UNIVERSIDADE DE SÃO PAULO
INSTITUTO DE BIOCIÊNCIAS

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Madeiras fósseis do vale do Rio Peruaçu: Testemunhas de eventos de inundações extremas no holoceno

Fossil woods from the Peruaçu River Valley:
Witnesses of holocenic extreme flooding events.

São Paulo
2024

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Versão Original

Dissertação apresentada ao Instituto de Biociências da Universidade de São Paulo, para a obtenção de Título de Mestre em Ciências, na Área de Botânica.

Orientador(a): Prof. Dr. Gregório Ceccantini

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2024

Ficha catalográfica elaborada pelo Serviço de Biblioteca do Instituto de Biociências da USP, com os dados fornecidos pelo (a) autor (a) no formulário:
'https://ficha-catalografica.ib.usp.br/ficha.php

Carvalho Beltrão Cavalcanti, Felipe
Madeiras fósseis das cavernas do vale do Rio Peruaçu : O Arco do André: identificação anatômica e interpretações paleoambientais / Carvalho Beltrão Cavalcanti Felipe ; orientador Cardoso Tápias Ceccantini Gregório -- São Paulo, 2024.
48 p. + anexo

Dissertação (Mestrado) -- Instituto de Biociências da Universidade de São Paulo. Ciências Biológicas (Botânica).

1. Anatomia Vegetal. 2. Paleobotânica. 3. Eventos climáticos extremos. 4. Bacia do Rio São Francisco. 5. Identificação de Madeiras. I. Cardoso Tápias Ceccantini, Gregório, orient. Título.

Bibliotecária responsável pela catalogação:
Elisabete da Cruz Neves - CRB - 8/6228

Nome: Carvalho Beltrão Cavalcanti, Felipe

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Aprovado em:

Banca Examinadora

Prof(a). Dr(a). ____

Instituição: ____

Prof(a). Dr(a). ____

Instituição: ____

Prof(a). Dr(a). Gregório Ceccantini ____________________________

Orientador(a)

Para Letícia.

AGRADECIMENTOS

Agradecer é sempre uma tarefa inglória. Sempre esquecemos de alguém. Na interconexão do universo, não há nada que não tenha sua parte em cada passo.
Às árvores que se deixaram levar pelas chuvas e vieram parar em minhas mãos séculos depois, obrigado. Que suas vidas continuem sendo nossas lições.
Ao Rio Peruaçu, obrigado. Rezo para que o novo clima não te desapareça. Mereces muito mais do que tudo isso que estamos causando a ti.
Aos animais e plantas com o qual me sustento, às algas que me permitem respirar e às bactérias que regulam meu corpo, obrigado.
À equipe de irmãs e irmãos de orientação, pelo apoio, dicas, feedbacks e palavras de encorajamento: Milena, Queren, Paula, Bruno, Betina, Sobral, Luciano, Evelyn, Victor, Mario, João, Selma, Amanda, Lana, Marcos, Luiza, Clara, Cadu; Obrigado.
Aqueles que sem seu profissionalismo este trabalho nunca teria sido possível: Gisele, Tassia, Lucimar, Branco, Guano. Vocês são exemplares. Obrigado.
Aos que trilharam este caminho antes e produziram as pesquisas que permitiram esta, e que só pude conhecer através de suas teses e dissertações: Ataliba, Guilherme, Placido. O trabalho de vocês ficou ótimo. Obrigado.
Aos professores do departamento que muito me ensinaram estes anos todos: Chico, Paulo, Verônica, Diego, Flávia. E Greg, quem mais teve de me aguentar. Obrigado.
Aos meus familiares que me deram as condições de trilhar esse caminho: Pai, mãe, manas, Tuca, tios e sobrinhos. Vos amo.
À minha companheira Letícia, que mesmo nos piores momentos ficou ao meu lado, e a nova família que estamos construindo. Lê, te amo. Obrigado por tudo.
Aos meus gatinhos que sem os quais a vida doméstica do eterno home office não teria o mesmo brilho. Link e Zelda, queria que pudessem ler isso. Amo vocês.
À minha filha, que nem chegou ao mundo ainda e mesmo assim não sai da minha cabeça e do meu coração. Gabi, te amo. Se um dia vier a ler isso, espero que goste. Rezo para que sua vida seja feliz, acima de tudo.

E olha só, tinha esquecido de alguém:
O presente trabalho foi realizado com apoio da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Código de Financiamento 001.
Obrigado pelo dinheiro! Vocês pagaram meu casório!

“Cada pássaro, um amigo.
Cada árvore, um professor.”

(Mantra animista)

Summary

Fossil woods from the Peruaçu River Valley: Witnesses of holocenic extreme flooding events.

Cavalcanti, F. C. B;

Ceccantini, G. C.T.

ABSTRACT

This study presents quaternary fossil woods discovered at the Peruaçu River Valley, Central Brazil, which offer critical insights into past climate patterns and extreme flood events around the São Francisco River basin. The fossil woods were preserved under very rare geological and climatic conditions, within the karst system of the Parque Nacional Cavernas do Peruaçu (PNCP). This area is significant due to its location at the top of the São Francisco River basin, and in an ecotonal area among Brazilian biomes such as Cerrado, Caatinga, and Atlantic Forest consisting in a vital region for understanding the climatic history of central Brazil. These fossil woods were deposited by ancient floods linked to high pluviosity events during the mid to late Holocene (1300-2000 CE), suggested to have been triggered by major volcanic eruptions around the world. These fossil specimens, found at different heights sheltered in a cave, provide a valuable record of past vegetative formations and climatic conditions. This study aimed to classify and identify these fossils to enhance our understanding of these historical extreme events and assess the potential risks of future extreme weather events at the São Francisco River basin. The 73 fossil woods comprised 28 different morphotypes, among which 21 were identified. The taxa identified suggest a paleoenvironment similar to the modern environment of the region. These findings have broader implications for extreme weather mitigation and public policy, highlighting the importance of actionable information in addressing the increasing frequency of floods, droughts, and other extreme events in Brazil.

RESUMO

Este estudo apresenta madeiras fósseis quaternárias descobertas no Vale do Rio Peruaçu, norte de Minas Gerais, que oferecem insights cruciais sobre padrões climáticos passados e eventos extremos de inundação na bacia do Rio São Francisco. As madeiras fósseis foram preservadas sob condições geológicas e climáticas muito raras, dentro do sistema cárstico do Parque Nacional Cavernas do Peruaçu (PNCP). Essa área é significativa devido à sua localização no topo da bacia do Rio São Francisco e em uma área de ecótono entre biomas brasileiros como o Cerrado, a Caatinga e a Mata Atlântica, constituindo uma região vital para a compreensão da história climática do centro do Brasil. Essas madeiras fósseis foram depositadas por inundações antigas ligadas a eventos de alta pluviosidade durante o Holoceno médio e tardio (1300-2000 EC), sugeridos como desencadeados por grandes erupções vulcânicas ao redor do mundo. Esses espécimes fósseis, encontrados em diferentes alturas abrigados em uma caverna, fornecem um valioso registro de formações vegetativas e condições climáticas passadas. Este estudo teve como objetivo classificar e identificar esses fósseis para aprimorar a compreensão desses eventos extremos históricos e avaliar os riscos potenciais de futuros eventos climáticos extremos na bacia do Rio São Francisco. As 73 madeiras fósseis compreendiam 28 diferentes morfotipos, dos quais 21 foram identificados. Os táxons identificados sugerem um paleoambiente semelhante ao ambiente moderno da região. Esses achados têm implicações para a mitigação de eventos climáticos extremos e para políticas públicas, destacando a importância de informações acionáveis no enfrentamento da crescente frequência de enchentes, secas e outros eventos extremos no Brasil.

1. INTRODUCTION

In tropical South America, quaternary fossil woods are rare and unusual findings, a fact often explained by fast deterioration rates due to the high levels of heat and humidity that characterize tropical environments, (CECCANTINI 2002, HOLZ & SIMÕES, 2002; SCHEEL-YBERT, 2006; FREIRE, 2011). Regardless of that, in this work, we present a collection of 73 quaternary fossil woods found in a single cave of the Peruaçu River Valley, central Brazil. These fossils were preserved by a unique conjunction of geological and climatic features, combined with past climatic extreme events (COELHO, 2013; BUARQUE, 2019). These fossils allow us a glimpse into the quaternary environment and climate in Central Brazil, unveiling relevant information regarding risks of extreme events in the São Francisco River basin and neighboring areas.

1.1. Climate preparedness and Extreme Events

Brazilian regions are in dire need of actionable information about climate patterns and the risks of extreme events. Recently it was observed in the country what the lack of preparedness can cause, in the shape of the weeks-long floods that covered the state of Rio Grande do Sul (RS) earlier this year, between the months of April and May of 2024. Those floods afflicted 452 municipalities, displacing 650.000 people and leaving 75.000 homeless, while reaching a death tool of at least 180 people (OLIVEIRA *et al*, 2024; RIZZOLOTTO *et al*, 2024).

Besides this last recent and impactful flood, the country has been repeatedly hit by other floods, as well as heat waves, forest fires, droughts, and tropical storms. Deciphering what risks each region is prone to and what measures to entail in each case is a complicated puzzle, one that connects climate sciences to public policy, government spending, and ultimately the very safety of citizens. This puts urgency in understanding climate patterns across this continental country (MARENGO, 2014; IWAMA *et al*, 2016).

In this study, we suggest turning some attention to the São Francisco River Basin, a hydrographic basin that houses more than 20 million habitants, in more than five hundred cities. Such area is of concern for climate change mitigation efforts because it houses a very important river in Brazilian policy and demographics, the São Francisco River, one that powers 9 important hydroelectric energy plants, alongside being a major resource for regional agriculture and urban water supplies (CODEVASF, 2021). This river also flows through areas of recurrent and lasting droughts and was by the same reason subject to two huge transposition projects that took the Brazilian government 16 years to complete (SOARES, 2013; DE LIMA MAIA *et al*, 2024). Thus, it is very important for Brazilian climate mitigation policies (as well as current water, food, and energy security policies) to be able to understand, and perhaps predict, future droughts or floods that may affect this important resource and the residents of this region (RIBEIRO *et al*, 2016).

We believe that, in the case of the climate regulating Central Brazil and the São Francisco River basin, we can find important clues to this understanding in our study site, the *Parque Nacional Cavernas do Peruaçu* (**PNCP**).

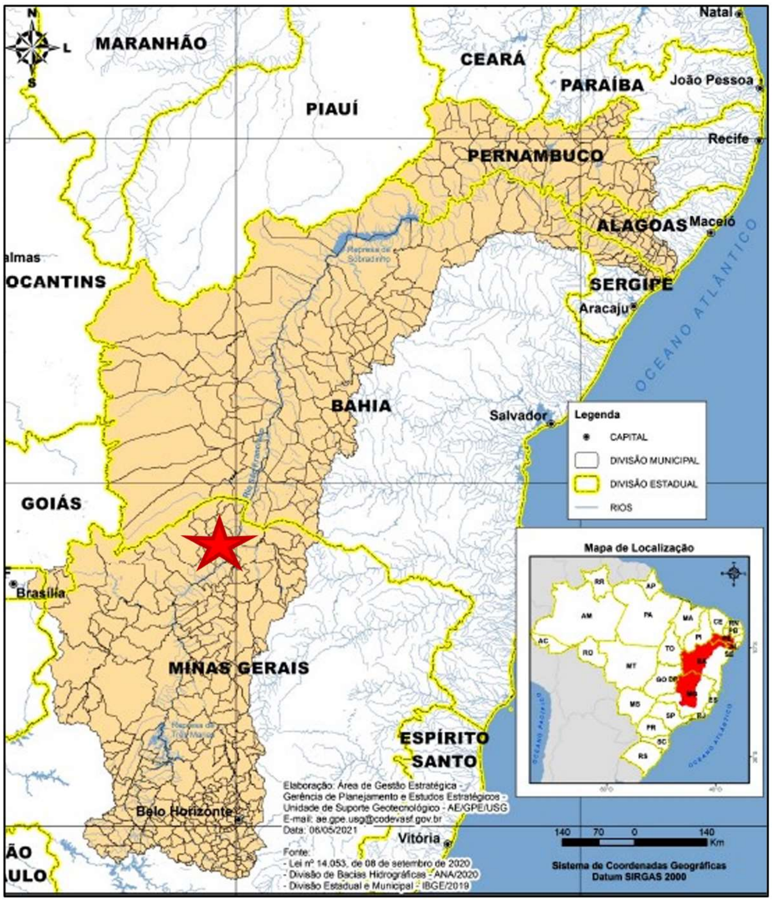

***Figure 1**. Location of the PNCP (red star) inside the São Francisco River Basin, a very important basin in Brazil's demography. Adapted from CODEVASF, 2021.*

1.2. Study Site: Parque Nacional Cavernas do Peruaçu (PNCP)

Nature has granted a helping hand for the understanding of the climate above the São Francisco River basin, by the form of the Peruaçu River Valley, a sub-basin within the São Francisco River Basin (**Figure 1**, above). There lies a small tributary of the São Francisco River, the Peruaçu River. In this valley, the small river carved the local karst system into a sequence of canyons with 17 km length and nearly 500 different caves. Those provide two sets of tools to understand the climate of central Brazil in the past: cave speleothems and seasonally marked tree rings. It is through those tools that earlier studies from our research group discovered the occurrence of past extreme events in the area (STRIKIS, 2011 & 2015; COELHO, 2013; BUARQUE, 2019; GODOY-VEIGA *et al*, 2019 & 2021). The extreme events in this case were exceptional floods, possibly correlated with the occurrence of major volcanic eruptions worldwide. Academically, these particular extreme events were defined as a very high pluviosity (above the 90% percentile) in a very short span of time (three continuous days), by Buarque (2019) when studying paleological data for the period between 1300 and 2000 CE. These rainy events caused large floods along the Peruaçu River Valley, and probably in the vicinity of the PNCP as well.

