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Paleofires and vegetation in a Late Pleistocene paleolake (>43 ka BP) of the savannas of central Brazil

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ABSTRACT: This study investigates paleoenvironmental changes at the Paleolagoa Seca site, an Upper Quaternary locality of lacustrine origin in central Brazil. We present charcoal and pollen analyses of this sedimentary sequence, and assess how they compare with previously published fossil macroflora and paleoclimatic reconstructions of the same site and adjacent localities. We identified a mosaic of savannas, forests and flooded environments before 43 ka BP with the presence of evergreen forest formations. For this period, we found charcoal particles resulting from natural fires that represent the oldest Quaternary record of fire in the Cerrado. By conducting a morphological analysis of charcoal particles, we were able to identify that the primary constituents of fire fuel were grasses, which suggests that surface fires were prevalent. During this Pleistocene wet phase, fire probably played a vital role in preserving areas of open vegetation. In contrast, at ~43 ka BP, an open landscape and a drier-than-present climate characterized the Paleolagoa Seca site. © 2023 John Wiley & Sons, Ltd.

KEYWORDS: Cerrado; charcoal; paleofires; Pleistocene

Introduction

The Paleolagoa Seca sedimentary succession is a lacustrine deposit of Pleistocene age located in the south of the Cerrado biome, in central Brazil (Fig. 1). The Cerrado is a Neotropical savanna that covers almost 2 million km^2 of the Brazilian territory, and extends from 5° to 24°S latitude. The vegetation of the Cerrado is classified as a humid savanna and comprises forest formations, savanna woodlands, savanna formations, savanna grasslands and shrubby-grasslands (Furley, 1999; Ribeiro and Walter, 2008). One of the main characteristics of the Cerrado flora is that most species are adapted to, or dependent on, fire (Simon et al., 2009). In addition to specialized flowering and fruiting phenologies, adaptations to fire among herbaceous species involve the existence of subterranean organs such as bulbs, underground shoots, rhizomes and xylopodia, which have the ability to regenerate after the aerial parts are destroyed by fire (Coutinho, 1990). For arboreal species, adaptations to fire include a robust suberization of the trunk and branches (Ratter et al., 1997; Simon et al., 2009). The high floristic diversity of the Cerrado – which is the most species-rich tropical savanna – is directly related to these fire adaptations (Simon et al., 2009). Beyond biodiversity, fire plays an important role in maintaining the structure and functioning of the Cerrado vegetation (Durigan and Ratter, 2016). In the Cerrado, high fire frequency usually leads to a decrease in arboreal coverage and an increase in open vegetation, while the absence of fire may lead to to forest encroachment (Miranda et al., 2002; Durigan and Ratter, 2016; Simon et al., 2009; Lehmann et al., 2014; Lenza et al., 2017). Natural fires in the Cerrado are caused by lightning, usually during the wet season, and have occurred since long before human arrival in South America (Ramos-Neto and Pivello, 2000; Scheel-Ybert et al., 2003). Culturally distinct groups that have occupied the Cerrado region during the last few millennia – the Bororo, Karajá, Parakanã, Kayapó, Canela, Krahô, Xavante and Xerente (Klink & Moreira, 2002) – probably used fire as a management tool, as do their descendants who utilized detailed fire knowledge and management practices (Mistry et al., 2005; Pivello, 2011, Melo, 2007).

The drivers that control the frequency of natural fires are still poorly understood, especially on larger temporal scales. The Cerrado is characterized by a highly seasonal climate, with almost all rainfall concentrated during the austral summer and a dry winter season (Oliveira-Filho and Ratter, 2002). Summer precipitation is related to activity of the South American Summer Monsoon (SASM) system (Silva and Kousky, 2012), the main features of which are the Intertropical Convergence Zone (ITCZ) and the South Atlantic Convergence Zone.

In Follador et al. (2021), we presented a study of a well-preserved macroflora contained in the Paleolagoa Seca sedimentary succession and discussed how SASM dynamics influenced the climate and vegetation of this Cerrado region during the Late Pleistocene. Here, we present charcoal data, and additional pollen samples, from this same sedimentary sequence and analyze the influence of fire on the Pleistocene dynamics of this vegetation.

