How Young is a 300-Year-Old Wetland? The Case of the Pantanal Marimbus, Chapada Diamantina, Brazil

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Abstract

The Chapada Diamantina, in Northeastern Brazil, is one of the few places where one can find drylands with a backswamp containing hundreds of dead deciduous trees in the floodplain. During the 18th century, the region was globally important due to the exploration of mineral resources. The death of these trees was caused by mining activities that silted the main river, leading to the impoundment of the tributary river, and resulting in a wetland known as Pantanal Marimbus, having as indicators: (i) backswamp morphological feature that remains permanently flooded in the axis of the fluvial course, and (ii) alluvial fans concentrated in one footslope area where mining activities at the Chapada Diamantina were also concentrated. The hydrological and sedimentological behavior was investigated to multi-methods. By analysing four different samples from the bark and core of the same tree, we obtained calibrated radiocarbon dates within the 18th century. For no robust dendrochronology could be performed, a simple sequence model was built, revealing a high probability that the tree lived until approximately 1700 AD. $^{14}$C-AMS measured pioneering possible to evaluate the 300-years-old wetlands juvenile evolutionary state.

1. Introduction

Wetlands are transitional lands between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water\(^9\). Globally, many wetlands form in broad valleys on low slopes, some being permanently flooded, while others are only flooded seasonally\(^51\). The first wetlands date back to the Silurian Period, being environments where many flora and fauna species had to adapt and therefore being importante for the evolution of life on Earth\(^16\). Wetlands continue to decline globally, both in area and in quality, and are sensitive to environmental and climatic changes over decadal to millennial timescales\(^21\). Wetlands contribute to water purification, flood control, and food production, both land- and water-based, and the maintenance of high levels of biodiversity and ecosystemic relevance to society\(^51\).

From a geomorphological point of view, wetlands represent a complex plain of alluvial-detrital coalescence\(^1\). River flood plains develop through erosion processes and through deposition of sediment on adjacent lands during floods\(^37\). Geomorphological studies in wetlands include analyses of landform shapes, i.e., quantification of surface and near-surface processes (e.g. runoff, sedimentation, surface water changes) that shape landforms, and landscape changes that occur in response to factors such as climate change and human activities\(^54\). Investigations may be directed towards reconstructing past processes, towards understanding present-day processes, or towards anticipating future processes\(^11\). Human activities such as mining, agriculture or settlement occur in or around wetlands and can promote increased erosion and sedimentation. Radiocarbon dating has been widely used to determine sedimentary dynamics and infer the origin and monitoring of wetlands, floodplains and lakes\(^31\), but existing data in the literature only refer to the Holocene/Pleistocene\(^34\)–\(^19\)–\(^30\)–\(^22\)–\(^51\)–\(^45\).

The Chapada Diamantina mountain range, the region with the highest elevations in northeastern Brazil, is an example of a place where we find a backswamp in drylands that remains permanently-to-seasonally flooded. The Pantanal Marimbus (Marimbus wetland), as it is known, contains hundreds of dead deciduous trees in what should be the riparian zone. Signs of avulsion show that there has been a relatively sudden change in channel belts and the construction of alluvial fans. It is known that the region has been subjected to intense diamond
exploration by independent miners (colloquial Portuguese: garimpeiros) with report that such activity generated a profound environmental and economic change in the Chapada Diamantina.

The discovery of diamonds in Chapada Diamantina (State of Bahia) is controversial. The earliest records of diamonds were made by travelers Spix and Martius, in 1820. Official records began in 1844, a rather ephemeral cycle due to the discovery of large deposits in Kimberley, South Africa, in 1867\(^3\), which forced the fall in mineral prices in the market and caused Brazil to lose its hegemony of world's largest diamond producer, at the height of the mining cycle. However, historical data indicate that the clandestine search and exploitation of the precious stone predated the 19th century\(^33\). It is possible that the existence of diamonds in the Chapada Diamantina has been known since the 18th century, based on the ban on exploitation by Brazilian viceroy, dated 1732\(^17\). Diamond mining in this region has been affected by long periods of drought causing a drop in production. Later, with the expansion of industrial activity in Europe and the United States, the excavation of the London Underground and the opening of the Panama Canal, carbonado (a variety of diamonds) brought new life to the local economy. The carbonado is a characteristic diamond of the Chapada Diamantina, dark and dull in color, of high hardness, with high resistance to friction and heat. This spurred a new diamond exploration cycle in the region that lasted until the first decade of the 20th century\(^3\), when its production declined again.