Furthermore, the Peruaçu River Valley sits in a crucial ecotone zone among three distinct and very significant brazilian biomes (**Figure 2, A**): the Cerrado, the Caatinga, and the Atlantic Forest (IBAMA, 2005) one of the facts that awarded this area the status of National Park in the first place. It also is worth mentioning that this region is geographically near to where recently fully arid climatic conditions have been detected in Brazil for the first time, a grim headline from recent years (CEMADEN & INPE, 2023) and also occurring over the São Francisco River Basin (among other basins – **Figure 2, B**). Thus, it is possible to say that the Peruaçu River Valley offers several windows to understand the climate of central Brazil, both to its recent past (mid and late Holocene) as well as its changing future, with repercussions that can impact populations living through the whole São Francisco River basin as well as the Northeastern Brazil as a whole.

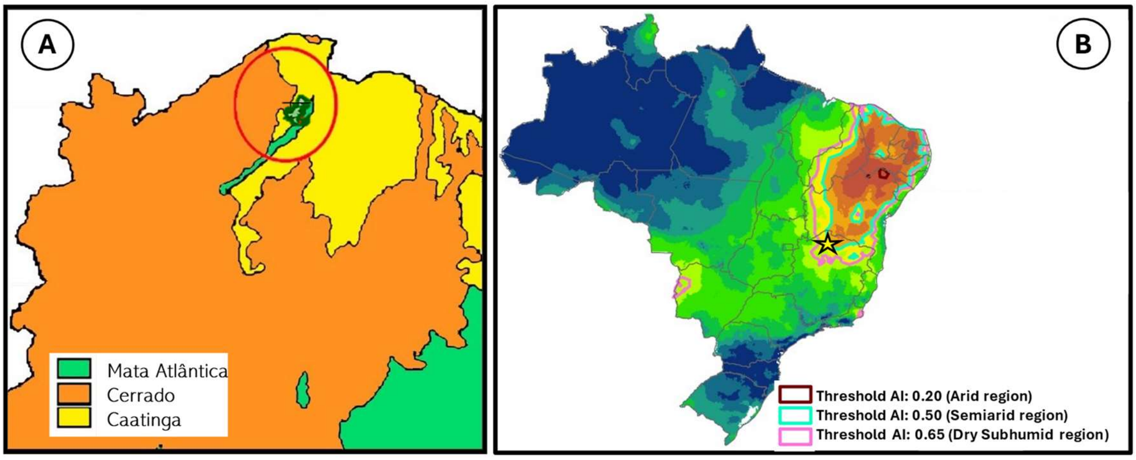

***Figure 2**. **A**: Map of the biomes neighboring the PNCP, shown with the northern part of the state of Minas Gerais. Outline of the PNCP in green, inside the red circle. Adapted from IBAMA, 2005. **B**: Brazilian climatological Aridity Index (AI) map showing areas with increasingly arid climate from 1980 to 2010. PNCP location marked with a yellow star. Adapted from INPE, 2023*

1.3. Fossil evidence of extreme floods

Of importance for this study is the fact that the Peruaçu River Valley also preserved inside one of its caves dozens of fossil wooden trunks and branches. The resting positions of these trunks and branches made clear (COELHO, 2013; BUARQUE, 2019) that they arrived there by the forces of past floods in the area (the very same extreme pluviosity events our team previously detected). They were found stuck in crevasses and plateaus, some up to nearly 40 meters from the current cave floor, in heights correlated with floodmarks dated to the same periods from the known flood events.

Thus, it is known so far that the climate from the last thousand years permitted huge floods in what is now a mostly dry region. It is known from previous studies that such floods were caused by huge volcanic eruptions happening worldwide (BUARQUE, 2019). It is known that these events gathered fossil specimens in one of the caverns of the region. What is not known, and this study intends to present, is if the climate of this recent past, prone to floods, is actually comparable to the modern climate in the region, since there is a lack of such flood events in recent times. We intend to answer that mystery by identifying the fossil trunks gathered in the cavern and analyzing the characteristics of the identified taxa.

This study therefore aims to describe, classify, and identify the species thus gathered and sampled, and show new information about the region's past vegetations, and by doing so also shed new information on the region's past climate as well.

Before moving on, one small clarification is needed on the concept of "fossil wood" adopted in this work. It was used the "fossil" definition proposed by Tomassi and Almeida (2015), to whom several previous definitions of "fossil" should be discarded upon the argument that they carry outdated biases within them. This means that the 73 fossils this study will be describing, identifying, and analyzing are not mineralized, are not from before the Holocene, and were not found embedded in rock, conditions preconized for "fossils" by authors like Moreira (1999), Mendes (1960), and Furon (1951), respectively. These fossil trunks and branches are important pieces of biological information preserved from the past, important enough to merit the word "fossil" and its implications.

1.4. Data from previous studies

This study continues research on the PNCP fossil trunks and on the Peruaçu river valley caverns. Such research was initiated by other correlated studies from our research team, especially studies by Coelho (2013) and Buarque (2019). Fossil collection in the *Arco do André* cave was initiated by Coelho, in a study that also detected and mapped the flooding events in the past of the Peruaçu river valley. Buarque continued research on those floods and on the fossils from that cave and managed to date (via Carbon-14) some of the fossils and found significant correlation of those dates with past volcanism, as show in the graph bellow (**Figure 3**).

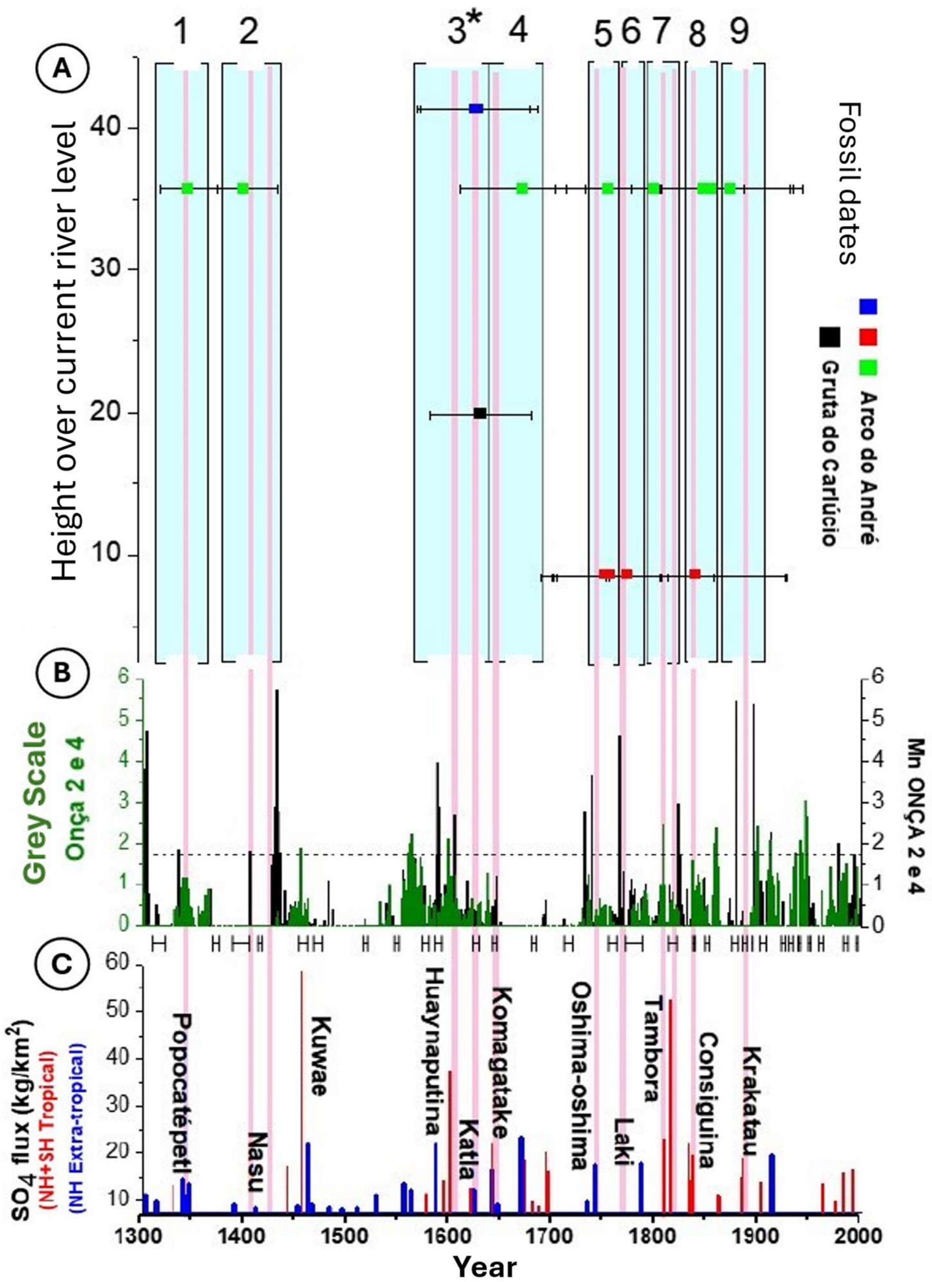

Figure 3. *Graphs adapted from Buarque, 2019.* ***A****: Each bar represents a date obtained via Carbon-14 spectography to one fossil. The colors indicate the different assemblages of origin from the fossils. None of those fossils are amongst the ones under scrutiny in this study, but they have come from the same assemblages. The bars are spread by date on the x axis and by height on the y axis (height in which they were found in the cave). Red fossils represent N1 at 12 meters high from current river level, green fossils represent N2 at 36 meters high, and blue fossils represent N3 at 41 meters. Black fossil was obtained in another cave (Carlúcio's grotto). Light blue bars show the dating range error bars.* ***B****: Grey scale (green) and Manganese levels (black) from stalagmites collected in Lapa da Onça cave.* ***C****: Data from Crowley & Unterman (2013), showing sulfate flux from major eruptions. Together, A, B and C show that the fossil deposition periods (and thus the floods that carried them to their deposition sites) were following major volcanic events, which were also recorded in local stalagmites. On the top, the numbers 1 to 9 represent the most likely scenario of 9 different floods in the area. For more details, check Buarque, 2019.*

2. MATERIALS AND METHODS

2.1. Fossil assemblages and deposition sites

The fossil wood trunks and branches were found inside the *Arco do André* cave ("André's Arch" – located at S 15º5'45.06'', W 44º14'8.24'' – **Figure 4**), one of the several caves located alongside the Peruaçu Riverbed. They were found in three distinct fossil assemblages, disposed in different heights. Even the lowest assemblage, located in the "bottom" of the cave, still is topographically located 12 meters above the modern riverbed, which currently doesn't go through nor underneath the cave.

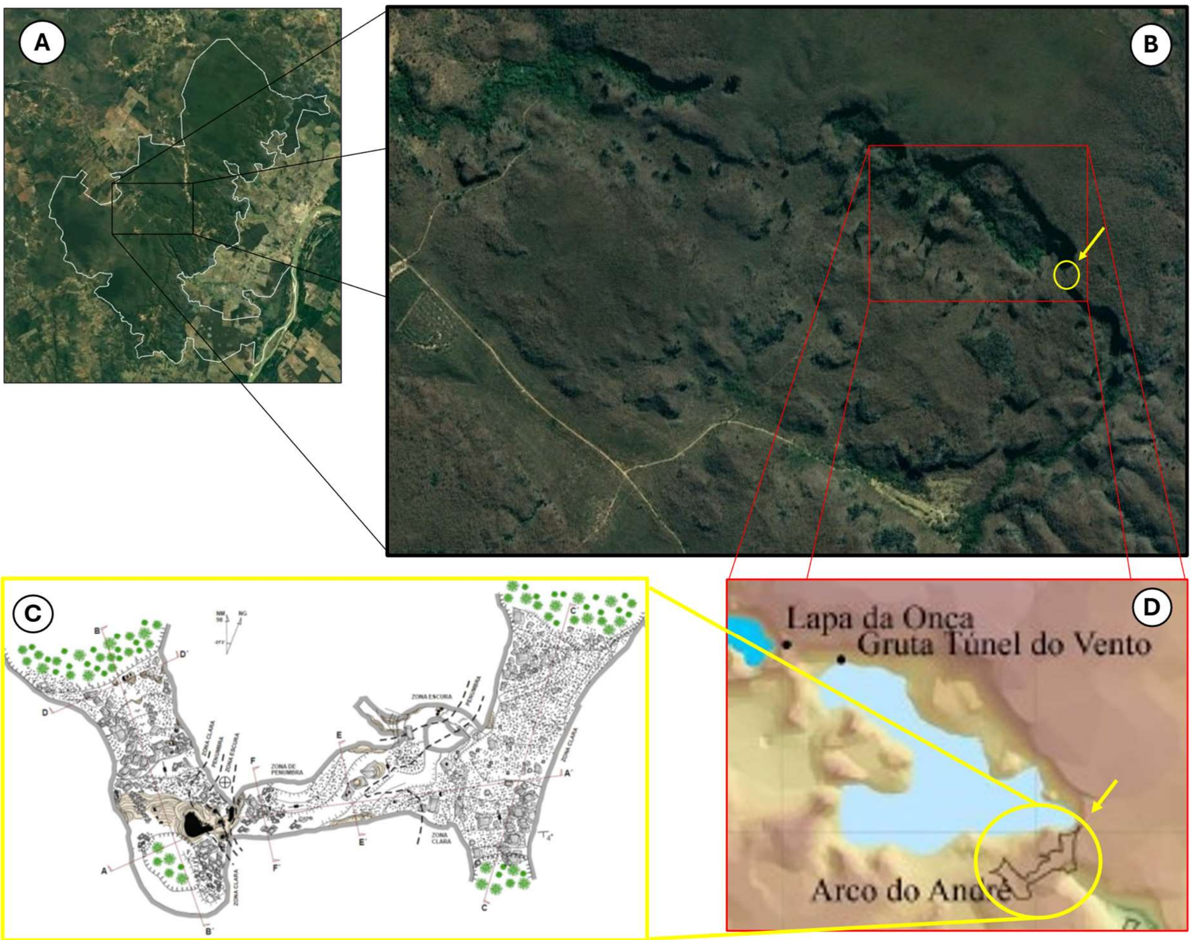

***Figure 4**. **A**: Full view of the PNCP, with inset in black for its central region, in B. **B**: View of the central canyon in the PNCP, where the Peruaçu river runs, from NW to SE. Inset in red for the location pictured in D, and yellow circle indicating the location of the Arco do André cave - S 15º5'45.06'', W 44º14'8.24''. **C**: Arco do André cave floor plan. Adapted from COELHO, 2013. **D**: Vicinity of the cave during the largest flooding event detected in the area, when water filled the canyon between the Arco do André cave (silhouetted) and the previous caves in the canyon ("Onça" cave and "Túnel do Vento" grotto). Adapted from COELHO, 2013*

The fossil samples were found in three distinct assemblages inside the cave. These assemblages were several meters apart, both horizontally and vertically, and thus can be seen as different heights reached by different flood events (or the same flood event in different moments). The three assemblages were named N1, N2, and N3, respectively, from the lowest to the highest flood heights necessary to reach them (12, 36 and 41 meters above the current riverbed). Their locations are shown below (**Figure 5**).