Study site

Geological setting

The Paleolagoa Seca locality consists of a sedimentary sequence, primarily interpreted as lacustrine (Ribeiro et al., 2001; Follador et al., 2021), around 50 m thick, that crops out in the eastern area of a phosphate mine located in the central area of an ultramafic–alkaline–carbonatite complex, named Catalão I (Fig. 1). The Catalão I complex is a carbonatite dome of Cretaceous age that forms a subcircular plateau supported by embedded quartzite rocks. The origin of the Paleolagoa

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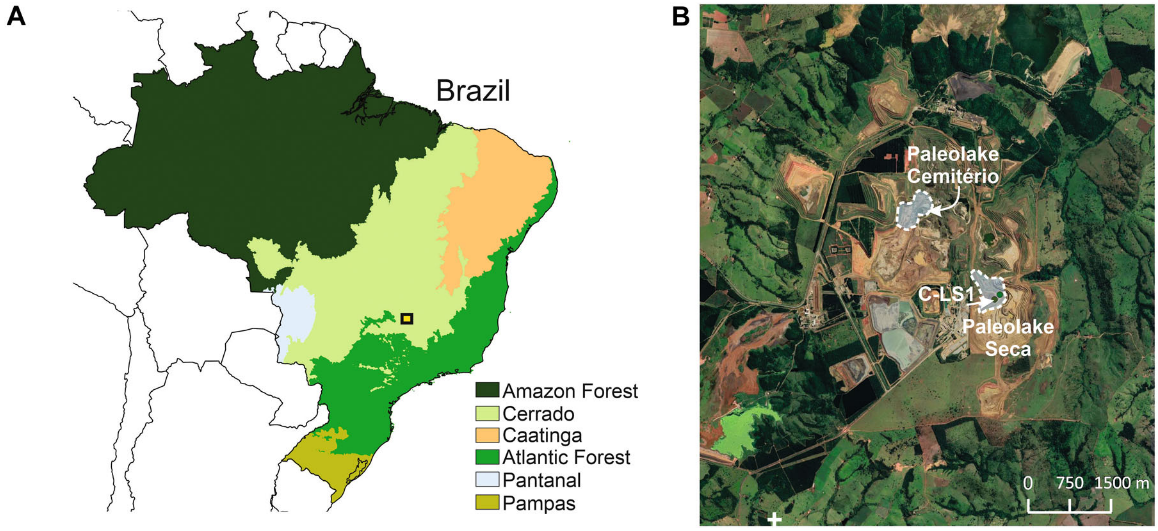

Figure 1. Location of the Paleolagoa Seca site. (A) Map of South America showing the distribution of Brazilian Biomes (IBGE, 2004) and the location of the study area (yellow rectangle). (B) Satellite image (Google Earth) of phosphate mines in the Catalão Magmatic Dome I showing the location of the Paleolagoa Seca and Paleolago Cemitério sites, and of the core (C-LS1) presented in this study. [Color figure can be viewed at wileyonlinelibrary.com]

Seca basin is probably related to the formation of a depression resulting from the leaching of carbonates from the carbonatite (Ribeiro et al., 2001). Near the Paleolagoa Seca, on the same carbonatite dome, there is another succession of lacustrine rocks, known as Paleolago Cemitério (referred to as Cemitério Paleolake by Machado et al., 2014) (Fig. 1B).

The Paleolagoa Seca lacustrine succession is composed of, from base to top: an ortho-conglomerate layer, a sequence of argillite with reworked argillite clasts interbedded with diatomite, a black argillite layer, an ~1.5-m-thick layer of gray argillite with fossil leaves, a layer of gray argillite with orange argillite clasts and a layer of orange–brown argillite (Follador et al., 2021; Fig. 2). The mineralogical association is characterized by the presence of kaolinite, quartz, hydrated phosphates (crandallite/plumbogommite group and goyasite), anatase, pyrite, hematite, magnetite, goethite and carbonates (dolomite, dawsonite and huntite) and indicates that the provenance of the Paleolagoa Seca sediments was the supergene profiles developed over the Catalão I dome (Follador et al., 2021).

Modern vegetation and climate

The Catalão I complex is located in the southern region of the Cerrado biome, close to the transition with the Atlantic Forest (Fig. 1A). Land cover mapping of the municipality of Catalão performed by Silva and Rosa (2019) indicated that the remaining native vegetation cover is mostly composed of open formations such as sparse savanna (*Cerrado Ralo*), shrubby grasslands (*Campo Sujo*) or montane savanna (*Campo Rupestre*). Riparian forests, gallery forests, palm swamps, savanna woodlands (*Cerradão*) and dry forests (*Mata Seca*) also occur subordinately (Silva and Rosa, 2019). The woody flora of these vegetation formations consists primarily of Fabaceae, Asteraceae, Vochysiaceae, Erythroxylaceae, Dilleniaceae and Myrtaceae (Oliveira Ferreira and Moreno, 2010; Oliveira Ferreira and Cardoso, 2013).

According to the Köppen classification, the climate of the region is of the Aw type, i.e. tropical with rainy summers and dry winters (Alvares et al., 2013). The dry season extends from April to September and the rainy season from October to March. Mean annual temperature (MAT) at Catalão, based on available data for the period between 1961 and 2019, is 22.6 °C and mean annual precipitation (MAP) for the same period is 1434 mm (Instituto Nacional de Meteorologia [n.d.] data from the Catalão meteorological station, available from BDMEP/INMET; http://www.inmet.gov.br).