In general, diamond extraction was carried out in a rudimentary manner, known as sawmill mining (open pit and subsurface), where the diamond gravel derived from the conglomerates was excavated on the flanks of the mountains. This action led to the rapid transfer of sediments from the Sincorá range, causing siltation and hydrodynamic change in the rivers.

There are no historical reports of natural events that could be responsible for the intense silting up of rivers. On the contrary, the people currently living in the region comment that their ancestors originally associated the Marimbus wetland origin with diamond mining. The Theodoro Sampaio's expedition (1879-1880) already mentioned in rich detail the presence of a "Lagoa Grande" (Great pond) referring to a large flooded area, with location and extent that are similar to the current Marimbus wetland features\(^42\). However, the date of the Marimbus wetland origin has always been uncertain.

The main objectives of this work are: (i) to verify if there are geomorphic features that indicate the change of fluvial environment to a wetland, (ii) to determine hydrogeomorphological behavior, (iii) to use isotopic data to assess the origin of water, whether surface or groundwater, and (iv) to determine by radiocarbon dating (\(^{14}\)C-AMS) the date and causes of the dead trees in the Marimbus wetland.

2. Physiographic Settings

The Chapada Diamantina (State of Bahia) represents the most prominent relief unit in northeastern Brazil, with elevations exceeding 2000 m. It is characterized as an extensive residual plateau, oriented N-S, considered the extension of the northern Espinhaço mountain range. Due to its prominent elevation, it is subjected to an intense erosion process. The Sincorá mountain range is the main mountain range in the region, with elevations reaching 1600 m. An open-to-soft folding system with E-W plunging controls the morphology of the Sincorá range by the influence of the Pai-Inácio anticline and Una-Utinga syncline transition and forces the groundwater flow to the east. This structural feature is related to the Neoproterozoic collisions (from 950-520 Ma) that led to the assembly of Gondwanaland and the formation of the orogenic belts\(^28\).
The Sincorá mountain range is formed by metasedimentary rocks (Chapada Diamantina group), of the Mesoproterozoic age, with transitional sedimentation records from continental (wind and fluvial) to shallow marine. They are lithotypes such as metaquartzarenite, well selected impure metarenite, poorly selected metarenite and conglomerate lenses containing buried distal kimberlitic diamonds located in the Sincorá range. The low slopes are sustained by the accumulation of eroded debris from the cliffs. Around the Sincorá range are found the metacarbonate sedimentary basins (Salitre formation) called Irecê and Una-Utinga (Fig. 1a), from the Neoproterozoic age, corresponding to the transition from glacial to marine environments where carbonates form notably karsts, abundant in caves. In 1985, the Chapada Diamantina National Park was created, protecting the Sincorá mountain range area, and forcing the closure of diamond mines.

Finally, the floodplain is located in a narrow depression (Una-Utinga sedimentary basin) made up of alluvial sediment, in which a permanently flooded area known as Marimbus wetland appears (Fig. 1b), resembling flooded dolines. The northern wetland sector is the highest and therefore least humid region, where the waters flow without damming. There is also the Encantada pond with dolines morphological features, with an area of 800 m² filled with water all year round. The main rivers that supply the Marimbus wetland are the Santo Antônio and São José rivers. All of the supplying rivers dry up completely during the dry season.

From the climate point of view, Chapada Diamantina is a humid climate enclave within the semiarid domain. This region is a point of convergence of air masses, which generates a very complex climate mosaic where the eastern edge of the mountain is wetter, and may be the natural cause of Una-Utinga sedimentary basin carbonates dissolving faster and generating a depression (Fig. 1a). The period of highest rainfall occurs between November and April. When torrential rains occur on the headwaters of the mountain, the water flows quickly through the canyons, carrying a large volume of sediment. However, prolonged periods of drought can occur and cause large-scale forest fires. The great catastrophic drought of 1877, for example, forced major migrations from the Chapada Diamantina, taking part in the decline of diamond mining.

With regard to vegetation, the rocky fields cover large areas in Chapada Diamantina, usually above 1000 m. They are characterized by their predominantly shrubby size, which grows on rocky outcrops or shallow soils. The floristic composition in these environments is strongly conditioned by the substrate, besides the altitude and the precipitation. Arboreal forests occur in fractures.

