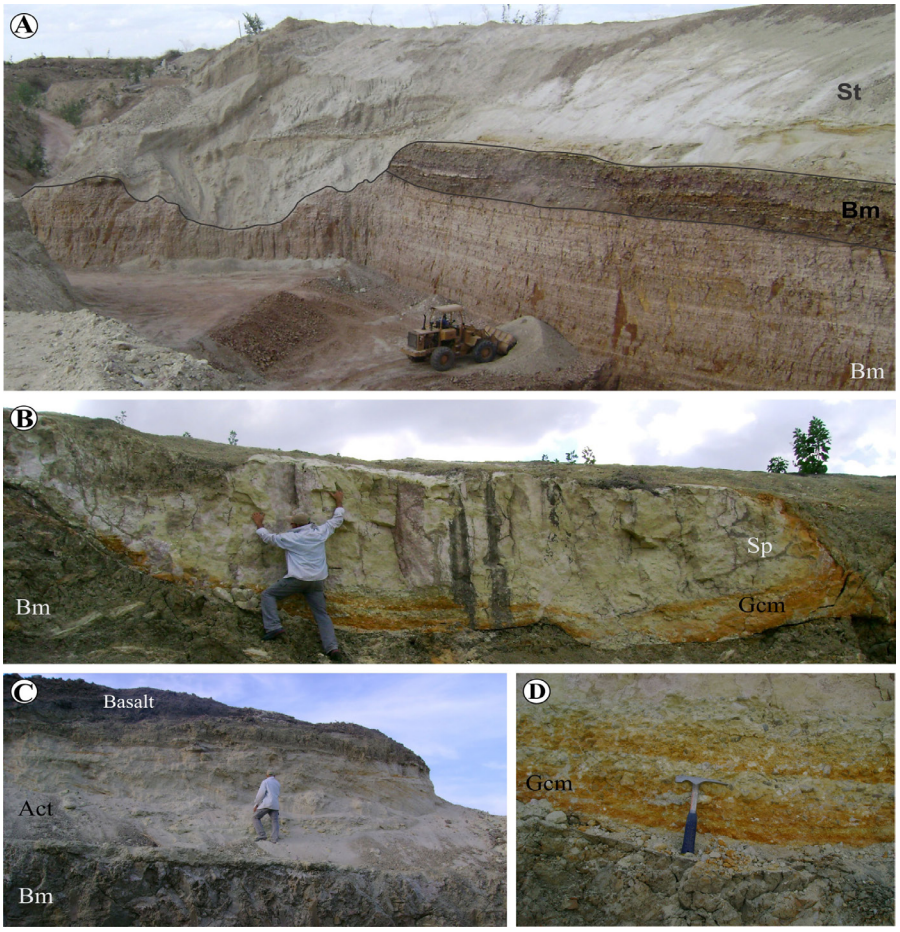

Figure 6. A) Discordant relationship of the Bm lithofacies with the St lithofacies associated with fluvial channels. B) The Fluvial channel with Sp and Gcm facies is in discordant contact with Bm facies. C) Basalt covering the Sp Facies. D) Detail of the Gcm facies.

6. Fossil content

In the light brown bentonitic clay facies, leaves, fruits, and wood fragments were identified, accompanied by ichnofossils in vertical and horizontal tubes (Figures 8 and 9). Autochthonous roots were also observed. The numerous and varied leaf impressions are dominated by laurophyllous, membranous, or coriaceous morphotypes characterized by smooth margins and brochidodromous venation. Some impressions show a reasonable preservation of third-order veins, which allows us to approximate their taxonomic affinities. The ensemble attests to a tropical to subtropical flora, with elements that still grow in the coastal areas of the same region today, with a dominance of leaves and leaflets related to the families Lauraceae, Fabaceae (aff. Caesalpinioideae), Anacardiaceae (aff. *Anacardium occidentale*), and Apocynaceae. These forms are also present in the drier inland areas of Central Brazil. The rarer forms are linked to the families Annonaceae, Tiliaceae (*Luehea* sp.), Chrysobalanaceae (aff. *Licania* sp.), and Burseraceae (aff. *Commiphora* sp.).