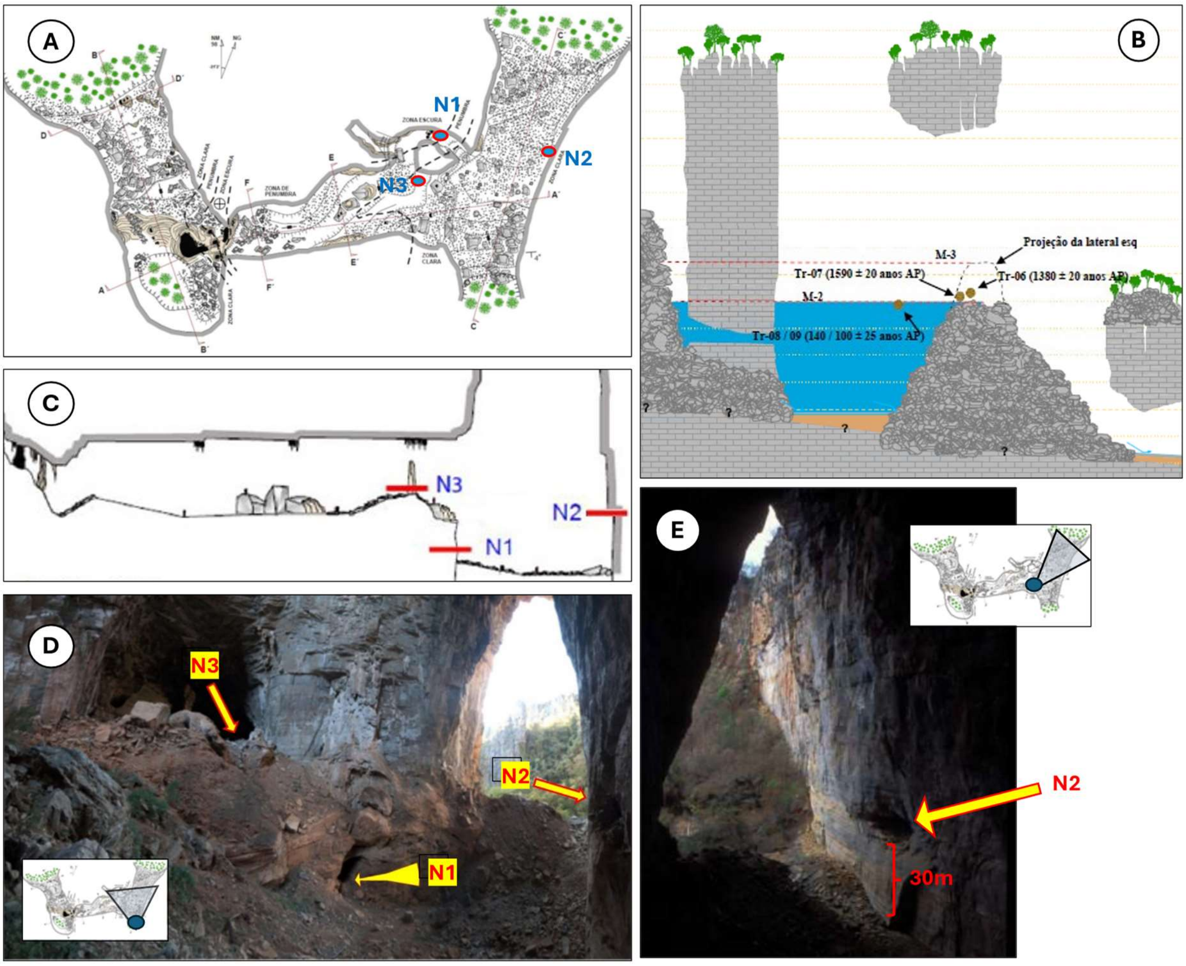

Figure 5. A: *Arco do André cave floor plan, with the rough location of the fossil assemblages marked with N1, N2, and N3. Adapted from COELHO, 2013.* ***B***: *Schematic profile of the area between Arco do André cave and the previous caves in the canyon, showing the highest watermark detected so far (41 meters higher than the current river level, which correlates to N3's height) and the correlated flooding. Adapted from COELHO, 2013.* ***C***: *Vertical profile of the Arco do André cave, showing the locations of the three fossil assemblages and the heights the floods needed to reach for fossil deposition in each. Adapted from COELHO, 2013.* ***D***: *View of the cave's main chamber, pointing the location of the three fossil assemblages. Note that N2 is locates in a crevice in the eastern wall, and N1 is located down a small shaft. Inset map showing the position of the camera regarding the cave floor plan. Adapted from COELHO, 2013.* ***E***: *View of the eastern cave wall, pointing the location of N2, 30 meters above the cave floor. Inset map showing the position of the camera regarding the cave floor plan.*

2.2. Sample Collection

The studied material consists of **73** wood pieces of several forms, shapes and sizes, summarized in **table 1**. Their collection is shown in **figure 6** and some fossil samples are exemplified in **figure 7**. More individual fossils details and images are gathered in **supplementary material 1.**

Table 1: *List of fossil samples. SPFw is the Xylarium International code for the Wood Library of the Institute of Biosciences of the University of São Paulo, and the number is the record number. Types: Disk - flat disk cut from a main stem; Section - cylinder that was part of either a main stem or a secondary branch; Block – Irregular shape of large proportions; Fragment – Irregular shape, small proportions; Branch – Small piece from a secondary branch or young sapling. Assemblages: N1, N2 or N3, the three fossil groupings found in the cave. Height: Height of the assemblage over the current riverbed.*

Nº SPFw	Description (Shape/ Approximate Size)	Type	Assemblage	Height	Sample Condition
8231	Disk collected from log. 25cm diameter.	Disk	**N3**	**41m**	Pristine, very solid.
8232	Branch, 5-10cm diameter, max length 20cm.	Section	**N3**	**41m**	Good, solid.
8233	Branch, 5-10cm diameter, max length 20cm.	Section	**N3**	**41m**	Good, solid.
8234	Branch, 5-10cm diameter, max length 20cm.	Section	**N3**	**41m**	Good, solid.
8235	Branch, 5-10cm diameter, max length 20cm.	Section	**N3**	**41m**	Good, solid.
8236	Branch, 10cm diameter, 14cm length	Section	**N3**	**41m**	Good, solid.
8237	Branch, 5-10cm diameter, max length 20cm.	Section	**N3**	**41m**	Good, solid.
8238	Branch, 5-10cm diameter, max length 20cm.	Section	**N3**	**41m**	Good, solid.
8239	Irregular block, max length 20cm	Block	**N3**	**41m**	Very fragile, breaking
8240	Branch, 5-10cm diameter, max length 20cm.	Section	**N3**	**41m**	Good, solid.
8241	Branch, 9cm diameter, 40cm length	Section	**N3**	**41m**	Good, solid.
8242	Branch, 6cm diameter, 40cm length	Section	**N3**	**41m**	Good, solid. Signs of fire.
8243	Branch, 6cm diameter, 40cm length	Section	**N3**	**41m**	Good, solid.
8244	Branch, 10cm diameter, 30cm length	Section	**N3**	**41m**	Good, solid.
8245	Branch, 5-10cm diameter, max length 20cm.	Section	**N3**	**41m**	Good, solid.
8246	Branch, 10cm diameter, 30cm length	Section	**N3**	**41m**	Good, solid.
8247	Branch, 5-10cm diameter, max length 20cm.	Section	**N3**	**41m**	Good, solid.
8248	Branch, 4cm diameter, 19cm length and fragments	Section	**N3**	**41m**	Good, solid.
8249	Branch, 2cm diameter, 24cm length	Section	**N3**	**41m**	Good, solid.
8250	Branch, 5-10cm diameter, max length 20cm.	Section	**N3**	**41m**	Good, solid.
8251	Small branch, 2cm diameter, 30cm length	Section	**N3**	**41m**	Good, solid.
8252	Small branches, 1cm diameter, 27cm length	Section	**N3**	**41m**	Good, solid.
8253	Large bark fragment, 15cm side 30cm length	Fragment	**N3**	**41m**	Good, solid. Signs of fire.
8254	Irregular block, max length 40cm	Block	**N3**	**41m**	Fragile, structurally weak
8255	Branch, 5-10cm diameter, max length 20cm.	Section	**N3**	**41m**	Good, solid.
8256	Branch, 6cm diameter, 25cm length	Section	**N2**	**36m**	Good, solid.
8257	2 branch fragments	Section	**N2**	**36m**	Good, solid.
8258	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8259	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8260	Irregular block, max length 20cm	Block	**N2**	**36m**	Fragile, structurally weak

8261	Irregular branch, 10cm diameter, 40cm side	Section	**N2**	**36m**	Good, solid.
8262	Irregular block, max length 40cm	Block	**N2**	**36m**	Fragile, structurally weak
8263	Irregular block, max length 40cm	Block	**N2**	**36m**	Fragile, structurally weak
8264	Irregular block, max length 40cm	Block	**N2**	**36m**	Fragile, structurally weak
8265	Branch, 5cm diameter, 21cm length	Section	**N2**	**36m**	Good, solid.
8266	Branch, 3cm diameter, 15cm length	Section	**N2**	**36m**	Good, solid.
8267	Branch (possibly bark), max length 30cm	Section	**N1**	**12m**	Good, solid.
8268	Wide branch, 7cm diameter, 20cm length	Section	**N1**	**12m**	Good, solid.
8269	Wide disk, diameter 20cm.	Disk	**N1**	**12m**	Good, solid.
8270	Wide disk, diameter 25cm.	Disk	**N1**	**12m**	Fragile, sapwood falling.
8271	Wide block, max length 20cm	Disk	**N1**	**12m**	Good, solid.
8272	Irregular block, max length 40cm	Block	**N1**	**12m**	Fragile, structurally weak
8273	Wide disk, diameter 25cm, with fragments.	Disk	**N1**	**12m**	Very fragile, dismantling
8274	Branch, 5-10cm diameter, max length 20cm.	Section	**N1**	**12m**	Good, solid.
8275	Fragment (possibly bark), 15cm max length	Fragment	**N2**	**36m**	Solid but dismantling.
8276	Branch, 3cm diameter, 18cm length	Section	**N2**	**36m**	Fragile, structurally weak
8277	2 branch pieces, 2cm diameter 19 cm length	Section	**N2**	**36m**	Fragile, structurally weak
8278	2 incomplete branch fragments, length 40cm	Section	**N2**	**36m**	Good, solid.
8279	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8280	Branch, 4cm diameter, 30cm length, dark.	Section	**N2**	**36m**	Good, very solid.
8281	Branch, 5cm diameter, 21cm length	Section	**N2**	**36m**	Fragile, structurally weak
8282	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8283	Branch fragment, max length 30cm.	Section	**N2**	**36m**	Good, solid.
8284	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8285	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8286	Branch, 6cm diameter, 30 cm length	Section	**N2**	**36m**	Good, solid.
8287	Small branch, less than 2cm diameter, 22cm	Section	**N2**	**36m**	Fragmenting bark.
8288	Branch, 6cm diameter, 20cm length.	Section	**N2**	**36m**	Good, solid.
8289	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8290	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8291	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8292	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8293	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8294	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8295	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8296	Branch, 10cm diameter, 28cm length	Section	**N2**	**36m**	Pristine, very solid.
8297	Irregular block, max length 40cm	Block	**N2**	**36m**	Very fragile, dismantling.
8298	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8299	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8300	Irregular block, max length 40cm	Block	**N2**	**36m**	Very fragile, dismantling.
8301	Branch fragment, max length 26cm	Fragment	**N2**	**36m**	Good, solid.
8302	Branch, 5-10cm diameter, max length 20cm.	Section	**N2**	**36m**	Good, solid.
8303	Fragment (possibly bark), 10cm max length	Fragment	**N2**	**36m**	Good, solid.