Material and methods

Core collection and chronology

In 2013, the Federal University of Minas Gerais (UFMG) in cooperation with *Vale Fertilizantes* company, which was at the time in charge of exploration of the Catalão phosphate mine, collected an ~37-m deep core, C-LS1, from the Paleolagoa Seca site at 18°8′30″S, 47°47′30″W, with an Atlas Copco model CS-14 probe. Description of the core lithology was performed during the sampling process and selected parts of the core were transported and stored at the *Laboratório de Paleontologia e Macroevolução* – CPMTC/IGC/UFMG. For core chronology, one sample from the black argillite layer (C-LS1-27.3), and two samples from the gray argillite layer (C-LS1-26.4 and C-LS1-25.9) were sent for radiocarbon dating by accelerator mass spectrometry (AMS) at Beta Analytic Laboratory (Miami, FL, USA). For each sample, 5 g of argillite was provided, and all pretreatments, which included sample crushing and repetitive application of HCl, were conducted by Beta Analytic Laboratory. Dates were obtained from bulk argillite samples and radiocarbon dates were calibrated with the SHCal13 calibration curve (Hogg et al., 2013).

Pollen and charcoal analyses

Four samples from the black argillite layer (C-LS1-27.8, C-LS1-27.6, C-LS1-27.45 and C-LS1-27.3) and one sample from the underlying diatomite layer (C-LS1-28) (Fig. 2) were prepared for pollen analysis using standard methods (Bennett and Willis, 2001), including treatment with 40% HF, 10% HCl and 10% KOH, and acetolysis. After each treatment, samples were centrifuged to concentrate the pollen grains, and three slides of each sample were mounted with Entellan. Additional non-permanent slides were mounted for each sample with glycerol to aid the identification of pollen types. A minimum of 200 terrestrial pollen grains were counted for each sample. Cluster analysis using stratigraphic constraint and chord distance was performed on pollen data.