Around the Marimbus wetland the vegetation is sub-montane deciduous open tree and abundant large species such as: Aspidosperma discolor and Terminalia brasiliensis (20 – 30%), Protium heptaphyllum, Copaifera langsdorffi, Pogonophora schomburgkiana, Pouteria ramíora and Hymenolobium janeirens var. stipulatum (10 – 20%), can reach 20 m height. Some of these trees can be observed dead in the Santo Antônio river floodplain as they have not adapted to the permanently flooded environment (Fig. 1c).

Inside the wetland, the most abundant aquatic plants are Cyperaceae family (15%), followed by Rubiaceae (10%), Poaceae (8%), Myrtaceae (7.6%), Leguminosae (6.8%) and Polygonaceae (3.8%). Amphibious plants are the most common ones (58%), the emergent, floating (fixed or free) and submerged specimens make up to 39% of the flora, which presents 25% of nanophanerophytes, 13% of geophytes and 12% of microphanerophyte.

3. Results And Discussion
3.1. Hydrogeomorphological behavior

The Fertém station data show Marimbus wetland hydrogeomorphological regime and maximum potential flooding (Fig. 3a), namely:

- the fluvial discharge;
- the variability of water levels (seasonally and yearly extent);
- how often it floods and dries (frequency);
- how far the water spreads (extent);

The catchment area of the Marimbus wetland covers 10.111 km$^2$, strongly influenced by the mountainous relief, which reduces the permanence of water in this sector of the basin and intensifies the flow. The average river discharge in the Marimbus wetland is relatively low, at 29.5 m$^3$ s$^{-1}$ and sedimentation is proportional, $<$5 ton.day$^{-1}$. However, discharge peaks of 878 m$^3$ s$^{-1}$ are observed (Fig. 2a), which move a higher sediments load than during long periods under normal conditions, reaching 962 ton.day$^{-1}$. These peaks are much lower than those found for average Brazilian and worldwide rivers, if proportionally considered the ratio between catchment areas versus solid and liquid river discharge$^{24}$.

The Marimbus wetland has maintained an average water level of 1.20 m (Fig. 2b). The floodplain is quite uneven with many shoals and low margins. This means that a rise of only 2 m in water level is enough to ensure the maximum lateral flooding of the wetland, which occurs 25% of the time, with several flooding cycles exceeding 5 m in height. This frequent waterlogging led to the death of the trees and new composition of vegetation formations. Most wetlands are shallow depressions and small catchments areas$^{8-9}$.

The highest elevation period of the Marimbus wetland water level extends from November to April, while the other months are considered as dry period, whose flood frequency rarely evades this pattern of seasonality (Fig. 2c). Several droughts reduced their levels drastically (December 2011-to-December 2013), but the freshwater remains. The opposite moisture event occurred between October 1977 and May 1979, when this wetland was flooded during all months, above the long-term monthly average. Both events are considered not seasonal. During the dry season, a mosaic of sandy islands emerges (Fig. 3a). During drought events, the alluvial fans are exposed and only isolated sedimentation rings remain flooded (with rounded dolines resemblance). The latter contain trapped silt and clay facies, while along the active channels there is fine to coarse sand. The overbank deposition enabled areas of shallow water to form in the adjacent backswamps. The abandoned meanders indicate these hydrodynamic energy oscillations in the flooded area$^{25-50}$, creating new channels on the floodplain and causing the abandonment of the old channel (avulsion).

The delimitation of the Marimbus wetland area was complex. We used a colored composition containing the band 4 (0.77-0.89 µm) commonly used for delineation of water bodies, and compared with SRTM contour lines extracted with 1 m equidistance from the 320 m above sea level (base station). Both boundaries extracted from the images show similarity in the 6 m maximum hydrological flood level (326 m asl), which occurred only in 1960 (see Fig. 2a) and its corresponding flood area of $\approx 58$ km$^2$.

The Marimbus surface water dynamics has been recorded from coarse-spatial-resolution satellite observations, and higher-resolution seasonality maps using all Landsat images over multiple decades have been used to map
seasonality and surface water changes. Hydrogeomorphological behavior analysis showed that Marimbus is a freshwater wetland, flooding periodically, currently located in a lithological depression. The three sectors (northern, central and southern) show changes over time and space, with the southern portion and the Encantada pond being the areas with the most permanent water levels. All areas were subject to ephemeral and seasonal floods, between 1984 and 2021 (Fig. 3b). This land supports predominantly hydrophytes, the substrate is mostly undrained hydric soil, and is saturated with water or covered by shallow water at some time during the growing season of each year.