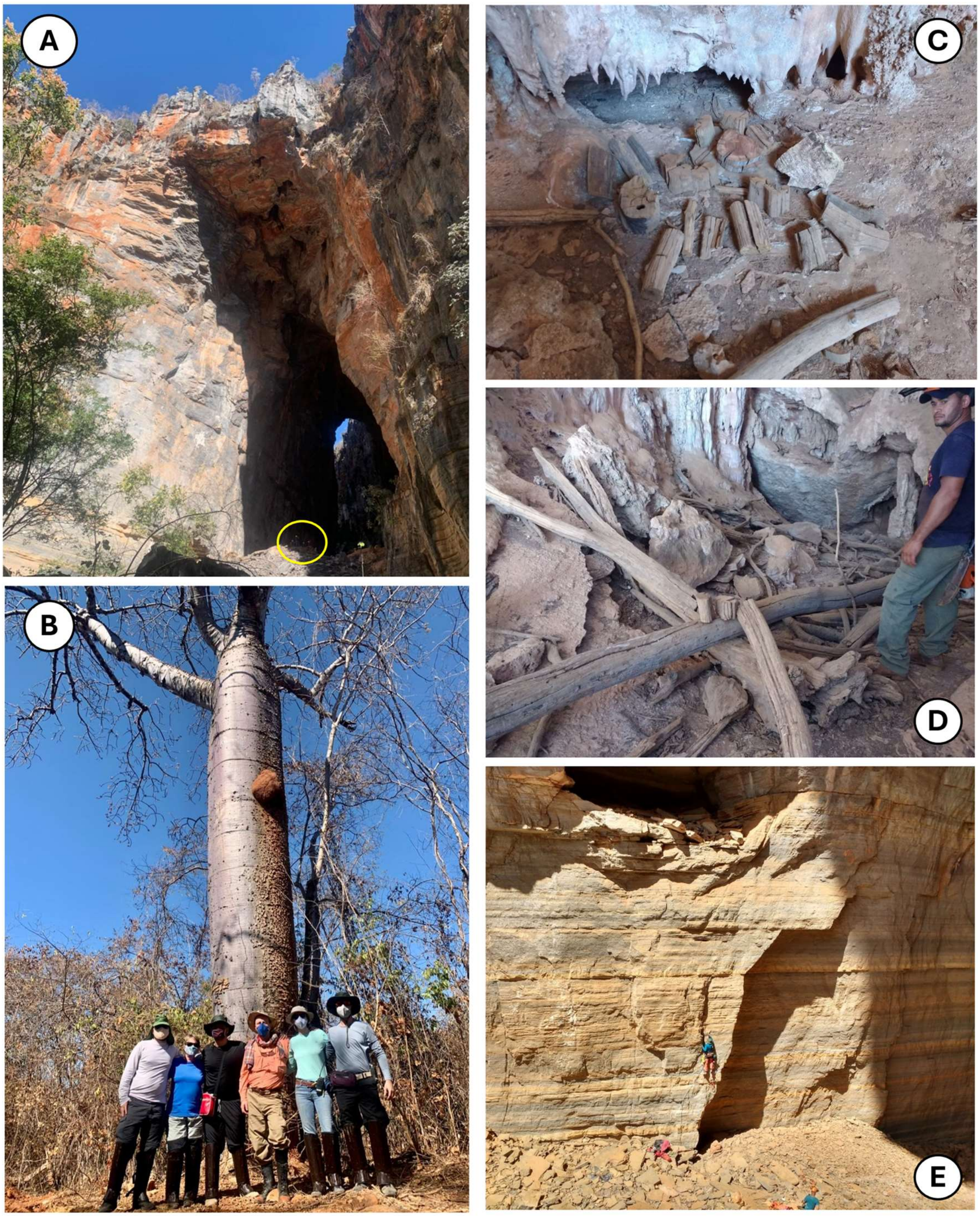

***Figure 6**. **A**: Arco do André cave' main entrance. Notice that inside the yellow circle is a group of people using yellow safety helmets, barely visible, for scale. **B**: One of the field teams posing in front of a Cavanillesia umbellata, one of the recurring species in the fossil assemblage. **C**: N3 fossil assemblage, pictured here still in the cavern but prepared for transportation (samples cut from logs). **D**: N3 fossil assemblage, picture here during sampling, with the logs still jumbled up as they were found. **E**: Climbing team starting the climb (30 meters) to N2 location for sample collection.*

Figure 7. *Photos of some of the fossil samples, as pictured in the SPFw laboratory during laboratory procedures.* ***A***: *SPFw 8253.* ***B***: *SPFw 8256.* ***C***: *SPFw 8248.* ***D***: *SPFw 8288.* ***E***: *SPFw 8242.* ***F***: *SPFw 8252.* ***G***: *SPFw 8261.* ***H***: *SPFw 8231.*

The smaller fossils were collected as a whole. Those that weren't small enough to be carried by hand by one person were sampled transectionally using handsaws or gas-powered chainsaws.

2.3. Laboratory procedures

Wood fossils were polished by hand with sandpaper of increasing grit size, from P100 up to P800 (STOKES, 1996), then sampled to get the form of cubes and prisms with sides between 1 cm and 3 cm (depending on the fossil structure, conservation and shape). Such cubes and prisms were then boiled in water and glycerin (3:1), for

30 minutes up to 4 hours (depending on the toughness of the material) as softening method for cutting on the sliding microtome (BARBOSA *et al*, 2010).

Some samples (6 out of the 72) were so degraded that polishing was unfruitful and they were submitted to inclusion in polyethylene glycol (PEG 4000, density 1.2 g/cm³ at 20 ºC) for microtomy (BARBOSA *et al*, 2010).

Microtome sections were bleached with weak solutions of sodium hypochlorite (10%) , followed by de-hydration with ethanol, amidst which they were colored with astra blue and safranin or fuchsin for better microscopic view. Finally, permanent slides were mounted using synthetic resins such as Entellan® or Canadian Balm. Most of the samples also had spare slides prepared without bleaching step to allow viewing of the natural color and fungi presence (BARBOSA *et al*, 2010).

The analysis used anatomical features detailed in the Hardwood Anatomy Identification Manual (IAWA Committee, 1989), and was mainly focused on qualitative features. Images and descriptions were then compared with online databases (INSIDEWOOD, 2004-onwards; SFB & LPF, 2024; IPT, 2024), samples present in local collections (SPFw and BCTw, which include samples collected previously in the PNCP), and the specific literature for hardwood identification of Brazilian woods from different ecosystems (MAINIERI & PEREIRA, 1964; ESAU, 1974; CARLQUIST, 1977; DÉTIENNE & JACQUET, 1983; CHIMELO & ALFONSO, 1985; MAUSETH, 1988; MAINIERI & CHIMELO, 1989; BURGER & RICHTER, 1991; CHIMELO *et al.*, 1993; IPT, 1993; KRAUS & ARDUIN, 1997; CECCANTINI, 2006; SONSIN *et al*, 2014).

2.4. Data Analysis

Once obtained the identified taxa list, similarity analyses were performed (JACCARD, 1908; SORENSEN, 1957) with comparable woody formations from Central Brazil (SILVA & SCARIOT, 2003; THOMAS *et al*, 2009; NETTESHEIM *et al*, 2010; COUTO *et al*, 2011; FREIRE, 2011). The woody vegetations from Central Brazil selected were picked to represent the following key vegetations and biomes: Cerrado Biome – deciduous forest on limestone and woody savannas; Atlantic Forest Biome – semi-deciduous forest; Biome Caatinga – deciduous forest. A similarity analysis was also performed against a paleovegetation construed from another fossil assemblage, gathered from the South region of the Minas Gerais state (and characterized as a woody savanna). Finally, each taxon was analyzed by their own characteristics, especially regarding their life cycle, preferred climatic conditions, and their current presence in extant Brazilian biomes.

3. RESULTS

3.1. Wood Paleontological Assemblage

The paleontological wood assemblage found at PNCP comprises 73 independent fossil samples. The majority of fossils are in a very good state of preservation (80,82%) what allowed us to prepare high quality microscopic slides and to observe almost all wood anatomical features needed for taxa identification. This can be observed in several plates of this work (**Figures. 8-11**). Some samples however were not so well preserved, with more difficult or even impossible conditions to be prepared and analyzed, even with utilization of several imbibing media such as paraffin, Paraplast®, or polyethylene glycol.

There were 24 samples that were suitable for anatomical preparation analysis (by being both in good conditions and representing a morphotype) and the taxa identified are presented at **tables 2** and **3**, below.

Table 2: *Fossil collection with identified taxa. SPFw is the Xylarium International code for the Wood Library of the Institute of Biosciences of the University of São Paulo "Nanuza Luiza de Menezes", and the associated number is the record number for each sample. Assemblages: N1, N2 or N3, the three fossil groupings found in the cave.*

Nº SPFw	Assemblage	Species name	Family	Local Name
8231	**N3**	*Parapiptadenia zehntneri*	Fabaceae	Angico
8232	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8233	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8234	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8235	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8236	**N3**	*Protium sp*	Burseraceae	Almecegueira
8237	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8238	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8239	**N3**			Indet.
8240	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8241	**N3**	*Pouteria sp*	Sapotaceae	Abiurana

8242	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8243	**N3**	*Protium sp*	Burseraceae	Almecegueira
8244	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8245	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8246	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8247	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8248	**N3**	*Cecropia hololeuca*	Urticaceae	Embaúba-prateada
8249	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8250	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8251	**N3**	*Protium sp*	Burseraceae	Almecegueira
8252	**N3**	*Aspidosperma sp*	Apocynaceae	Peroba-do-Cerrado
8253	**N3**	*Protium sp*	Burseraceae	Almecegueira
8254	**N3**	*Cavanillesia umbellata*	Malvaceae	Barriguda
8255	**N3**	*Pouteria sp*	Sapotaceae	Abiurana
8256	**N2**	*Ficus sp1*	Moraceae	Gameleira
8257	**N2**	*Protium sp*	Burseraceae	Almecegueira
8258	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8259	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8260	**N2**	*Cavanillesia umbellata*	Malvaceae	Barriguda
8261	**N2**	*Parapiptadenia zehntneri*	Fabaceae	Angico
8262	**N2**	*Cavanillesia umbellata*	Malvaceae	Barriguda
8263	**N2**	*Cavanillesia umbellata*	Malvaceae	Barriguda
8264	**N2**	*Cavanillesia umbellata*	Malvaceae	Barriguda
8265	**N2**	*Ficus sp3*	Moraceae	Mata-Pau
8266	**N2**	*Protium sp*	Burseraceae	Almecegueira
8267	**N1**	*Protium sp*	Burseraceae	Almecegueira
8268	**N1**	*Handroanthus sp.*	Bignoniaceae	Ipê
8269	**N1**	*Protium sp*	Burseraceae	Almecegueira
8270	**N1**	*Protium sp*	Burseraceae	Almecegueira
8271	**N1**	*Protium sp*	Burseraceae	Almecegueira
8272	**N1**	*Cavanillesia umbellata*	Malvaceae	Barriguda
8273	**N1**			Indet.
8274	**N1**	*Pouteria sp*	Sapotaceae	Abiurana
8275	**N2**	*Cereus sp*	Cactaceae	Mandacaru
8276	**N2**	*Cavanillesia umbellata*	Malvaceae	Barriguda
8277	**N2**	*Cavanillesia umbellata*	Malvaceae	Barriguda
8278	**N2**	*Guettarda sp*	Rubiaceae	Veludo-branco
8279	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8280	**N2**	*Goniorrhachis marginata*	Fabaceae	Itapicuru
8281	**N2**	*Cecropia sp.*	Urticaceae	Embaúba
8282	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8283	**N2**	*Maclura tinctoria*	Moraceae	*Taiúva*
8284	**N2**	*Pouteria sp*	Sapotaceae	Abiurana

8285	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8286	**N2**	*Ficus sp2*	Moraceae	Figueira-brava
8287	**N2**			Indet.
8288	**N2**	*Commiphora leptophloeos*	Burseraceae	Amburana-vermelha
8289	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8290	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8291	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8292	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8293	**N2**	*Jacaranda mimosifolia*	Bignoniaceae	Jacarandá-Mimoso
8294	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8295	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8296	**N2**	*Astronium cf. urundeuva*	Anacardiaceae	Aroeira-do-Sertão
8297	**N2**			Indet.
8298	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8299	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8300	**N2**			Indet.
8301	**N2**		Malvaceae	Indet.
8302	**N2**	*Pouteria sp*	Sapotaceae	Abiurana
8303	**N2**	*Protium sp*	Burseraceae	Almecegueira

***Table 3**: Summary of identified taxa by morphotypes. Sample: SPFw number for the sample used in the analysis. 4 Morphotypes were too fragile for analyses, while four others remain indetermined so far.*

Morphotype	Repetitions	Sample	Family	Species name	Local name
001	**32**	**8298**	Sapotaceae	*Pouteria sp*	Abiurana
002	**8**	**8260**	Malvaceae	*Cavanillesia umbellata*	Barriguda
003	**7**	**8269**	Burseraceae	*Protium sp*	Almecegueira
004	**1**	**8231**	Fabaceae	*Parapiptadenia zehntneri*	Angico
005	**1**	**8239**			
006	**1**	**8252**	Apocynaceae	*Aspidosperma sp.*	Peroba-do-Cerrado
007	**1**	**8256**	Moraceae	*Ficus sp1*	Gameleira
008	**1**	**8261**	Fabaceae	*Parapiptadenia zehntneri*	Angico
009	**1**	**8268**	Bignoniaceae	*Handroanthus sp*	Ipê
010	**1**	**8273**	-	-	-
011	**1**	**8275**	Cactaceae	*Cereus sp*	Mandacaru
012	**1**	**8278**	Rubiaceae	*Guettarda sp*	Veludo-branco
013	**1**	**8280**	Fabaceae	*Goniorrhachis marginata*	Itapicuru
014	**1**	**8283**	Moraceae	*Maclura tinctoria*	Amoreira-brava
015	**1**	**8287**	-	-	-
016	**1**	**8288**	Burseraceae	*Commiphora leptophloeos*	Amburana-vermelha
017	**1**	**8296**	Anacardiaceae	*Astronium cf. urundeuva*	Aroeira-do-sertão
018	**1**	**8297**			
019	**1**	**8300**			
020	**1**	**8301**	Malvaceae	-	-

021	**1**	**8248**	Urticaceae	*Cecropia hololeuca*	Embaúba-prateada
022	**1**	**8272**	Malvaceae	*Cavanillesia umbellata*	Barriguda
023	**1**	**8281**	Urticaceae	*Cecropia sp*	Embaúba
024	**1**	**8266**	-	-	-
025	**1**	**8265**	Moraceae	*Ficus sp3*	Mata-Pau
026	**1**	**8286**	Moraceae	*Ficus sp2*	Figueira-brava
027	**1**	**8293**	Bignoniaceae	*Jacaranda mimosifolia*	Jacarandá-Mimoso
028	**2**	**8270, 8271**			

As shown above, we identified in the assemblage 11 different families, among which there were 15 different genera, totaling at 17 different species so far. From the 73 samples, 64 were identified (87,67%). From the original 28 morphotypes, 21 were identified (with some of those repeating species, thus why a lower species number). The most common species / morphotype was *Pouteria sp* (Sapotaceae), with 32 repetitions, followed by *Cavanillesia umbellata* (Malvaceae) with 9 repetitions and *Protium sp* (Burseraceae) with 7 repetitions. 2 other taxa had 2 repetitions: *Parapiptadenia zehntneri* (Fabaceae) and one indetermined morphotype. The most diverse family was Moraceae (with 4 taxa), where we also found the most diverse genus, *Ficus*, with 3 taxa.