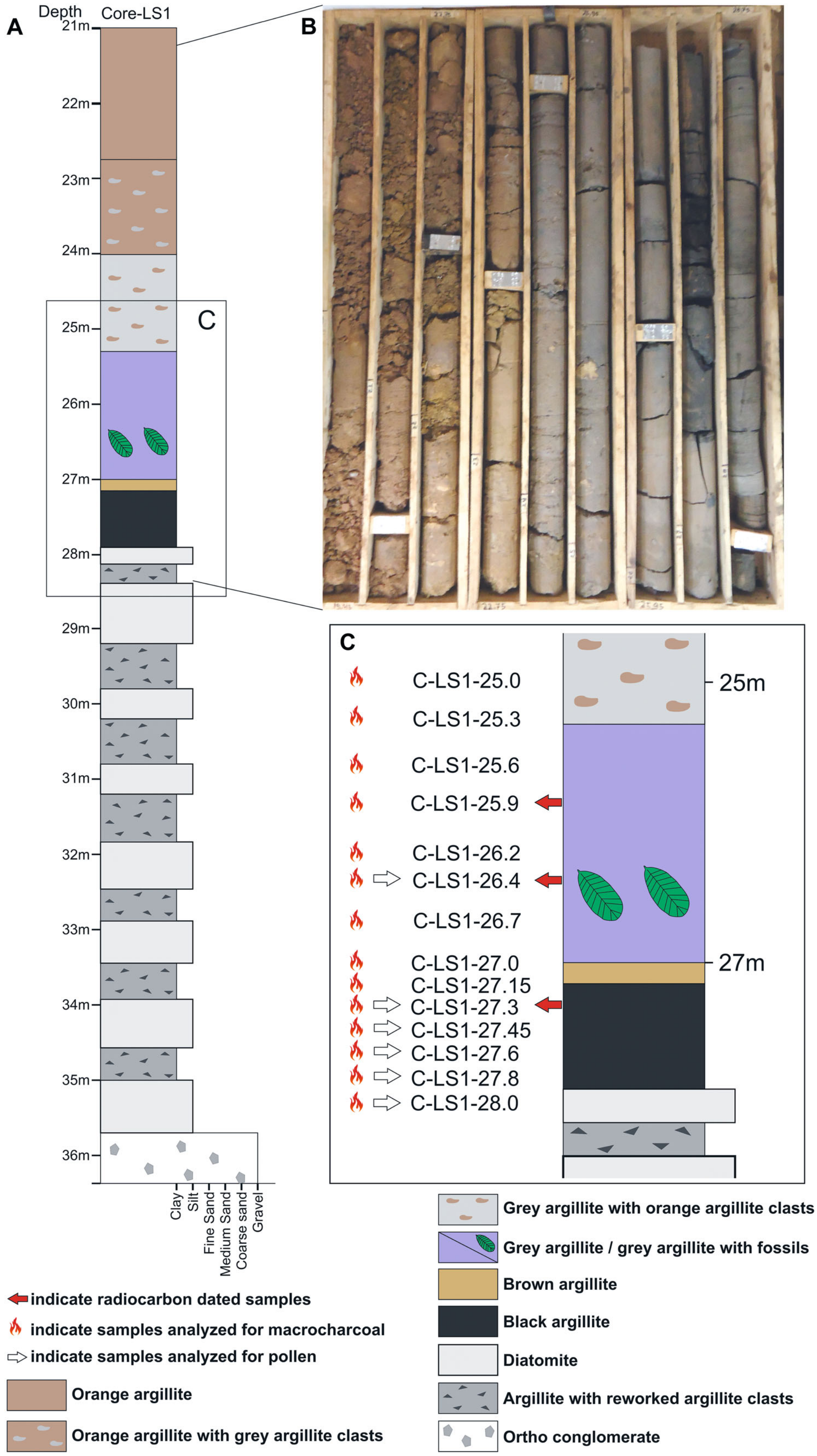

Figure 2. Lithostratigraphy of the Paleolagoa Seca core (C-LS1). (A) Lithostratigraphic column for the C-LS1 core. (B) Photography of the C-LS1 segment from 28.75 to 19.45 m. (C) Detail of the core segment used in this study with an indication of analyzed samples. [Color figure can be viewed at wileyonlinelibrary.com]

Fourteen samples from the core (one from the diatomite layer, five from the black argillite, one from the brown argillite, six from the gray argillite and two from the gray argillite with orange clasts; Fig. 2) were prepared for macro-charcoal analysis using the method of Stevenson and Haberle (2005), which uses NaOH and KOH to concentrate charcoal fragments. For each sample, 1 cm^3 of sediment was used for charcoal extraction. After 24 h, the samples were sieved through 100-μm mesh and analyzed in the stereoscopic microscope to separate charcoal fragments. For each sample, charcoal fragments were carefully separated from opaque minerals and other clasts by manual selection under the stereoscopic microscope; charcoal fragments were then photographed and analyzed with ImageJ (Abràmoff et al., 2004). Initially, photographs were converted to grayscale, then the 'Threshold' and 'Particle Analyzer' tools were used to count and measure the charcoal fragments.

Charcoal fragments were classified into morphotypes according to the classification of Enache and Cumming (2006). In this classification, seven types of morphotypes (types M, P, S, B, C, D and F) are presented according to morphological characteristics, such as irregular versus geometric, elongated versus compact, and presence or absence of internal structures.

Table 1. Radiocarbon dates of the C-LS1 core from Paleolagoa Seca. Ages were calibrated using SHCal13 (Hogg et al., 2013).

Lab. code	Sample code	Depth (m)	Age (^{14}C a BP)	$\delta^{13}C_{org}$ (‰)	Calibrated age range (cal a BP), 2σ
Beta - 556165	C-LS1-25.9	25.90	30 880 ± 160	−22.2	34 400–35 096
Beta - 489233	C-LS1-26.4	26.40	39 140 ± 380	−25.1	42 376–43 575
Beta - 556164	C-LS1-27.3	27.30	>43 500 BP	−24.5	—

Table 2. Pollen types from the diatomite, black argillite and gray argillite of the Paleolagoa Seca with their respective life form types and occurrence within the Cerrado biome according to Mendonça et al. (2008), Cassino and Meyer (2011) and Cassino et al. (2016). Pollen types are organized by groups (HS, terrestrial herbs and shrubs; M, marsh plants; T, trees).