Paniz (2015) presented 24 taxa, including a new species, belonging to seven botanical families. These taxa have affinities with fossil floras known from tropical basins in the Cenozoic and with modern analogous floras (Appendix 1).

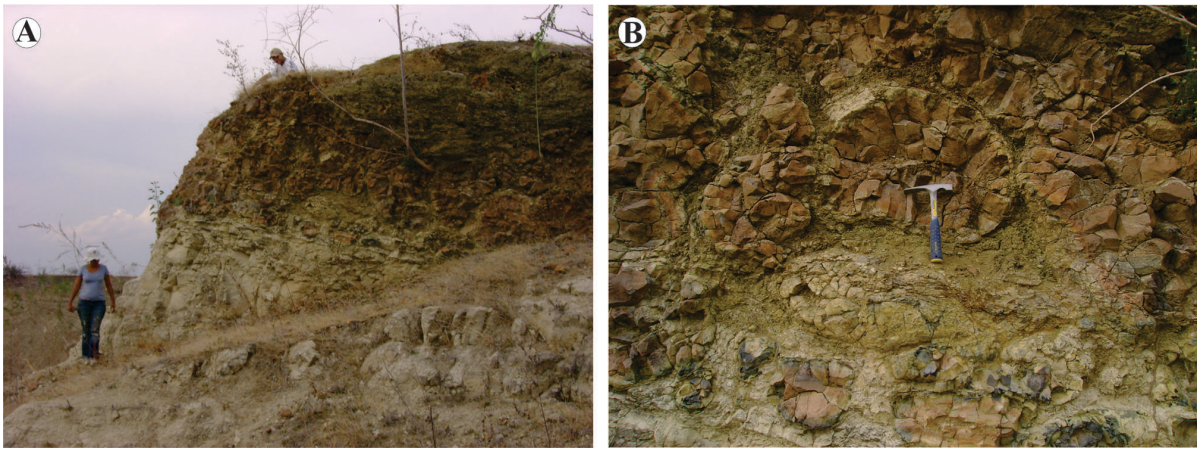

Figure 7. A) The main section shows the relationship of the St facies with the pillow lavas. B) Detail of the pillow lava texture.