3.2 The water’s source

For the determination of the origin of the Marimbus wetland waters, isotopic analyzes were performed at several points. The samples presented values of $\delta^{18}O$ ($V_{SMOW}$) and $\delta^2H$ ($V_{SMOW}$) ranging from -21.1‰ to 9.0‰ and from -3.13‰ to 3.31‰, respectively. Most of the samples presented data coinciding with the global meteorological curve$^{10}$, due to the marked influence of precipitation in the runoff.

Figure 4 shows the excess deuterium parameter of the waters collected in the Marimbus wetland. The values of this parameter ranged from -21‰ to +17‰. In this figure there is a group of samples with negative values and another group with positive values of this parameter. Samples MB1 through MB6 were collected in the permanently flooded area. MB1 to MB3 in the Encantada pond, MB4 and MB5 in a large lake and MB6 in a shallow lake that, due to the smaller volume of water and water depth, undergoes more evaporation, presenting the most negative value of excess of deuterium (-21‰). Samples MB1, MB2, MB3, MB4, MB5 and MB6 showed different behaviors when compared to the other samples. They have negative excess deuterium parameter, which consists of a higher enrichment of water in $\delta^{18}O$ with respect to $\delta^2H$. Therefore, the points located in the floodplain (annually flooded) of the north and central portions of the Marimbus contain water that presents an underground recharge component that undergoes considerable evaporation. To confirm the different isotopic compositions, a local evaporation line was developed only for samples MB1 to MB6. This curve was defined by the following linear regression: $\delta^2H = 5.097\delta^{18}O - 8.76‰$. Note that the slope coefficient of line 5.097 is less than that of the global meteoric line (GML) which is 8, which characterizes water presenting more evaporation$^{39}$.

The negative excess deuterium in these samples indicate waters that have undergone considerable evaporation or waters that have underground recharge more evaporated than precipitated. When evaporation occurs in water bodies, deuterium-containing water molecules evaporate more easily than $^{18}$O-containing molecules. This effect causes an $^{18}$O enrichment with respect to deuterium in the remaining water and, consequently, the calculated values of deuterium excess will become more negative as its evaporative loss increases. Samples collected between sites MB7 and MB20 show significant influence of rain water. The sample points in the chart below are very close to the GML.

Another evidence of rainfall in the isotopic composition is recorded in the values of excess deuterium that varied between +6.1 and +16.5‰, with an average value of +10.9±3.0‰, very close to the linear coefficient of the GML $\delta^2H = 8. \delta^{18}O+10.8‰$. It does not corroborate the values obtained by Sales (2017), when the Santo Antônio river crossing carbonate rocks (see Fig. 1), where the values of excess deuterium, calculated with their isotopic data, ranged from +9.3 to +16.2‰, with an average value of +12.9±2.2‰ (Fig. 4). MB19 and MB20, collected in the Garapa and Paraguacu rivers before reaching the Pantanal, presented the highest values of excess deuterium: +14.8‰; +15.3‰ and +16.5‰, respectively.
Generally, this enrichment can be the result of the recharging of cloud rains that are not generated in the region, with several consecutive episodes. This causes a rapid depletion of the $^{18}$O in the cloud generating positive excess deuterium. The data collected in the southern portion, points MB8 to MB18, showed slightly positive deuterium values, closer to the value of the GML coefficient, indicating that the meteoric waters were their main source of recharge. The MB16 and MB17 points, collected in the southern Marimbus wetland, show the lowest values of deuterium for this data group: +7.9 and +7.6‰, respectively. The MB7 point, collected at the confluence of the São José and Santo Antônio rivers, showed the lowest value of positive deuterium due to its proximity to the sedimentation rings of the central portion of the wetland. It suggests the interaction between groundwater and river, which maintains the minimum levels in the dry period and amplifies the quotas in the rainy periods.

The similarity in isotopic information at these points is due to the marked influence of precipitation on runoff. These waters are typical of the floodplain which remains saturated for extended lengths of time (backswamps) and is often isolated from the river channel as a result of aggradation occurring elsewhere on the floodplain\textsuperscript{25}. The waters in the karstic aquifer that feed into the springs of the Santo Antônio river in the Irecê carbonate basin range from calcic sodium chlorinated composition to calcium bicarbonate\textsuperscript{40}. The isotopic composition of aquifer waters refers to the natural waters of an isolated karstic system, its isotopic signature distinct from the waters of the Marimbus wetland (Fig. 4). They are rounded shaped ponds typically found in wetlands and floodplains too, but these body waters are alkaline salines and present pH values of up to 10, with the presence of bicarbonate, chlorinated and sodic waters\textsuperscript{5}. Some of these ponds are isolated from pluvial surface flow and are characterized by white-sand beaches and brackish to saline water during Holocene-Pleistocene.