Taxonomy	Group	Diatomite	Black argillite	Gray argillite	Life-form type	Habitat (Cerrado physiognomy)
Acalypha	HS		X	X	Herb, shrub, tree	Gallery forest, dry forest
Asteraceae	HS		X	X	Herb, shrub	All physiogonomies
Cuphea	HS		X		Herb	Marsh, grassland, gallery forest, palm swamp
Galianthe	HS		X	X	Herb, liana, shrub	Marsh, grassland, shrubby grassland
Hydrocotyle	HS		X		Herb	Edge of forests, marsh
Poaceae	HS	X	X	X	Herb	All physiogonomies
Sebastiania type	HS		X	X	Shrub	Cerrado (*sensu stricto*), shrubby grassland, gallery forest
Sida type	HS		X	X	Herb, shrub	Cerrado *sensu stricto*
Smilax	HS		X		Liana	Cerrado (*sensu stricto*), gallery forest, dry forest, shrubby grassland
Waltheria	HS		X		Shrub	Dry forest, gallery forest, Cerrado *sensu stricto*
Cyperaceae	M	X	X	X	Herb	Marsh, shrubby grassland, palm swamp
Eryngium	M		X		Herb	Marsh, palm swamp
Ludwigia	M		X	X	Shrub, herb	Marsh, gallery forest, palm swamp
Polygonum	M		X	X	Herb	Marsh
Utricularia	M	X	X		Herb	Marsh, gallery forest, palm swamp
Xyris	M	X	X	X	Herb	Marsh, palm swamp
Annonaceae	T		X		Tree	Various physiognomies
Arecaceae	T	X	X	X	Tree	Shrubby grassland, gallery forest, cerradão woodland
Bignoniaceae	T		X	X	Tree, shrub, liana	Various physiognomies
Cabralea	T		X	X	Tree	Gallery forest, riparian forest
Cecropia	T	X	X		Tree	Gallery forest, dry forest, cerrado *sensu stricto*
Celtis	T	X	X		Tree	Gallery forest, riparian forest, dry forest, cerradão woodland
Chrysophyllum	T		X	X	Tree	Cerrado *sensu stricto*, forest
Cupania	T		X	X	Tree	Cerrado (*sensu stricto*), gallery forest, dry forest
Doliocarpus	T		X	X	Liana	Cerradão woodland, gallery forest, palm swamp
Forsteronia type	T	X	X	X	Tree	Gallery forest, dry forest, cerradão woodland, cerrado *sensu stricto*
Hedyosmum	T		X		Tree	Gallery forest, marsh, palm swamp
Ilex	T		X	X	Tree	Gallery forest, riparian forest, palm swamp
Melastomataceae	T	X	X	X	Shrub, tree, herb	Various physiognomies
Moraceae	T	X	X		Tree	Dry forest, gallery forest, cerrado *sensu stricto*
Myrsine	T		X	X	Tree	Gallery forest, riparian forest, dry forest, palm swamp
Myrtaceae	T	X	X	X	Tree, shrub	Various physiognomies, with greater abundance in gallery forests
Podocarpus	T		X		Tree	Gallery forest, dry forest and transition zone with the atlantic forest
Pouteria	T		X		Tree	Gallery forest, dry forest, cerrado *sensu stricto*
Protium	T	X	X	X	Tree	Marsh, gallery forest, palm swamp
Roupala	T	X	X		Tree	Dry forest, cerradão woodland, gallery forest, cerrado *sensu stricto*
Sapium	T	X	X		Tree, shrub	Gallery forest, grassland, cerrado *sensu stricto*
Schefflera	T		X		Tree	Gallery forest, dry forest, cerrado *sensu stricto*
Symplocos	T		X	X	Tree	Gallery forest, dry forest, cerradão woodland
Trema micrantha	T	X	X	X	Tree	Gallery forest, riparian forest, palm swamp

Results

Core chronology

The radiocarbon date obtained from the black argillite layer (C-LS1-27.3) exceeded the laboratory dating range of 43 500 years and did not produce an age (Table 1). The ^{14}C age of the fossiliferous level of the gray argillite (C-LS1-26.4) showed an age of 39 140 ± 180 a BP (42 376–43 575 cal a BP). The ^{14}C age yielded by sample C-LS1-25.9 from the gray argillite layer above the fossiliferous level was 30 880 ± 160 a BP (34 400–35 096 cal a BP) (Table 1).

Pollen and charcoal

Pollen analysis of the five samples from the diatomite and black argillite layers identified a total of 43 pollen types (Table 2), three spore types and one algae zygospore. The sample from the diatomite layer was dominated by terrestrial herbs and shrubs (47%), mainly represented by Poaceae (46%); arboreal pollen reached 35% of the pollen sum, with *Celtis* (7.5%) as the most abundant forest taxon (Fig. 3); marsh plants totaled 17%, with the presence of Cyperaceae (11%), *Utricularia* (3%) and *Xyris* (2%). The black argillite layer was also dominated by terrestrial herbs and shrubs (56–65% of the pollen sum), with high percentages of Poaceae (max. 61%) and Asteraceae (max. 21%); arboreal pollen varied from 10 to 30%, with the presence of Melastomataceae (max. 10.5%), *Sapium* (max. 6.5%), Bignoniaceae (max. 6%), *Myrsine* (max. 3.5%), Arecaceae (max. 3%) and *Forsteronia* (max. 3%) (Fig. 3); and marsh plants (14–25% of the pollen sum) were represented by Cyperaceae (max. 24%), *Eryngium* (max. 6.5%) and *Polygonum* (max. 4.5%). In comparison, the pollen assemblage of the overlying fossiliferous argillite layer, already presented in Follador et al. (2021), although also dominated by terrestrial herbs and shrubs (58% of the pollen sum), presented a higher arboreal pollen percentage (36% of the pollen sum), with a significant presence of Melastomataceae (12%), Myrtaceae (10.5%) and *Symplocos* (7%), and lower percentage of marsh plants (5%) (Fig. 3).