It is worth noting that we could not find significant differences between the three assemblages (N1, N2 and N3) in regard to their diversity or composition, with the most common taxa appearing in all of them.

3.2. Comparison to Extant Flora - Similarity Analysis

Despite the small number of different taxa, we performed statistical comparisons between this fossil collection and regional formations, including one paleoformation. As visible in the **table 4** below, the collection has more similarity (albeit not much) with formations of deciduous forests over limestone, which exactly one of the most common vegetations in the PNCP today. There’s also good similarity with the paleoformation described by Freire (2011), with fossils from Lagoa Santa – MG, about 500 km from the PNCP.

***Table 4**: Similarity indexes comparison between the fossil collection and 4 regional formations and 1 paleoformation. Greater values found in the comparison with deciduous limestone formation from the Cerrado biome.*

Formation	Paleoformation	Semi-deciduous	Deciduous on limestone	Woody savannah	Semi-deciduous
Biome	Cerrado/ Atlantic Forest	Atlantic Forest	Cerrado	Cerrado	Caatinga
Total genera	26	170	31	73	85
Genera in common	4	7	5	3	2
Exclusive - This study	11	8	10	12	13
Exclusive - Formation	22	163	26	70	83
Similarity Indexes					
Jaccard	0,108	0,039	0,122	0,035	0,020
Dice-Sorensen	0,195	0,076	0,217	0,068	0,040
Sources:	Freire, 2011	Thomas *et al*, 2009	Silva & Scariot, 2003	Nettesheim *et al*, 2010	Couto *et al*, 2011

3.3. Fossil Descriptions

We've chosen a 4 species to showcase here (**figures 8** to **11**) and describing them in detail. Similar details for the remaining morphotypes can be found in **Supplementary Materials 2.**

Morphotype 001 – Sample SPFw 8298. Plate A. This morphotype, 001, contains the majority of the collection, accounting for 32 specimens. This was observed as belonging to the Sapotaceae family, with an approximation between a few possible genera before narrowing it to *Pouteria*. This morphotype presents: Distinct growth layer, marked by fibrous zones; Diffuse porosity, with radial arrangement in chains of 3 to 6 vessels; Parenchymal rays with 1 to 3 cells in thickness; Axial parenchyma in narrow bands of up to 3 cells in thickness; Simple perforation plates; Alternate intervascular pitting; Septate and non-septate fibers with thick walls; Presence of vasicentric tracheids; Rays with the uniseriate part the same width as the multiseriate part; Radiovascular pitting with different sizes within the same cell; Ray body composed of procumbent cells, with 3 to 6 rows of square marginal cells; Presence of siliceous bodies in the fibers; Presence of dark substance in the rays and, more rarely, in the vessels; Absence of tyloses and solitary vessels with angular shapes. Of these characteristics, one of the most relevant observed was the presence of radiovascular pitting of different sizes and shapes within the same cell, a distinctive characteristic of Sapotaceae. Another noteworthy characteristic is the presence of growth rings marked by fibrous zones. Along with the abundant quantity of fossils collected from this same species, from the same locality, this morphotype becomes an excellent candidate for subsequent dendrochronological studies. Finally, one last striking characteristic is the quite common presence of a dark substance in ray cells, but this could only be observed in untreated sections (natural coloring, that is, not bleached with bleach and artificially colored with safranin and astra blue). All we know about this substance is that it is completely destroyed by some of the various substances used in the staining process (bleach, alcohol, safranin, astra blue, butyl acetate).

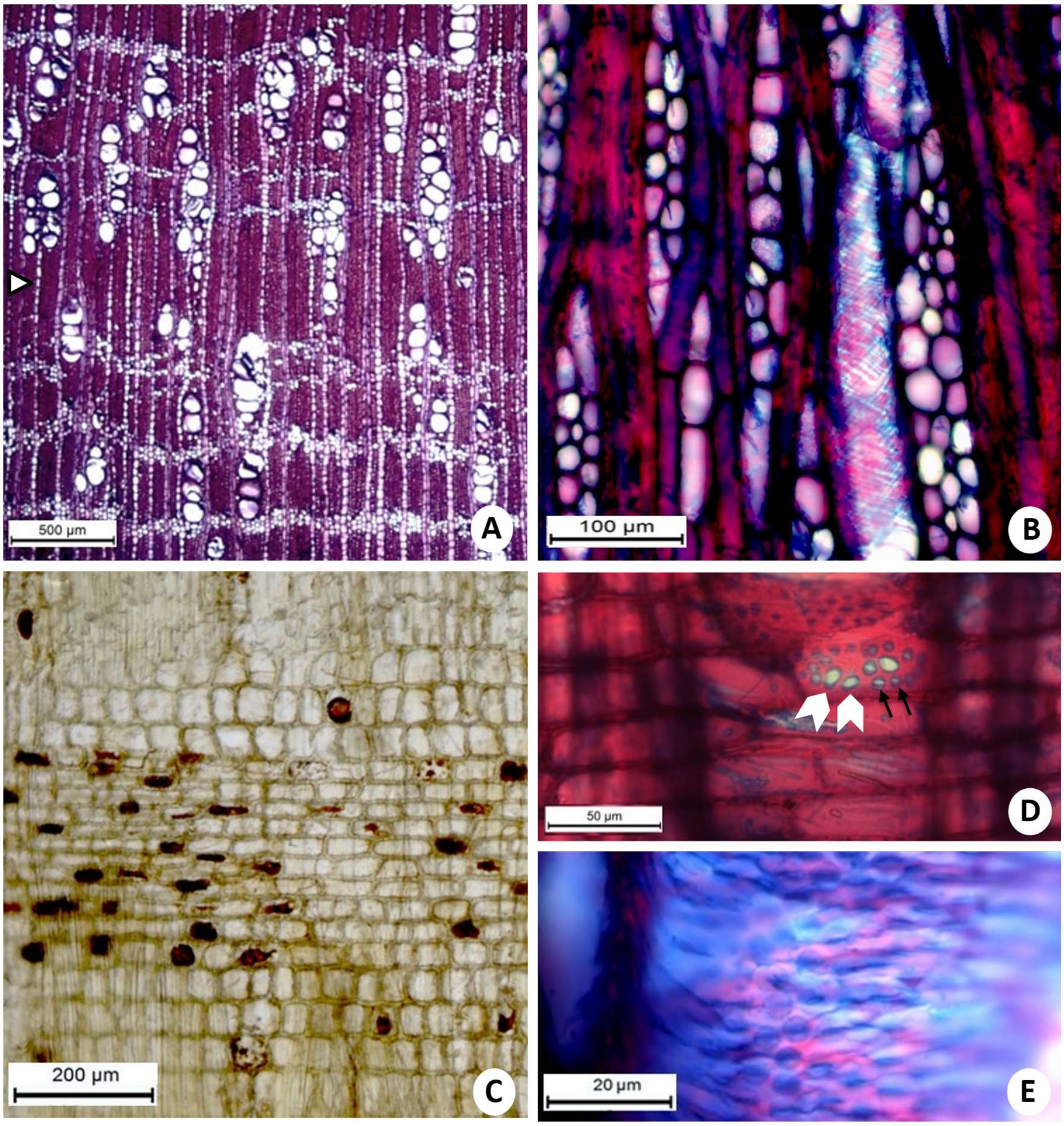

Figure 8. *Plate A: Sample SPFw 8298. Sapotaceae,* Pouteria *sp.* ***A****. Cross section showing growth ring marked by fibrous zone (arrow);* ***B****. LTG section;* ***C****. LRD section showing rays composed by central rows procumbent with marginal rows upright, and dark organic substance present in ray cells;* ***D****. Detail of LRD section showing wide vessel-ray pits of variable size (different arrows);* ***E****. Detail of LTG section showing alternate intervessel pits.*

Morphotype 022 – Sample SPFw 8272. Plate BW. This morphotype, 022, belongs to the second most recurring species in the collection, *Cavanillesia umbellata* (Malvaceae). Initially diagnosed as its own morphotype due to its much better condition than other *C. umbellata* fossils (which seem to degrade very fast and were classified as Morphotype 002), its good conditions also allowed us to properly prepare slides and plates to describe it. These fossils present very large vessels, often visible with the naked eye. They also present rays in two distinct sizes, the “smaller” ones already being pretty big, reaching 3 – 5 cells wide, while the larger rays can reach upward to 20 cells wide. These fossils also present alternate intervessel pits and large vessel-ray pits without distinct borders. Its rays are composed of rows of exclusively procumbent cells. Diffuse axial parenchyma is present, alongside few fibers with thins walls and short length. These fossils also present growth rings, marked by zones of more abundant axial parenchyma and less fibers, often visible with the naked eye as well. All in all, it is a very lightweight wood, full of parenchyma and weaker fibers. These characteristics tie neatly with the species well known rapid growth and explain the perceived poor resistance of its fossils.

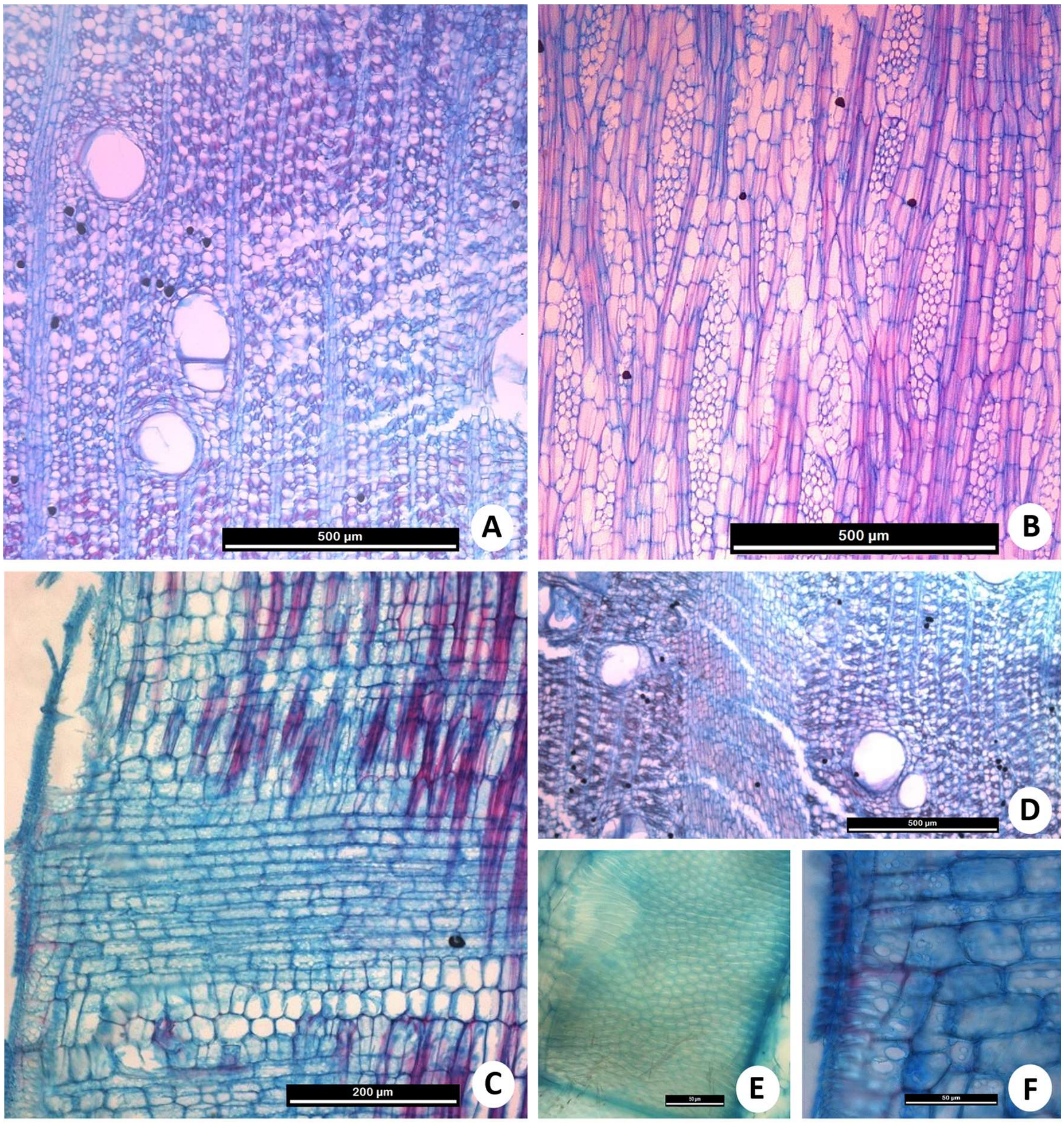

***Figure 9**. Plate B: Sample SPFw 8272 – Malvaceae,* Cavanillesia umbellata*: **A**. Cross section showing rays with sheath cells; **B**. Longitudinal tangential section showing rays involved by sheath cells; **C**. Longitudinal radial section showing ray composed of procumbent cells; **D**. Detail of cross section showing a large ray amidst smaller rays (wood with two distinct ray sizes); **E**. Detail of LTG section showing alternate intervessel pits; **F**. Detail of LRD section showing ample and large vessel-ray pits without borders.*

Morphotype 003 – Sample SPFw 8269. Plate C. The third most common morphotype, identified as *Protium sp.* (Burseraceae), has 7 repetitions in the collection. This species has: Absent axial parenchyma; Growth rings marked by fiber densification; Parenchymal rays thin to wide, from 1 to 6 cells in thickness; Parenchymal rays also entirely composed of procumbent cells; Simple perforation plates; Alternate and bordered intervascular pitting; Simple and wide radiovascular pitting (forming a set of "fitted windows"); Presence of prismatic crystals and siliceous bodies in the fibers; Thin-walled fibers; Presence of septate and non-septate fibers; Absence of bodies or substances blocking the vessels; Absence of angular-shaped solitary vessels. Being the third most common morphotype in the assemblage, and like the previous ones also containing growth rings, it is another potential candidate for subsequent dendrochronological studies.