### 3.3 Radiocarbon dating geomorphic change

The radiocarbon results for each tree ring sample are presented in table 1. The piece of trunk used for radiocarbon ($^{14}$C-AMS) analyses was sampled along the growth rings sequence, so that an age model could be built. This was done because the independent dating of the bark would result in a wide probability range, covering the industrial period when the input of fossil carbon has diluted the atmospheric radiocarbon concentration, preventing precise dates to be estimated\textsuperscript{47}.

By dating four different samples from the bark and core, it was possible to obtain radiocarbon dates that correspond to the 18th century. For no robust dendrochronology could be performed, a simple sequence model was built, revealing a large probability that the tree lived until approximately 1700 AD (Fig. 5). Based on the dating results there would still be a slight probability of the bark reaching 1800 AD. However, the size of the sample indicates that, even if some rings were missing, it could not represent more than 100 years of growth for the *Hymenolobium sp.* Previous work on the growth rates of some Amazon trees revealed that such species usually grows less than 40 cm y$^{-1}$\textsuperscript{32}. Therefore, the death of the tree most probably took place around 1700 AD.

Recents radiocarbon analysis showed that landslides were responsible for creating two lakes in the western United States after earthquake events, including the A.D. 1700 Cascadia earthquake. Generally, mountainous settings commonly trigger thousands of landslides, and slope failures are typically significant for landslide-dammed aquatic environments\textsuperscript{46}. As there was never any record of earthquakes in Chapada Diamantina, we strongly suggest that Marimbus wetland were formed approximately 1700 AD, by mining activities that silted the main river, leading to the impoundment of the tributary river.
It has been frequently stated that the world has lost 50% of its wetlands (or 50% since 1900 AD). The reported long-term loss of natural wetlands averages between 54–57% but loss may have been as high as 87%, since 1700 AD\textsuperscript{11}. Thus, the environmental impact caused by siltation in Chapada Diamantina had the benefit of expanding the local wetlands.

The Marimbus wetland represents a scenario described in the literature, recording a few centuries of landscape changes in response to human activities, especially when the dead trees could still be found preserved in their life position. Other debates about the age of wetlands are important to know the implications of secular-and-millennial geomorphic changes, including their ecological significance. The Marimbus water level change caused the death of large trees, replacing them with aquatic vascular plants. These new aquatic plants were able to adapt to water level fluctuations in the Marimbus wetland and are concentrated in areas where water flows and levels cannot vary both seasonally and from year to year. However, the vascular plant composition in the Marimbus wetland showed low similarity to that of other wetlands present in the Brazilian territory\textsuperscript{12}. This characteristic corroborates the relatively juvenile evolutionary state of this wetland. It is currently known that the floodplains of tropical South America may be considered as areas of speciation, contributing to the great species diversity in the area\textsuperscript{20}. However, the low similarity index of macrophyte vegetation, recorded in the Marimbus wetland\textsuperscript{12}, may be an indicator of the frequent changes in the young braided stream (avulsion), which capture the sediments inside the wetland, where plants respond to this pulsing with a large set of physiological adaptations.

There are three possibilities to evaluate the 300-year-old Marimbus wetland: (i) insufficient time to deposit the alluvial fans, given the observed river discharges, demonstrating the anthropogenic origin of sediments, (ii) the exploration and/or use of mineral resources (not necessarily diamonds) existed since the 18th century in the Sincorá mountain range and has not been historically documented, and (iii) the vascular plant composition showed low similarity to that of other wetlands present in the Brazilian territory, corroborating the relatively juvenile evolutionary state of this wetland.

### Table 1. AMS \textsuperscript{14}C data of dead trees in the Marimbus wetland

| Sequence Marimbus | From | To   | %     | From | To   | %     | A   | C   |
|-------------------|------|------|-------|------|------|-------|-----|-----|
| Boundary inside   |      |      |       |      |      |       |     |     |
| R_Date 14p34a01c2 | 1499 | 1799 | 95.4  | 1507 | 1797 | 95.4  | 108.8 | 98.5 |
| R_Date 14p34a01c1 | 1509 | 1876 | 95.4  | 1626 | 1809 | 95.4  | 115.4 | 99  |
|                   |      |      |       |      |      |       |     |     |
| R_Date 14p34a01a  | 1671 |     | 95.4  | 1664 | 1884 | 95.4  | 97.4 | 99.2 |
|                   |      | ...  |       |      |      |       |     |     |
| R_Date 14p34a01c1 | 1683 | 1948 | 95.4  | 1689 | 1948 | 95.4  | 101  | 98.9 |
|                   |      |      |       |      |      |       |     |     |
| Before C_Date (1950,1) |      | 1948 | 1952 | 1947 | 1952 | 95.4  | 100 | 100 |
| Before Tau_Boundary Bark |      | 1581 | 2267 | 1581 | 2267 | 95.4  | 97.1 |     |