The presence of charcoal fragments was observed exclusively in the black argillite and diatomite layers; the seven samples from the overlying argillite layers showed no charcoal fragments (Fig. 4). The higher peak of charcoal almost reached 400 particles cm^{-3}, and occurred on the top of the black argillite layer (Fig. 3). Analysis of charcoal morphotypes identified the presence of types F, C, S and P in samples from the black argillite and diatomite layers, with a predominance of type F (51–85%), which is characterized by having an elongated shape without ramifications (Fig. 4).

Discussion

Paleovegetation reconstruction for the Paleolagoa Seca site

The pollen assemblages of the diatomite, black argillite and gray argillite layers of the Paleolagoa Seca core indicate that the vegetation that existed before 43 ka BP was not substantially different in composition from the modern Cerrado and that a mosaic of savannas, forests and flooded environments subsisted on the Catalão plateau. The proportion of flooded and forested areas, as well as the forest types, however, varied throughout this period. During deposition of the diatomite, the arboreal stratum was composed of *Protium*, *Forsteronia*, *Trema micrantha*, Arecaceae, Moraceae, Melastomataceae, *Celtis* and *Cecropia*. Ribeiro & Walter (2008) and Mendonça et al. (2008) classify four of these taxa – *Celtis*, *Cecropia*, *Forsteronia* and *Trema micrantha* – as typical of the semi-deciduous riparian forests in the Cerrado biome. In the upper black argillite, the three upper samples present *Myrsine* and either *Hedyosmum*, *Symplocos* or Melastomataceae, which are common components of evergreen flooded gallery forests (Ribeiro & Walter, 2008).

In contrast, the pollen and macrofossil record of the overlying gray argillite layer, already discussed in Follador et al. (2021), indicated the presence of open savannas and shrubby grasslands around 43 ka BP, with reduced swampy areas and gallery forests, i.e. a vegetation mosaic associated with a drier climate. The paleoclimatic reconstruction performed from fossil leaves for the 43 ka BP Paleolagoa Seca fossiliferous level (Follador et al., 2021) obtained higher-than-present MAT values (22.6–26.3 °C) and lower-than-present MAP values (647–948 mm) (Fig. 3). Follador et al. (2021) related these dry conditions, which are also registered by other paleoclimatic records in Central Brazil (Stríkis et al., 2018), to weakening of the SASM, associated with the northward displacement of the ITCZ. Thereby, at the Paleolagoa Seca site, the differences between the paleovegetation reconstructed from the diatomite–black argillite level and from the gray argillite level (43 ka BP) can be attributed to precipitation variations due to interhemispheric climate forcing.

Paleofires at the Paleolagoa Seca site

In the Paleolagoa Seca C-LS1 core, charcoal particles were only registered in the black argillite and diatomite layers, indicating that natural fires were present during the deposition of these layers, which occurred before 43 ka BP. This makes the charcoal record of the Paleolagoa Seca the oldest record of

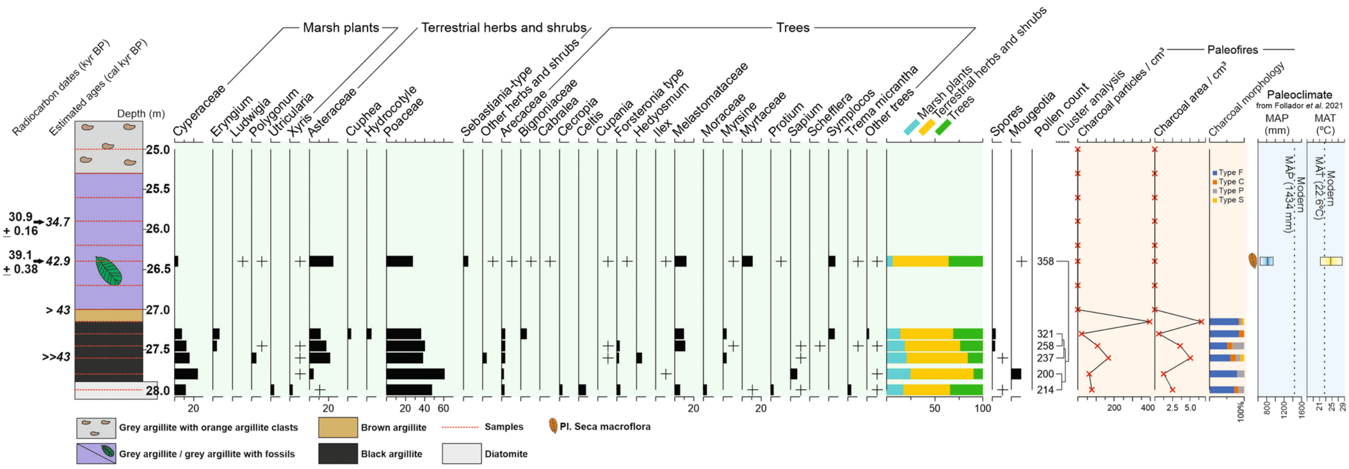

Figure 3. Lithology, pollen percentage and charcoal diagrams of the Paleolagoa Seca core (C-LS1). [Color figure can be viewed at wileyonlinelibrary.com]