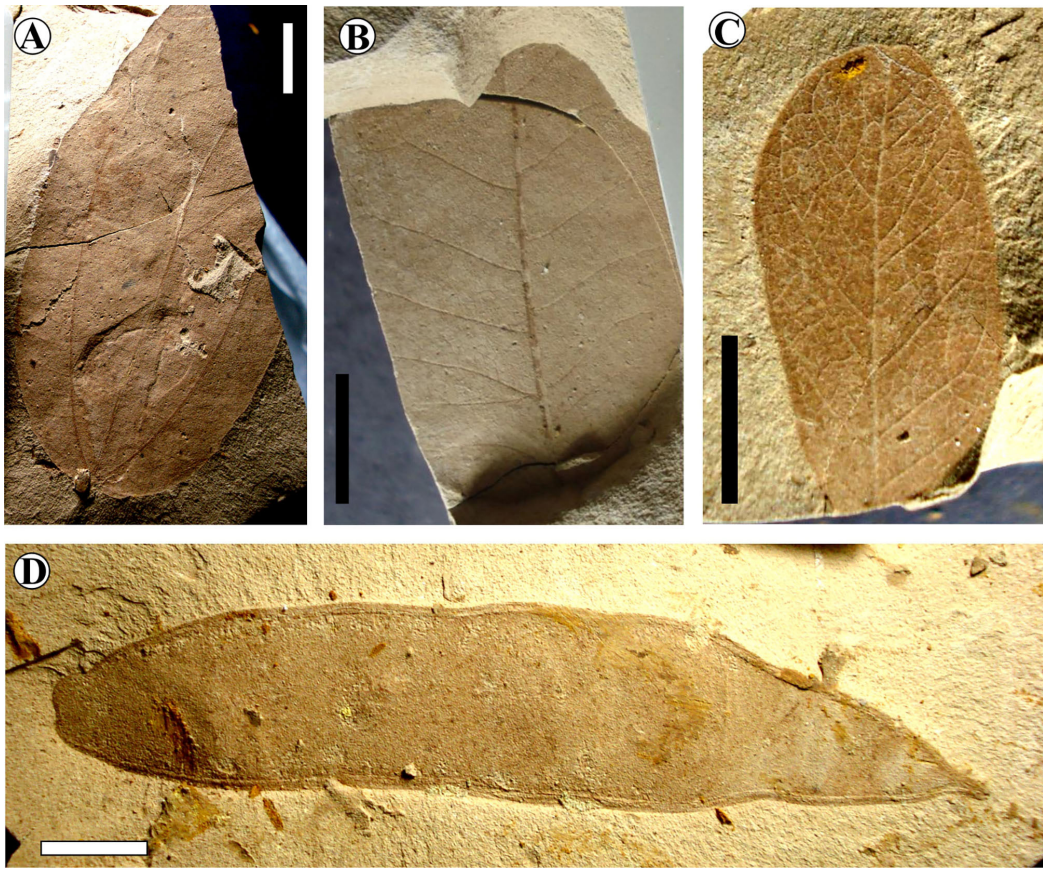

Figure 8. A) *Luheopsis* cf. L. *hoehmei* Burret (CPRM-CM 0232F). Family Malvaceae; B) *Anacarduim aff. Anacarduim occidentalis* (CPRM-CM0223F); C) *Dinizia aff. D. excelsa* Ducke (CPRM-CM0226); D) *Leguminocarpum paraibensis* Paniz (CPRM-CM0228F) (Paniz 2015). The scale bar is equal to 1 cm.