Satellite images show that alluvial fans on the Sincorá range footslope are concentrated between parallels $12^\circ20'00''S$ and $13^\circ00'00''S$ (Fig. 6). Historical data showed that diamond mining activities at Chapada
Diamantina also concentrated approximately between these same parallels. Outside this area there was not diamond exploration at Chapada Diamantina, and the rivers flow from the mountain without accumulating sediment.

The alluvial fans divide the Marimbus wetland into three sectors, all located at the confluences of the rivers. A narrow and elongated alluvial fan separates the northern portion from the central portion at the confluence of the São José and Santo Antônio rivers. Another alluvial fan with elongated radial axis extending for approximately 1.5 km separates the central portion from the southern portion, at the confluence of the Garapa and Santo Antônio rivers (Fig. 7). This fan system is broadly divisible into three parts: (i) an upper entry corridor, approximately 6 km long and 40 m wide; (ii) a central zone of seasonal swamps transected by several distributary channels confined by densely vegetated banks, and (iii) a lower zone of perennial swamps where flow is mostly unconfined. In the final stretch, the Santo Antônio river (tributary) was dammed by the Paraguaçu alluvial fan (main river) because, due to its intense siltation, it became topographically higher than the tributary river (Fig. 8). We suggest that the transfer of sediments from the mountains to the confluence of rivers was responsible for allowing the river system to become a wetland.

If we use radiocarbon dating of the geomorphic change of the Marimbus wetland as a marker, it is observed that the alluvial fans present exceptionally high sedimentation rates and could not have occurred in natural conditions. In this case, 300 years would be a short time to deposit this volume of sediment, where the sedimentation rate should be 6 to 8.6 cm y\(^{-1}\). Sedimentation rates > 1 cm y\(^{-1}\) are associated with great rivers (Walling and Fang 2003). Soundings indicated alluvial fans maximum thickness, between 18 to 26 m.

The combination of intense river discharge, high slope and the mining activity may explain the alluvial fans (Fig. 8), forming placers deposits that are still active today, and where coridon, rutile, cianite, limonite and turmaline can be found in the diamonds levels. The occurrence of gold is not very significant. The volume of these alluvial fans containing only diamond pebble-supported has been estimated at 20 x 10\(^6\) m\(^3\), where: Paraguaçu alluvial fan has been 6.8 x 10\(^6\) m\(^3\) (Fig. 8), Santo Antônio alluvial fan has been 10 x 10\(^6\) m\(^3\) and São José alluvial fan has been 3.2 x 10\(^6\) m\(^3\).

The geomorphic change dating (this work) suggests that the exploration of mineral resources has existed since the 18th century in the Sincorá mountain range. In this scenario, it is not clear whether the existence of diamonds in the Chapada Diamantina has been known since the 18th century. It is possible that alluvial fans originated from the gold search phase and consequently formed the Marimbus wetland. Only after 1844 did Chapada Diamantina intensify exploration and attract thousands of miners to the region, where Chapada had its name linked to Diamonds (Toponymy: Chapada roughly means sedimentary plateau on Precambrian rocks, and Diamantina concerning Diamonds). This date only symbolizes one fact, due to the fact that the discovery of the mineral was kept secret and occasionally a diamond buyer was forced to reveal its existence.

Historical documents show that between the 17th and 18th centuries, explorers circulated intensively in the coastal and semi-arid region of the State of Bahia (site of the discovery of Brazil, in 1500 AD) in search of metals and precious stones. In reality, this movement dates back to the 16th century. The first expedition entered the Paraguaçu river, in 1559 and reached Chapada Diamantina region in the 17th century. The search for mineral wealth was hard and slow and lasted a long time without major discoveries.
Early indications of Brazil’s mineral potential were sporadic, but there is evidence that crystals were found in Bahia within a century of Columbus’s discovery of the New World. In one of the earliest descriptions, historian Pero de Magalhães Gândavo (1576) mentioned the existence of “certain mines of white stones such as diamonds”. In another account, Gabriel Soares de Sousa (1587) noted that fine, eight-sided crystals (possibly diamond) had been found during the dry winter months along certain rivers.