fires ever described for the Quaternary of the Cerrado. Previously, Ferraz-Vicentini and Salgado-Labouriau (1996) registered the abundant presence of charcoal particles in the bottom part of a palm swamp sediment core dated to 36.5 cal ka BP, collected at Cromínia, around 200 km northwest of Catalão. Other Pleistocene records of charcoal particles include the Águas Emendadas core (Barberi et al., 2000) in which charcoal is present from around 30 cal ka BP, and the Caçó core, located on the northernmost Cerrado, in which charcoal was found in samples older than 19.1 cal ka BP (Ledru et al., 2002). The Paleolagoa Seca record thus pushes back the registration of fires in the Cerrado to before 43 ka BP.

Although charcoal is present during the deposition of the diatomite and black argillite layers, charcoal particles are no longer present in the upper part of the core. The absence of charcoal in the gray argillite could be due to depositional or taphonomic factors, or to a decrease in fire occurrence around the site. In samples containing charcoal particles, the predominant shape was morphotype F of the Enache and Cumming (2006) classification, for which the suggested source is highly fibrous fragments or grass cuticles. Type C was also present in most samples, and is related to the burning of tree bark (Enache and Cumming, 2006). Type S was present in two samples and is similar to Type C, but is more fragile, and may

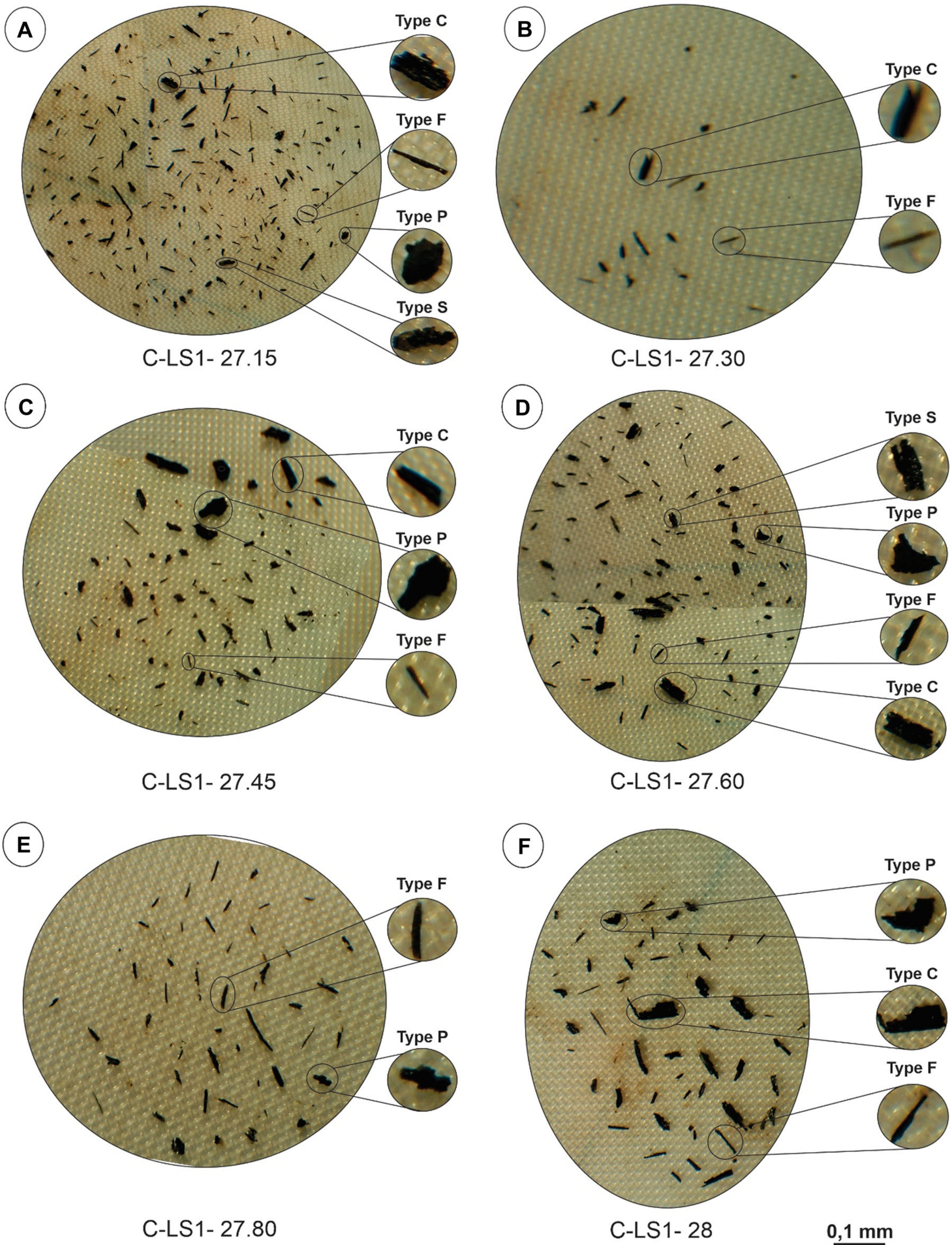

Figure 4. Charcoal particles from the C-LS1 core with an indication of morphological types. [Color figure can be viewed at wileyonlinelibrary.com]

be constituted from a series of layers, suggesting that the fuel source could be uni- or multi-seriate rays, fibers, parenchyma or tree bark (Enache and Cumming, 2006). Type P, which was present in most samples, originates from the burning of small amorphous leaves (Enache and Cumming, 2006). Studies that analyzed charcoal shape from experimentally produced charcoal reinforce the interpretation that charcoal of elongated shape is produced when grasses are the predominant fuel source. Crawford and Belcher (2014) experimentally burned several plant types and submitted the resulting charcoal fragments to transport simulation. Their results showed that grasses produced charcoal particles with significantly higher aspect ratios; Umbanhowar and McGrath (1998) and Pereboom et al. (2020) reached similar conclusions with other plant species. Additionally, Vachula et al. (2021) compiled a comprehensive dataset of experimental charcoal measurements and reached the conclusion that charcoal particles with L:W ratios >3.5 are produced by grassy fuels.