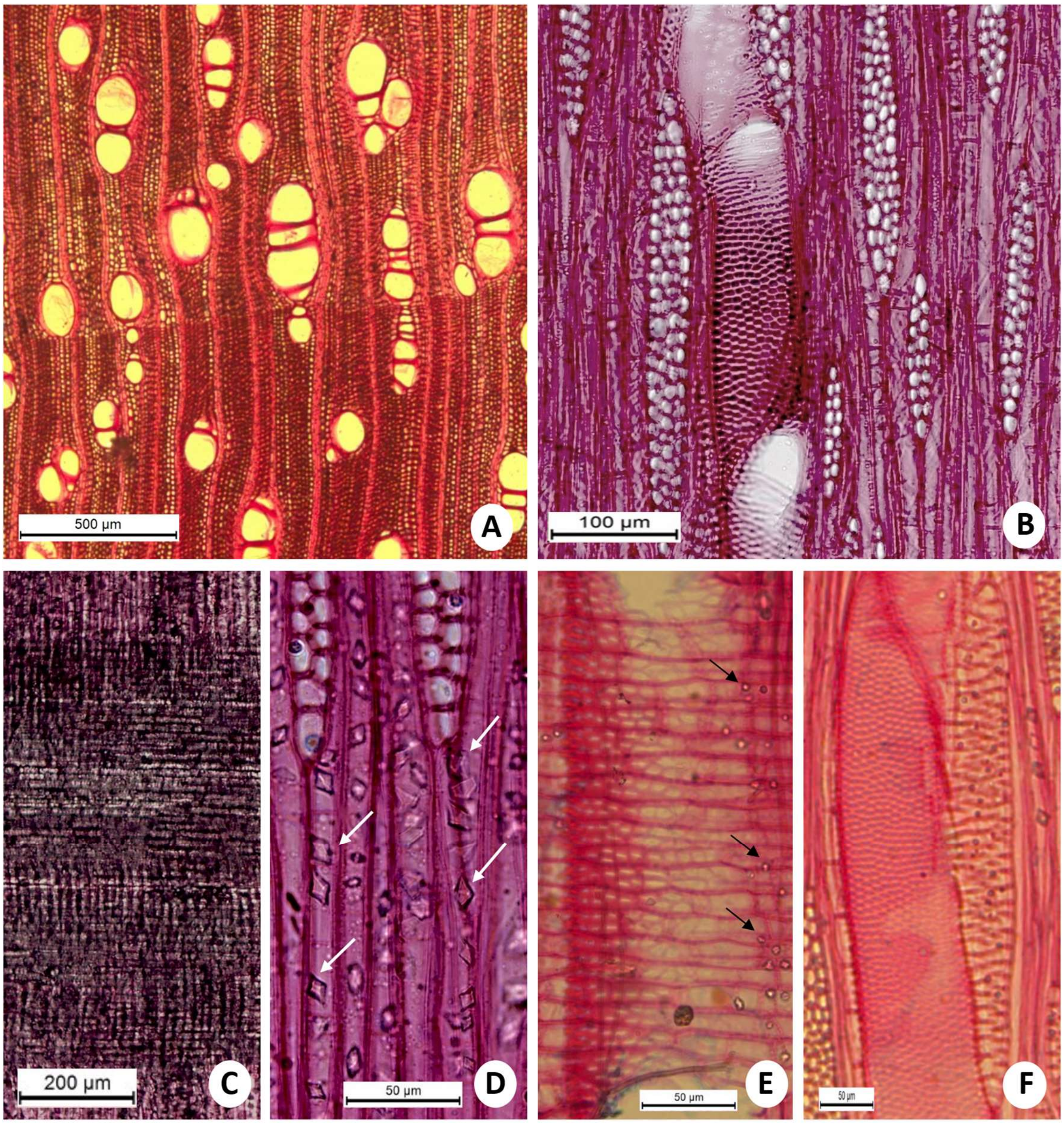

***Figure 10**. Plate C: Sample SPFw 8269. Burseraceae,* Protium *sp.: **A**. Cross section showing growth ring marked by flattened fibers; **B**. Longitudinal tangential section showing septate fibers, alternate intervessel pits and rays with up to three cells wide; **C**. Longitudinal radial section showing rays composed exclusively by procumbent cells; **D**. Detail of LTG section showing prismatic crystals inside fibers (arrows). **E**. Detail of LRD section showing large vessel-ray pits without distinct borders and silica bodies in ray cells (arrows); **F**. Detail of LTG section showing alternate intervessel pits.*

Morphotype 004 – Sample SPFw 8231. Plate ZG. This is a representative of *Parapiptadenia zehntneri* (Fabaceae). This species appeared in two different morphotypes of the collections, separated due to belonging to very different fossils macroscopically (one was a branch piece, with some damage, the other a disk sawed from a trunk, mostly pristine). Having growth rings as well, is another prime candidate to further studies. These fossils both presented distinct aliform to confluent axial paratracheal parenchyma, thin rays (only one cell wide, rarely two cells), and growth rings marked by fibrous zones. They also had distinctly long rows of prismatic crystals in chambered axial parenchyma cells and dark substances (possibly resin) blocking vessels (but only visible in slides in natural coloration). They present alternate intervessel pits, with similar vessel-ray pits, small and bordered. Rays are composed of procumbent cells.

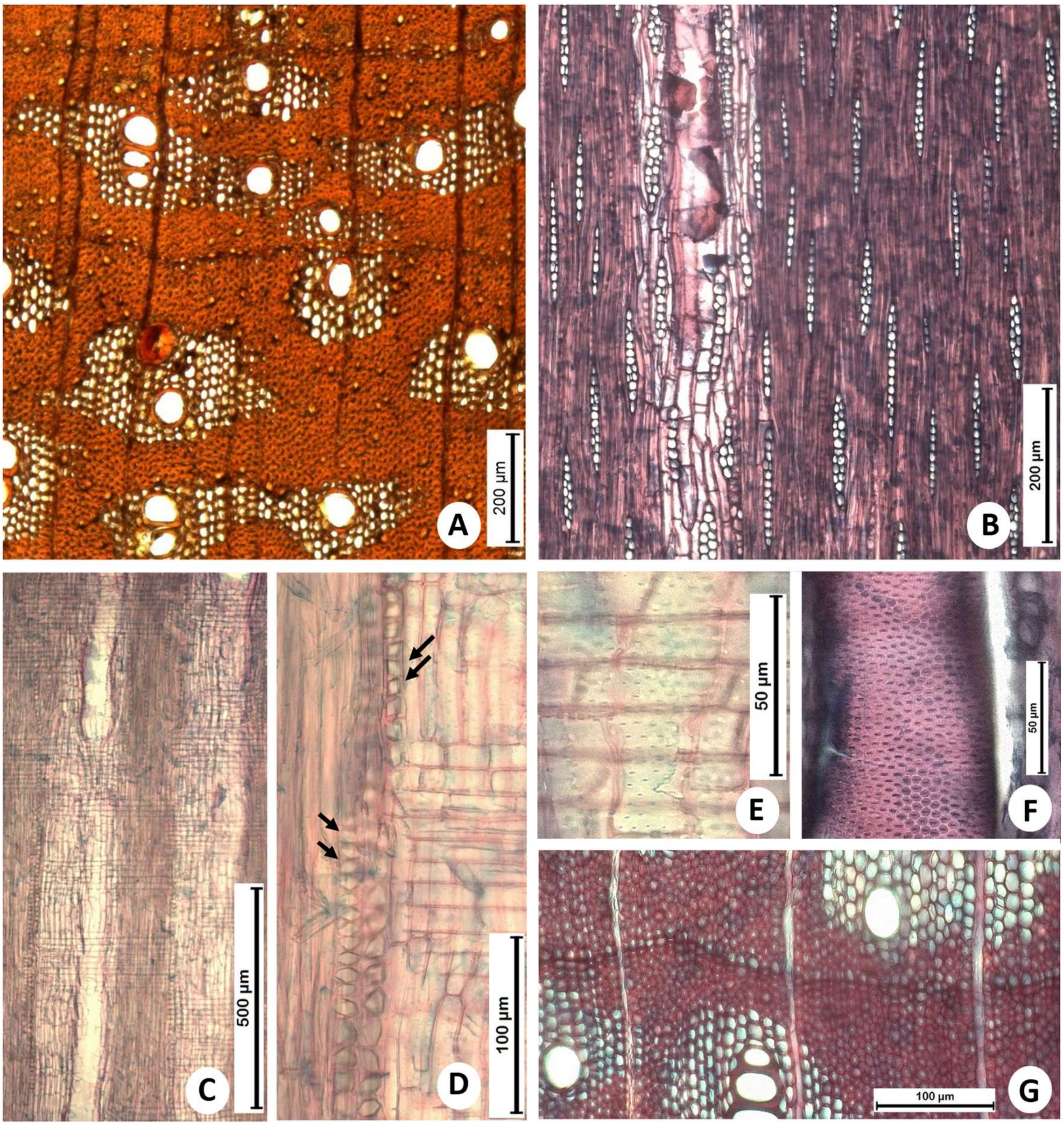

***Figure 11**. Plate Z: Sample SPFw 8231. Fabaceae,* Parapiptadenia zehntneri ***A**. Cross section showing growth ring, aliform and confluent axial paratracheal parenchyma; **B**. LTG section showing uniseriate (occasionally biseriate) rays; **C**. LRD section showing rays entirely composed by procumbent cells; **D**. Detail of LRD section showing prismatic crystals in chambered axial parenchyma cells (arrows); **E**. Detail of LRD section showing vessel-ray pits with distinct borders, similar to intervessel pits; **F**. Detail of LTG section showing alternate intervessel pits; **G**. Detail of cross section showing growth ring marked by thickened fiber cell walls and flattened fibers.*

4. DISCUSSION

4.1. Identified Taxa

There is a limited number of taxa identified in the fossil assemblages (only 17 species spread among 11 families). However, many of these can tell us something about earlier periods of the PNCP and taken together they wield useful and valuable information.

The most common taxa in the collection, *Pouteria sp*, was a particularly difficult fossil to narrow down since it belongs to the Sapotaceae family. This family has gone through several revisions (PENNINGTON, 2004; SWENSON & ANDERBERG, 2005; ARMSTRONG *et al*, 2014; DE FARIA, 2017), and even without considering these revisions, separating between its genus via anatomical features is particularly complicated (KUKACHKA, 1978; MELFI, 2017). This means that unfortunately, so far, we can't extract much information from the most common morphotype in the collection.

Regarding other species present in the assemblages, we have for example the genus *Cecropia*, represented by two specimens (one confirmed to belong to *Cecropia hololeuca*, while the other could not be analyzed anatomically for distinction between *C. hololeuca* or *pachystachya*). Both species currently occur in the PNCP, which is a first indication of ecological stability since the period in which the fossil trunk was initially deposited. Furthermore, this genus is notably tolerant to flooding (BATISTA et al, 2008). While it is known that all those fossils have been collected by flooding events, it still isn't known if those floods were instantaneous and short-lived (draining out in a few days) or slow and somewhat long-lasting (forming temporary lakes for months or years). The presence of this genus in the assemblages, while it does not confirm the long floods scenario, at least it does not rule it out. Besides this flood tolerance, *Cecropia* is also commonly associated with dry, scrubland regions (BERG & ROSSELLI, 2005).

Goniorrhachis marginata is another taxon still present among modern PNCP formations. This species is tree with late secondary growth that counterintuitively has an inverse correlation with canopy cover (BARRETO et al, 2022). In other words, it is a species that prefers open areas, with a low proportion of canopy cover. It is also known for its preference for dry environments.

Parapiptadenia zehntneri, with two samples in the assemblages, is mentioned in the literature mainly as a Caatinga-occurring species, covering a limited region between the states of Ceará and Bahia. It can occasionally appear in areas of northern Minas Gerais, such as the PNCP itself, but always in dry seasonal forests (OLIVEIRA *et al*, 2014; RIBEIRO *et al*, 2016; MORIM, 2024).

Cavanillesia umbellata is the second most common taxa found in the assemblage, with 9 specimens. Known locally as "barriguda" or big belly, it is today a species-symbol of the PNCP, due to its size and beauty. The species is considered endemic to dry forests, where it is structurally dominant, towering over other trees. They typically form an enlarged trunk, nicknamed "belly", resulting from parenchymatic tissues accumulating water - in a known survival strategy tailored for dry environments. (LORENZI, 1982; PENNINGTON & RATTER, 2006; MELO-JUNIOR, 2010).

Another noteworthy genus present is *Cereus sp*. This Cactaceae genus comprises mostly of stereotypical cacti: thorny plants with photosynthesizing stems and parenchyma specialized for water reserves, characteristics suited for hot and dry environments (ROMEIRO-BRITO *et al*, 2016; TAYLOR *et al*, 2023).

As we can see from these examples, there is a pattern emerging: all taxa are correlated with hot and dry environments, very similar to the environment currently present in the PNCP. Furthermore, while this following point needs to be properly addressed in a separate study in the future, many of the samples presented anatomical features in common (small vessels, heavy presence of tiles and substances blocking the vessels), features that perhaps point to environmental stressors like the ones present in the park today: an overall dry climate, prone to droughts.

4.2. Comparisons between assemblages

Moving now the focus to the three assemblages found, N1, N2 and N3, it is worth considering if we can find discernible differences between them.

The three assemblages, even if located in different heights inside the cave and encompassing very different fossil numbers, surprisingly did **not** show noticeable differences in their taxa or morphotype compositions. For example, all species that presented several specimens (more than three), were found in all three deposition heights. The only discernible difference between deposition heights was the overall tendency towards better preserved fossils in the higher assemblages, probably due to the increased protection both from daylight and water granted by greater heights.

It could be argued however that such homogeneity could be deceitful, since these samples could have been subjected to reworking by successive floods. The argument points that it is possible that each high pluviosity and flooding event could have moved and changed the position of some or even all fossils previously laid to rest, not only the ones brought to the cave by each new flooding. This means that, theoretically, paleobiological information could have been already lost in the configuration in which the fossils were found. However, balancing these objections, we can look back to the data presented by Buarque (2019 – **Figure 3**), where it was found out that the known fossil ages correlate very well with the volcanic eruptions and associated watermarks. This points to a very low occurrence of reworking, if any at all.