The search for diamonds, gold and other valuable natural products was a major driving force for the exploration and colonization of the interior of the country in the 17th and 18th centuries. The discovery of gold in the state of Bahia was the result of much investment by the Portuguese government which, throughout the 17th century, stimulated, subsidized and gave rewards to anyone who ventured in search of metals and precious stones.

The largest results of the expeditions were achieved first with gold, found in the 18th century, then diamond, whose first deposits were discovered in the early 19th century. The Sabugosa Viscount, Brazilian viceroy, decreed in 1731, the elaboration of precise maps on the terrestrial ways conditions, to enable the Portuguese monarchy to know the productive capacity of gold deposits, in addition to transport conditions to the coast and new mining territories of the Chapada Diamantina.

Although the exact year is uncertain, the accepted discovery of diamonds in Brazil is thought to have occurred sometime between 1710 and 1730. In Minas Gerais, diamonds were officially found around 1714, and soon attracted the attention of the Portuguese monarchy, which imposed the first legislation to regulate their exploitation dated 1732. Eventually, reports of diamonds in Brazil began to reach Europe. Accounts from the colonial governor came to the attention in Portugal, and the discovery was officially announced in 1729. Portugal moved aggressively to control the area, restricting gold and diamond mining and imposing high taxes. Despite efforts by the crown, clandestine mining and diamond smuggling increased.

4. Materials And Methods

4.1 Hydrogeomorphology

The hydrogeomorphological behavior was calculated by last gauging station in the Santo Antônio river (Fertém Station), upstream the Marimbus wetland. The data were obtained from the Hydrological Information System, in the Brazilian National Water Agency – Agência Nacional das Águas - ANA (ANA, 2018), with hydro-sedimentologic historical series, between 1948 and 2012. This station (code: 51190000; Lat 12°45’26”S / Long 41°19’44”W) represents the Santo Antônio river calibrated base level, with 320 meters (above sea level) between the central and southern sectors.

Topographic profiles were extracted to verify the level differences in the region from Shutter Radar Topography Mission (SRTM). The present research used processed SRTM models with 30-meter resolution. The water base level of the hydrological data (Fertém Station) was compared to the SRTM, and satellite images were interpreted to then determine the maximum flooding area in the Marimbus wetland. Multitemporal satellite images acquired between 1984 and 2021, from the Global Surface Water Explorer data platform provided accurate, up-to-date, high-resolution geospatial data depicting surface water changes in the Marimbus wetland.
Satellites images were also used to identify sedimentary deposits along the rivers and to compare them with the historical records of the diamond mining areas in Chapada Diamantina\(^{41}\). Field work was carried out for the hydrogeomorphological recognition of the region and an overflight was performed to obtain aerial photographs of the wetland and its surroundings.

4.2. Stable isotope analysis (\(\delta^{18}O\) and \(\delta^2H\)) of water surface

Surface water samples were collected from the Marimbus wetland, São José, Santo Antônio, and Paraguaçu rivers to determine their origin through \(^{18}O\) and \(^2H\) isotopic data. The samples were packaged and stored in amber glass bottles with caps and lids, with volumes equal to 50 mL. During collection, the vials were completely filled to avoid isotopic fractionation. Each vial was identified and covered with clear plastic wrap and kept refrigerated until analysis. The \(^{18}O\) and \(^2H\) measurements were made by Mass Spectrometer (Finningan MAT Delta Plus) and H-Device Thermo Quest Finningan automatic reactor at the Applied Nuclear Physics Laboratory of the Federal University of Bahia. The measurement error is \(\pm 1%\) for hydrogen and \(\pm 0.1%\) for oxygen.

The method presented by Brand et al. (2000)\(^7\) was used to determine the deuterium-hydrogen ratio (D / H). The authors propose the transformation of water into hydrogen by reducing water at 850°C with metallic chrome. In this case, approximately 1.0 \(\mu\)l aliquots of each water sample are injected into an automatic reactor, where the oxidation reaction of chromium occurs at 850°C, with the consequent release of \(H_2\). The released \(H_2\) enters the mass spectrometer where it is analyzed. The technique used to determine the \(\delta^{18}O\) values in water is the isotopic equilibrium between carbon dioxide and water at a controlled temperature of 25°C for at least 18 hours.