The charcoal particle morphology of the CLS-1 core thus indicates that the main fuel source of natural fires that occurred in the surroundings of Paleolagoa Seca before 43 ka BP was the herbaceous stratum, with a minor contribution of tree trunks and roots. This type of fire is characterized as a surface fire and is very common in the Cerrado today (Miranda, 2010). These fires are prompted by the accumulation of biomass from C4 grasses, which grow rapidly during the wet season and become flammable during the dry winter (Simon et al., 2009). Due to their rapid regrowth, grasses are favored at the expense of trees and shrubs, and thereby the high frequency of fires leads to a decrease in the tree stratum and maintains open herbaceous vegetation (Bond et al., 1993; Durigan and Ratter, 2016; Lehmann et al., 2014; Lenza et al., 2017; Miranda et al., 2002; Simon et al., 2009). The presence of fires before 43 ka BP in the Paleolagoa Seca record was thus probably an important factor in maintaining the presence of savanna vegetation, despite a relatively humid climate, shown by the presence of marsh environments. High water availability could generate forest encroachment, but the seasonality of rainfall resulted in favorable conditions for fire occurrence, maintaining a vegetation mosaic containing open savannas and grasslands, similar to the present-day Cerrado.

Conclusions

Study of the Paleolagoa Seca sedimentary sequence based on pollen and charcoal data and on previously published mineralogical, macrofossil and paleoclimatic data showed that before 43 ka BP a vegetation composed of a mosaic of savanna, forest and marshes, with a composition similar to the modern-day Cerrado, was already present. This vegetation was subject to the occurrence of natural fires, and, although evergreen and semi-deciduous forests were present, savanna formations persisted, probably due to the occurrence of frequent surface fires. These results illustrate the interaction between climate, fire and vegetation in the Cerrado during the Pleistocene and the importance of natural fires in shaping Cerrado landscapes.

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Data availability statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Abbreviations. Aw, tropical wet and dry or savanna climate; BDMEP/INMET, Banco de Dados Meteorológicos para Ensino e Pesquisa/Instituto Nacional de Meteorologia; C-LS1, Core Paleolagoa Seca 1; CPMTC/IGC/UFMG, Centro de Pesquisa Manoel Teixeira Costa/Instituto de Geociências/Universidade Federal de Minas Gerais; ITCZ, Intertropical Convergence Zone; KOH, Potassium Hydroxide; MAP, mean annual precipitation; AMS, accelerator mass spectrometry; MAT, mean annual temperature; SASM, South American Summer Monsoon; SHCal13, Southern Hemesphere Calibration 2013; UFMG, Universidade Federal de Minas Gerais.

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