This also means that, contrary to what would be expected in taphonomically active zones where fossils are still being moved around by biotic or abiotic forces (HOLZ & SIMOES, 2002), the material deposition inside the cave in the different assemblages was actually stable. It is possible that the fossil deposition mechanics favored the interlocking of fossils among themselves and the crevasses of the cavern structures (walls, floors, and speleothems). This caused the successive floods to not relocate or reshuffle previously laid specimens.

Thus, it is arguable that the three assemblages, even though gathered in distinct flooding events, did not differ significantly between themselves because the environment did not differ significantly between events.

4.3. Similarity with other formations

All of the species identified in the collection are still occurring in the PNCP nowadays. Many of them are also species known for their preference to dry habitats, deciduous forests, and even deciduous forests over limestone. Other examples are *Aspidosperma macrocarpon* and *Astronium urundeuva*, species very common in

Cerrado and Caatinga formations, and especially in the park's current forests (CASTELLO *et al*, 2024; SILVA-LUZ *et al*, 2024).

While the similarity indexes analysis yielded overall low similarity indexes, those can be attributed to the small size of our collection, that produced only 15 genera to compare against other formations.

Between the similarity indexes compared, the greater values clearly point to the PNCP paleovegetation identified being much more similar to vegetative formations of deciduous forests over limestones, which is exactly the description given to the wood formations most abundant in the area today.

Thus, it is our interpretation that the identified taxa points towards a dry paleoenvironment, very similar to the brazilian Cerrado (regionally) and the PNCP's deciduous forest on limestone (locally). This interpretation also points towards a paleoclimate essentially identical to the one currently existing in the area, which would be very dry and hot, since this climate is one of the most important limiting factors operating over the PNCP's vegetation today, alongside it's edaphic conditions.

4.4. Comparison with previous studies

Coelho (2013), the first study to describe these past floods and the existence of these fossils, already had shown, through geological and isotopic studies in the cave system, data pointing to a climatic continuity during mid and late Holocene in the area. This somewhat contrasted with the realization that the area suffered from such high floods, just as it does now.

Buarque (2019), also came to similar conclusions. In this case, the isotopic data from cave speleothems was also compared against initial data from fossil trunks. Having identified and dated a few fossil trunks, Buarque pointed out a troubled continuity in the regional climate, where the usual hot and dry climate known in the area today was rarely but eventually broken by huge precipitation events, and those events correlated with the dates obtained for the studied fossils.

The findings from this current study therefore agree with previous studies performed in the study site. It is possible now to have a better understanding of the paleovegetation that witnessed the Peruaçu floods, and with that it is possible to ascertain that the mid-late Holocene vegetation in the area is indeed similar to today's vegetation. This similarity in vegetation agrees with the similarity in climate patterns found by other researchers.

4.5. Further studies

Now that the identification of these fossil trunks and branches is complete, new avenues of research open up, capable of obtaining more detailed data about PNCP's paleoclimate.

As mentioned, some anatomical features were very common among the fossil samples and could point to known stressors. This however still demands further measures and proper statistical treatment.

Several of the specimens identified are prime for dendrochronological studies, presenting discernible growth rings. Such analysis can bring greater nuance and understanding of the climate going on in the years and months immediately preceding the large floods that gathered these fossils in the caves. The taxa that we suggest being further analyzed in dendrochronological studies are:

- *Pouteria sp.*: with its 32 specimens, it could provide plentiful data.
- *Cavanillesia umbellata*: this species has 9 specimens in the collection, and it is also already featured in modern dendrochronological studies occurring in the study area. Most of these specimens, however, are in poorly preserved.
- *Protium sp.*: 7 different specimens, in varying degrees of preservation. One of those specimens is a complete disk, although not well preserved.
- *Parapiptadenia zehntneri*: Only 2 specimens, but this species features heavily in dendrochronological studies, both in the study site and in other Brazilian regions. One of these 2 specimens (SPFw 8231) was collected as a full disk, very well preserved. More disks of this specimens can still be collected back in the study site (the disk was sawed off from a big log)
- *Commiphora leptophloeos*: Even though it only comprises one specimen in this collection (SPFw 8288), it is a well-studied species, and this specimen is very well preserved.

5. CONCLUSION

We conclude that yes, the paleoclimate in the region, the same climate that produced those enormous past floods detected in previous studies, is indeed similar, if not identical, to today's climate in the region, since the flora of the region is heavily bound to the climatic conditions operating over it and no discernible differences were seen in the identified paleovegetation.

This should be somewhat worrisome to policy makers and politicians, since this means that large floods like the ones detected in the past could come to repeat again, this time harming lives and damaging livelihoods in the area, and very likely having great consequences in regions further downriver, or in the entirety of the São Francisco River basin. Since what triggered the past floods were major volcanic eruptions around the globe, new major volcanic events should raise alarms. But we should also be alert to the possibility that chaotic influences like the ongoing anthropogenic climate change could trigger similar events, or similarly impactful scenarios in the region.

6. ACKNOWLEDGEMENTS

This study was carried out with the support of the Coordination for the Improvement of Higher Education Personnel (CAPES) – Brazil.

7. REFERENCES

ALENCAR-SILVA, T., & MAILLARD, P. Delimitação, caracterização e tipologia das veredas do Parque Estadual Veredas do Peruaçu. Revista Geografias, 24-39. 2011.

AMAIS, R. S., MOREAU, P. S., FRANCISCHINI, D. S., MAGNUSSON, R., LOCOSSELLI, G. M., GODOY-VEIGA, M., ... & ARRUDA, M. A. Trace elements distribution in tropical tree rings through high-resolution imaging using LA-ICP-MS analysis. Journal of Trace Elements in Medicine and Biology, 68, 126872. 2021.

ARMSTRONG, K. E., STONE, G. N., NICHOLLS, J. A., VALDERRAMA, E., ANDERBERG, A. A., SMEDMARK, J., … & RICHARDSON, J. E. Patterns of diversification amongst tropical regions compared: a case study in Sapotaceae. *Frontiers in Genetics*, *5*, 362. 2014.

BARBOSA, A. C., PACE, M. R., WITOVISK, L., & ANGYALOSSY, V. A new method to obtain good anatomical slides of heterogeneous plant parts. IAWA Journal, v. 31, n. 4, p. 373-383, 2010.

BARRETO, A. M. R., GOMES, L. P., KUNZ, S. H., DIAS, H. M., & ABREU, K. M. P. DE. Estrutura, composição florística e relações ambientais da regeneração natural em uma floresta estacional semidecidual. Ciência Florestal, 32(2), 757–775. 2022.

BARTH, O. M., BARROS, M. A., & FREITAS, F. O. Análise palinológica em amostras arqueológicas de geoprópolis do vale do Rio Peruaçu, Januária, Minas Gerais, Brasil. Arquivos do Museu de História Natural e Jardim Botânico, 19(1), 277-290. 2009.

BATISTA, C. U. N. et al. Tolerância à inundação de Cecropia pachystachya Trec. (Cecropiaceae): aspectos ecofisiológicos e morfoanatômicos. Acta Botanica Brasilica [online]. v. 22, n. 1, pp. 91-98. Epub 06 Maio 2008. ISSN 1677-941X. 2008.

BERG, C. C. & ROSSELLI, P. F. Cecropia. Flora Neotropica. Monograph 94. The New York Botanical Garden, Bronx, New York. 230 pp. 2005.

BUARQUE, P. F. S. M. Variabilidade do Sistema de monção da América do Sul no centro-leste do Brasil durante os anos de 1255-2016 (CE) a partir de registros paleoclimáticos em estalagmites e troncos de árvores. Tese de doutorado apresentada ao programa de pós-graduação em Geoquímica e Geotectônica do Instituto de Geociências da Universidade de São Paulo. 2019.

BURGER, L.M. & H.G. RICHTER. Anatomia da madeira. Nobel, São Paulo, 154p. 1991.

CASTELLO, A.C.D.; PEREIRA, A.S.S.; SIMÕES, A.O.; KOCH, I. *Aspidosperma* in Flora e Funga do Brasil. Jardim Botânico do Rio de Janeiro. Disponível em: < https://floradobrasil.jbrj.gov.br/FB21888>. Acesso em: 05 set. 2024

CARLQUIST, S. Ecological factors in wood evolution: a floristic approach. Amer. J. Bot., 64: 887-896. 1977.

CECCANTINI, G. T. Os tecidos vegetais têm três dimensões. Revista Brasil. Bot.,29 (2), p.335-337. 2006.

CEMADEN – CENTRO NACIONAL DE MONITORAMENTO E ALERTAS DE DESASTRES NATURAIS & INPE – INSTITUTO NACIONAL DE PESQUISAS

ESPACIAIS. Nota Técnica: Elaboração dos Mapas de índice de Aridez e Precipitação Total Acumulada para o Brasil. MCTI - Ministério da Ciência, Tecnologia e Inovação. Governo Federal, Brasil, Novembro de 2023.

CHENG, H., SINHA, A., CRUZ, F. W., WANG, X., EDWARDS, R. L., D'HORTA, F. M., & AULER, A. S. Climate change patterns in Amazonia and biodiversity. Nature communications, 4(1), 1-6. 2013.

CHIMELO, J.P. & ALFONSO, V.A. Anatomia e identificação de madeiras. In: INSTITUTO DE PESQUISAS TECNOLÓGICAS DO ESTADO DE SÃO PAULO-IPT. Madeira: o que é e como pode ser processada e utilizada. São Paulo, Associação Brasileira de Preservadores de Madeira, 1985. p. 23-58. (Boletim ABPM 36).

CHIMELO, J.P.; ZENID, G.J.; MIRANDA, M.J.A.C.; CECCANTINI, G.C.T. IMAC - Identificação de madeiras brasileiras com auxílio do computador. In: Congresso Florestal Panamericano 1 e Congresso Florestal Brasileiro 7, Curitiba. Anais. SBS e SBEF, vol.2, p. 641-643. 1993.

CODEVASF - Companhia de Desenvolvimento dos Vales do São Francisco e do Parnaíba. Mapa de Municípios na Bacia Hidrográfica do Rio São Francisco. Companhia de Desenvolvimento dos Vales do São Francisco e do Parnaíba. Brasília: Codevasf, 2021.

COELHO, A. H. F. Registros de grandes alagamentos no cânion do rio Peruaçu, Parque Nacional Cavernas do Peruaçu –PNCP, MG. Dissertação de mestrado apresentado ao programa de pós-graduação em Geografia da Universidade de Minas Gerais. 2013.

COPERNICUS, European Union's Earth Observation Program. "Global temperature exceeds 2°C above pre-industrial average on 17 November". European Centre for Medium-Range Weather Forecasts. https://climate.copernicus.eu/global-temperature-exceeds-2degc-above-pre-industria l-average-17-november. Published on November 21st, 2023. (Last visit: May 20th, 2024)

COUTO, A. P. L. D., FUNCH, L. S., & CONCEIÇÃO, A. A. Composição florística e fisionomia de floresta estacional semidecídua submontana na Chapada Diamantina, Bahia, Brasil. Rodriguésia, 62, 391-405. 2011.

CROWLEY, T. J.; UNTERMAN, M. B. Technical details concerning development of a 1200 yr proxy index for global volcanism. Earth System Science Data, v. 5, n. 1, p. 187-197, 2013.

CRUZ JR., F. W.; BURNS, S. J.; KARMANN, I.; SHARP, W. D.; VUILLE, M.; CARDOSO, A. O.; FERRARI, J. A.; SILVA DIAS, P. L.; VIANA JR., O. Insolation-driven changes in atmospheric circulation over the past 116,000 years in subtropical Brazil. Nature, 434, 63-66, 2005.

DE ALMEIDA RODRIGUES, A., DA CUNHA BUSTAMANTE, M. M., & SANO, E. E. As far as the eye can see: Scenic view of Cerrado National Parks. Perspectives in Ecology and Conservation, 16(1), 31-37. 2018.

DE ARAUJO, H. R., LOBO, H. A. S., & TRAVASSOS, L. E. P. Evaluation of the private participation in the implementation and management of ecotourism in cavernas do Peruaçu national park, Brazil. Acta Carsologica, 48(3). 2019.

DE FARIA, A. D., PIRANI, J. R., RIBEIRO, J. E. L. D. S., NYLINDER, S., TERRA-ARAUJO, M. H., VIEIRA, P. P., & SWENSON, U. Towards a natural classification of Sapotaceae subfamily Chrysophylloideae in the Neotropics. *Botanical Journal of the Linnean Society*, *185*(1), 27-55. 2017.

DE LIMA MAIA, L. L. C., DE OLIVEIRA, O. V., BEZERRA, M. M., GRIGOLON, D., & DE FREITAS OLIVEIRA, F. R. Impactos socioeconômicos e gestão hídrica na transposição do Rio São Francisco. Boletim de Conjuntura (BOCA), Boa Vista, v. 17, n. 51, p. 550–571, 2024. DOI: 10.5281/zenodo.10963273. Disponível em: https://revista.ioles.com.br/boca/index.php/revista/art icle/view/3826. 2024. (Last visit: May 20th, 2024)

DÉTIENNE, P., JACQUET, P. Atlas d’identification des bois de l’Amazonie et régions voisines. Centre Technique Forestier Tropical, Nogent-sur-Marne, 640p. 1983.

ESAU, K. Anatomia das plantas com sementes. Edgar Blucher. São Paulo. 1974.

FERREIRA, G. B. When the blanket is too short: Potential negative impacts of expanding indigenous land over a national park in a high priority area for conservation. Land use policy, 76, 359-364. 2018.

FREIRE, G. Q. Madeiras fósseis holocênicas de Ribeirão da Mata: anatomia ecológica, relações florísticas e interpretação paleoambiental da região arqueológica de Lagoa Santa, MG. Tese de doutorado apresentada ao programa de pós-graduação em Botânica do Instituto de Biociências da Universidade de São Paulo. 2011.