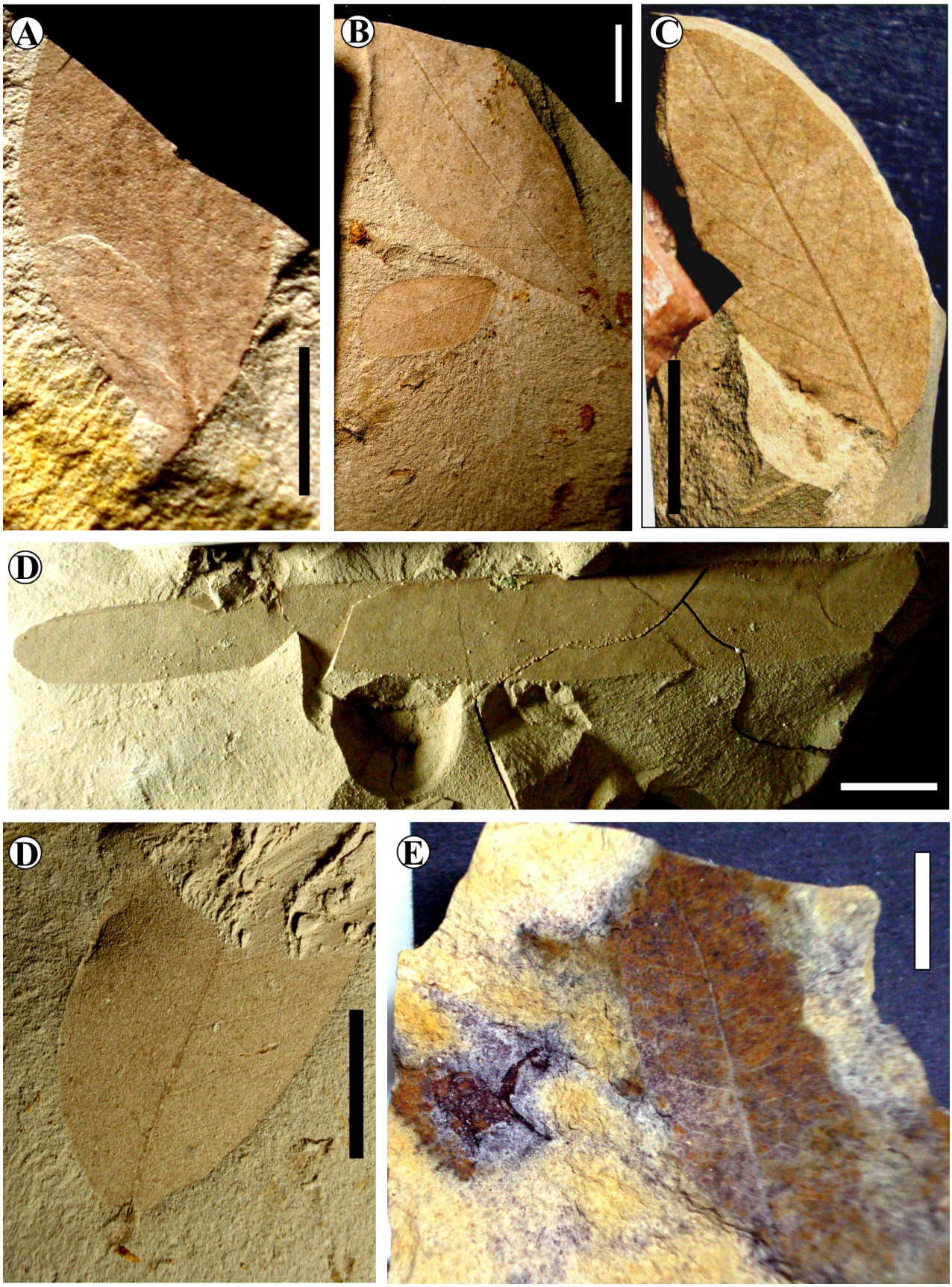

Figure 9. A) Laurophyllous morphotype related to the Apocynaceae family; B) Bottom left corner *Cassia* sp. (family Fabaceae) and *Nectandra* sp. family Lauraceae (1); C) *Dicotylophyllum* sp. 2. D) *Typha* sp., family Typhaceae, monocotyledon. D) Laurophyllous morphotype related to the Annonaceae family (1); E) probable element of the Sapindaceae family. The scale bar is equal to 1 cm.

7. Discussions and Conclusions

The bentonitic clays of the Campos Novos Formation constitute a significant deposit for the region's economy. The material studied was collected along the pits for clay extraction at the principal mines. Continuing the collection of fossil material, in partnership with mining companies, would be a path to broaden knowledge about the region's flora during the Cenozoic. From the analysis of this fossil ensemble described by Paniz (2015) and Dutra et al. (2023) in the Boa Vista Basin, it was possible to understand that there is a preferential affinity of this flora with regionally dry environments, but which are formed in humid areas. This affinity indicates that the environments, at the time of deposition, were characterized by dry climates, with rain seasons concentrated in a part of the year, similar to today's climate in the region but with more humidity. It suggests a relationship with the drier phases that accompanied the intervals of global temperature decline at the Oligocene-Miocene and Lower Miocene boundaries, supporting the geological age data. Some of the remains identified, especially those exhibiting morphologies found in the families Tiliaceae, Lauraceae, Annonaceae, and Fabaceae, had already been recorded in Brazil in older levels, in the Fonseca and Aiuruoca basins, in Minas Gerais, and for the Miocene, in the Pirabas Formation, in Pará. The physiognomic characteristics point to a tropical climate with seasonal or prolonged drought. Comparison with other assemblies shows proximity to the middle Eocene to lower Oligocene in central Brazil (Paniz 2015), corroborating the isotopic age data for the volcanic-sedimentary sequence of the Boa Vista Basin by Sousa et al. (2013). This paleoflora possibly reflects a dispersal (or contraction) of the region towards the tropics.

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Appendix 1

Paleobotany of the Fossil Site at Juá II Mine, Boa Vista Basin (Paniz 2015)

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