4.3. Radiocarbon \(^{14}C\)-AMS

Radiocarbon Accelerator Mass Spectrometry (\(^{14}C\)-AMS) was based on a sample from the dead forest (obtained February 2014), in the southern portion of the swamp (Lat 12°45'16.57"S / Long 41°18'7.48"W). The sampled tree was characterized as being from the genus *Hymenolobium sp.* Sample preparation and measurement were performed at the Radiocarbon Laboratory of the Federal Fluminense University, Brazil (LAC-UFF). A sample of approximately 2 cm in width was analyzed with a microscope and four subsamples were collected from three growth rings of the trunk plus the bark. Each of these samples was prepared separately so that a sequence model could be constructed.

Samples were washed in ultra-pure (UP) water and subjected to a chemical treatment for the extraction of cellulose. The Acid-Base-Acid (ABA) protocol comprised a sequence of treatments with 1.0M HCl acid for 2 h, 1.0M NaOH base for 1h (repeated until the supernatant was clear) and a final treatment with 1.0M HCl acid for 2h (all treatments at 90°C). Holocellulose was then extracted with 1.0M NaClO\(_2\) and 1.0M HCl at 70°C for about 4h and repeated until the sample was clear\(^{44}\). Samples were rinsed with UP water and dried. Next, they were combusted in independently sealed quartz tubes with CuO and Ag wire at 900°C for 3h. After purification of the obtained CO\(_2\), samples were transferred to pyrex tubes with Zn,TiH\(_2\) and Fe, torch sealed and heated at 550°C for 7h in a muffle oven\(^{55−27}\). The graphite was analyzed at the NEC 250 kV Single Stage Accelerator System at LAC-UFF. The results were calibrated with the SHCal20 curve\(^{18}\) and the sequence model was built within the OxCal software v4.4.2\(^{38}\).

Declarations
Acknowledgements

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Author contributions

The authors declare that made substantial contributions to the conception analysis, interpretation of data, drafted the work or revised its critically intellectual content, approved the version to be published, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy of any part of the work are appropriately investigated and resolved. All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by G.M.P.L, J.R.L.F. and A.B.C. The first draft of the manuscript was written by G.M.P.L. and all authors commented on previous versions of the manuscript. G.M.P.L. analyzed and interpreted sedimentological and mining historical data, K.C.D.M. analyzed and interpreted $^{14}$C-AMS data, A.B.C. analyzed and interpreted isotopic data, E.Q.A. analyzed and interpreted $^{14}$C-AMS data, J.R.L.F. analyzed and interpreted isotopic data and C.A.P. analyzed and interpreted ecological data. All authors read and approved the final manuscript. The authors declare that made substantial contributions to the conception analysis, interpretation of data, drafted the work or revised its critically intellectual content, approved the version to be published, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy of any part of the work are appropriately investigated and resolved.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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**Figures**
Figure 1

Sincorá mountain range in the Chapada Diamantina (a). The white lines refers to carbonatic basins separated from the older siliciclastic basin. Landsat-5 TM image shows the main features around the Marimbus wetland (b). Dead deciduous trees in the southern Marimbus wetland and the sample used for radiocarbon dating (c).
**Figure 2**

Fertém station hydrological data (a), average water level (b) and wet and dry periods (c) in the Marimbus wetland.
Figure 3

Sandy islands emerge during the dry season (a), and main surface water changes between 1984 and 2021(b) in the Marimbus wetland.
Figure 4

Excess deuterium parameter (‰) in the surface waters (a) and isotopic data from the surface samples analyzed (b) in the Marimbus wetland (in green) and from karstic aquifer (in blue40). The red line represents the Global Meteoric Line.
Figure 5

Radiocarbon ages obtained from deciduous dead trees in the Marimbus wetland.
Figure 6

Main diamond mines and alluvial fans area concentration in the Chapada41. The drashed white rectangle indicates where alluvial fans on the Sincorá range footslope are concentrated.
Figure 7

Mining activity in the Sincorá mountain range (a, b). Note that there are not alluvial fans without mining área (c), and combined intense Paraguaçu river discharge and high slope (d, e) may explain alluvial fans.
Figure 8

Sub-sectors into Marimbus wetland. Note that the Paraguaçu river is topographically higher than the Santo Antônio river (b). The intense sedimentation at the confluence of rivers was responsible for allowing the river system to become a wetland. Note that the 326 m-elevation corresponds to the maximum flood area.