FURON, R. La Paléontologie, 9a. edição. Editora Payot, Paris, 286p. 1951.

GILL, R. B.; KEATING, J. P. Volcanism and Mesoamerican archaeology. Ancient Mesoamerica, v. 13, n. 1, p. 125-140, 2002.

GODOY-VEIGA, Milena et al. Improved tree-ring visualization using autofluorescence. Dendrochronologia, v. 55, p. 33-42, 2019.

GODOY-VEIGA, Milena et al. The value of climate responses of individual trees to detect areas of climate-change refugia, a tree-ring study in the Brazilian seasonally dry tropical forests. Forest ecology and management, v. 488, p. 118971, 2021.

GROSE, S. O., & OLMSTEAD, R. G. Taxonomic revisions in the polyphyletic genus Tabebuia s. l.(Bignoniaceae). Systematic Botany, 32(3), 660-670. 2007.

HEMPEL, C. G., & OPPENHEIM, P. Studies in the Logic of Explanation. Philosophy of science, 15(2), 135-175. 1948.

HOLZ, M.; SIMÕES, M. G. Elementos fundamentais de tafonomia. Ed. Universidade, 2002.

IAWA COMMITTEE. IAWA list of microscopic features for hardwood identification. IAWA Bull. ns, v. 10, p. 219-332, 1989.

IBAMA, MINISTÉRIO DO MEIO AMBIENTE, FIAT AUTOMÓVEIS S/A, CSD GEOCLOCK GEOLOGIA E ENGENHARIA AMBIENTAL LTDA. Plano de manejo do Parque Nacional Cavernas do Peruaçu, Vol. 1, Encartes 1, 2 e 3. 2005.

INPE – INSTITUTO DE PESQUISAS ESPACIAIS. Nota Técnica: Elaboração dos Mapas de índice de Aridez e Precipitação Total Acumulada para o Brasil. Centro Nacional de Monitoramento e Alertas de Desastres Naturais. Ministério da Ciências, Tecnologia e Inovação. Brasil. 2023.

INSIDEWOOD. 2004-onwards. Available in: http://insidewood.lib.ncsu.edu/search. Access on multiples occasions between 2020 and 2024.

IPT - INSTITUTO DE PESQUISAS TECNOLÓGICAS DO ESTADO DE SÃO PAULO. Identificação de espécies de madeira. São Paulo, IPT, Relatório Nº 31.832. 34p., 1993.

IPT - INSTITUTO DE PESQUISAS TECNOLÓGICAS DO ESTADO DE SÃO PAULO. Informações sobre madeiras (Database). Available in: https://madeiras.ipt.br/. Last access: August, 13th, 2024.

IWAMA A.Y., BATISTELLA M., FERREIRA L. DA C., ALVES D.S., FERREIRA L. DA C. Risk, vulnerability and adaptation to climate change: an interdisciplinary approach. Ambiente & Sociedade, 19(2), 93–116. 2016.

JACCARD, P. “Nouvelles recherches sur la distribution florale”. Bull. Soc. Vandoise des Sci. Nat.,44, 223–270. 1908.

JENKINS, S., POVEY, A., GETTELMAN, A., GRAINGER, R., STIER, P., & ALLEN, M. Is Anthropogenic global warming accelerating? Journal of Climate, 35(24), 7873-7890. 2022.

KRAUS, J. E. e ARDUIN, M. Manual básico de métodos em morfologia vegetal. Seropédica: EDUR, 1997

KOWALEWSKI, M. Time-averaging, overcompleteness, and the geological record. The Journal of Geology, v. 104, n. 3, p. 317-326, 1996.

KUKACHKA, B. F. Wood anatomy of the neotropical Sapotaceae. Forest Products Laboratory, Forest Service, US Department of Agriculture, 1978.

LORENZI, H., Árvores Brasileiras: Manual de Identificação e Cultivo de Plantas Arbóreas do Brasil, Plantarum, Brazil. 1982.

MAILLARD, P., PEREIRA, D. B., & SOUZA, C. G. Incêndios florestais em veredas: conceitos e estudo de caso no Peruaçu. Revista Brasileira de Cartografia, 61(4), 321-330. 2009.

MAINIERI, C. &; CHIMELO, J.P. Fichas de características das madeiras brasileiras. 2.ed. São Paulo, IPT. 418p. (IPT Nº 1791). 1989.

MAINIERI, C. &; PEREIRA, J. A. Madeiras do Brasil - Sua caracterização macroscópica, usos comuns e índices qualitativos, físicos e mecânicos. Anuário Bras. de Econ. Florestal, 17: 259. 1965.

MANNING, J. G., LUDLOW, F., STINE, A. R., BOOS, W. R., SIGL, M., & MARLON, J. R. Volcanic suppression of Nile summer flooding triggers revolt and constrains interstate conflict in ancient Egypt. Nature communications, 8(1), 900. 2017.

MARENGO, J. A. O futuro clima do Brasil. **Revista USP**, São Paulo, Brasil, n. 103, p. 25–32, 2014.

MAUSETH, J. D. Plant Anatomv. Benjamin/Cummings. California. 1988.

MCPHILLIPS, L. E., CHANG, H., CHESTER, M. V., DEPIETRI, Y., FRIEDMAN, E., GRIMM, N. B., & SHAFIEI SHIVA, J. Defining extreme events: A cross-disciplinary review. Earth's Future, v. 6, n. 3, p. 441-455, 2018.

MELFI, A. D. C. C. Anatomia da madeira em Sapotaceae. 2006. Tese (Doutorado em Botânica) - Instituto de Biociências, University of São Paulo, São Paulo, 2007.

MELO-JÚNIOR, A. F., Fenologia, diversidade e estrutura genética de populações naturais de Cavanillesia arborea k. schum por meio de marcadores ISSR, no norte de minas gerais. Tese de Doutorado. Lavras, Minas Gerais. 2010.

MENDES, J.C. Introdução à Paleontologia Geral. Ministério da Educação e Cultura, Instituto Nacional do Livro, Biblioteca Cientifica Brasileira, Coleção do Estudante: vol. V, 384 p. 1960.

MOREIRA, L.E. Paleontologia Geral e de Invertebrados. Editora da Universidade Católica de Goiás, Goiânia, 320 p. 1999.

MORIM, M.P. *Parapiptadenia in* Flora e Funga do Brasil. Jardim Botânico do Rio de Janeiro. Disponível em: <https://floradobrasil.jbrj.gov.br/FB18920>. Acesso em: 04 set. 2024

NETTESHEIM, F. C., CARVALHO, D. C. D., FONSECA, C. C. D., NUNES, R. S., CAVALCANTI, D. M., GABRIEL, M. M., & MENEZES, L. F. T. D. Estrutura e florística do estrato arbóreo no cerrado sensu stricto de Buritis, Minas Gerais, Brasil. Rodriguésia, 61, 731-748. 2010.

OLIVEIRA, F. M., HOLANDA, T. C., RAMALHO, A. L. DE O. S., KLOECKNER, N. V. DA R., MOURA, I. E. M. O. DE, RICARTE, T. L., & RIBEIRO, K. V. Rains, Tragedies and Media Coverage: Analysis of Floods In Rio Grande do Sul. *Revista De Gestão Social E Ambiental*, *18*(4), e06861. 2024.

OLIVEIRA, L. A. R., PEREIRA, R. F., SANTOS, F. M. S., SANTOS, F. Caracterização Morfológica de Frutos e Sementes de Parapiptadenia zehntneri. In: Silva, SA (Ed.) Anais do IV Workshop de Sementes e Mudas da Caatinga. Petrolina, Pernambuco. p. 71-75. 2014.

PENNINGTON, R. T.; RATTER, J. A. (Ed.). Neotropical savannas and seasonally dry forests: plant diversity, biogeography, and conservation. CRC press, 2006.

PENNINGTON, T. D. Sapotaceae. In: Kubitzki, K. (eds) Flowering Plants · Dicotyledons. The Families and Genera of Vascular Plants, vol 6. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-07257-8_41. 2004

RIBEIRO, E. P., MOREIRA, E. B. M., SOARES, D. B., BILAR, A. B. C., & LIMA, M. S. DE. Climate change and desertification in the semiarid region of northeastern Brazil | Alterações climáticas e desertificação no semi-árido do Nordeste do Brasil. *Revista Geama*, *2*(2), 93–105. 2016.

RIBEIRO, P. G., DE QUEIROZ, L. P., & MORIM, M. P. Flora of Bahia: Leguminosae – Parapiptadenia (Mimosoideae: Mimoseae). *SITIENTIBUS série Ciências Biológicas*, *16*. 2016

RITTER, M. N., & ERTHAL, F. Time-averaging e suas implicações para o registro fóssil marinho. Terrae Didática, 12(2), 81-103. 2016.

RIZZOTTO, M. L. F., COSTA, A. M., & LOBATO, L. DE V. DA C. Crise climática e os novos desafios para os sistemas de saúde: o caso das enchentes no Rio Grande do Sul/Brasil. *Saúde Em Debate*, *48*(141), e141ED. 2024.

ROMEIRO-BRITO, M., MORAES, E. M., TAYLOR, N. P., ZAPPI, D. C., & FRANCO, F. F. Lineage-specific evolutionary rate in plants: Contributions of a screening for Cereus (Cactaceae). *Applications in Plant Sciences*, *4*(1), 1500074. 2016.

SCHEEL-YBERT, R. et al. Coleções de referência e bancos de dados de estruturas vegetais: subsídios para estudos paleoecológicos e paleoetnobotânicos. Arquivos do Museu Nacional, v. 64, n. 3, p. 255-266, 2006.

SFB - SERVIÇO FLORESTAL BRASILEIRO, LPF - LABORATÓRIO DE PRODUTOS FLORESTAIS. Banco de dados de Madeiras Brasileiras. Available in: https://lpf.florestal.gov.br/pt-br/madeiras-brasileiras. Last access: August, 13th, 2024.

SIGURDSSON, H. Volcanic pollution and climate: the 1783 Laki eruption. Eos, Transactions American Geophysical Union, 63(32), 601-602. 1982.

SILVA, L. Á. D., & SCARIOT, A. Composição florística e estrutura da comunidade arbórea em uma floresta estacional decidual em afloramento calcário (Fazenda São José, São Domingos, GO, Bacia do Rio Paranã). Acta Botanica Brasilica, 17, 305-313. 2003.

SILVA-LUZ, C.L.; PIRANI, J.R.; PELL, S.K.; MITCHELL, J.D. *Anacardiaceae in* Flora e Funga do Brasil. Jardim Botânico do Rio de Janeiro. Disponível em: < https://floradobrasil.jbrj.gov.br/FB115185>. Acesso em: 05 set. 2024

SIMÕES, M. G., KOWALEWSKI, M., CARROLL, M., BARBOUR-WOOD, S. L., KRAUSE JR, R. A., RODRIGUES, S. C., & WEHMILLER, J. F. Taphonomy and time averaging as a tool in (paleo) oceanography: a case study on a shallow subtropical shelf from Brazil. In: XLII Congresso Brasileiro de Geologia, Anais, CD-ROM, Araxá S27-696. 2004.

SMITH, S. J., EDMONDS, J., HARTIN, C. A., MUNDRA, A., & CALVIN, K. Near-term acceleration in the rate of temperature change. Nature Climate Change, 5(4), 333-336. 2015.

SOARES, E. Seca no Nordeste e a transposição do rio São Francisco. Revista Geografias, 9(2), 75-86. 2013.

SONSIN, J. O., GASSON, P. E., MACHADO, S. R., CAUM, C., & MARCATI, C. R. Atlas da diversidade de madeiras do Cerrado Paulista - Atlas of wood diversity in the Cerrado of São Paulo. 2014.

SORENSEN, T. A method of establishing groups of equal amplitude in plant sociology based on similarity of species and its application to analyses of the vegetation on Danish commons. – Biologiske Skrifter/Kongelige Danske Videnskabernes Selskab 5: 1-34. 1957.

STOKES, M. A.: An introduction to tree-ring dating, University of Arizona Press., 1996.

STRIKIS, N. M. Paleopluviosidade no norte de Minas Gerais durante o Glacial tardio e Holoceno com base em registros de espeleotemas. Dissertação de Mestrado, Instituto de Geociências da Universidade de São Paulo, São Paulo, 2011.

STRIKIS, N. M. Atividade do Sistema de Monção Sul-Americana na porção central do Brasil durante o último período glacial a partir da aplicação de isótopos de oxigênio em espeleotemas. Tese de Doutorado, Instituto de Geociências, Universidade de São Paulo, São Paulo, 2015.

SWENSON, U., & ANDERBERG, A. A. Phylogeny, character evolution, and classification of Sapotaceae (Ericales). Cladistics, 21(2), 101-130. 2005.

TAYLOR, N. P., ZAPPI, D. C., ROMEIRO-BRITO, M., TELHE, M. C., FRANCO, F. F., & MORAES, E. M. A phylogeny of Cereus (Cactaceae) and the placement and description of two new species. *Taxon*, *72*(6), 1321-1333. 2023.

THERRELL, Matthew D. et al. Tree-ring reconstructed maize yield in central Mexico: 1474–2001. Climatic Change, v. 74, p. 493-504, 2006.

THOMAS, W. W., JARDIM, J. G., FIASCHI, P., MARIANO NETO, E., & AMORIM, A. M. Composição florística e estrutura do componente arbóreo de uma área transicional de Floresta Atlântica no sul da Bahia, Brasil. Brazilian Journal of Botany, 32, 65-78. 2009.

TOMASSI, H. & ALMEIDA, C. O que é fóssil? Diferentes conceitos na paleontologia. What is a fossil? Different concepts in paleontology. 10.13140/RG.2.1.4439.6885. 2015.

WHEELER, E.A. InsideWood - a web resource for hardwood anatomy. IAWA Journal 32 (2): 199-211. 2011.

WMO – WORLD METEOROLOGICAL ORGANIZATION. The Global Climate 2011-2022: A decade of accelerating climate change. ©United Nations. ISBN 978-92-63-11338-2. 60p. DOI: https://doi.org/10.18356/9789263113382. 2023.