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The peopling of Amazonia: Chrono-stratigraphic evidence from Serranía La Lindosa, Colombian Amazon

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ABSTRACT

Amazonia constitutes one of the most ethnically diverse regions in the world. However, our understanding of the arrival and historical trajectories of people in Amazonia is still poorly understood. Our recent excavations in the Serranía de la Lindosa have begun to fill this gap and provide new insights into the first human societies that settled in the Colombian Amazon region during the Younger Dryas (YD) period of the late Pleistocene. This paper details the stratigraphy, taphonomy and chronological framework of two rock shelters, Cerro Montoya 1 and Limoncillos, from excavations carried out by the LASTOURNEY project between 2021 and 2022. Based on radiocarbon dates from five multicomponent sites (Cerro Azul, Cerro Montoya 1, Limoncillos, Angosturas II and Casita de Piedra), four distinct phases of occupation are modelled using OxCal program (v.4.4). late Pleistocene-early Holocene (*12.6–10.0* cal *ka BP*); early to middle Holocene (*9.5–5.9* cal *ka BP*); initial late Holocene (*4.1–3.7* cal *ka BP*), and late Holocene (*3.0–0.3* cal *ka BP*). We establish the arrival date of the first human groups to the Colombia Amazon by ~*12.6* cal *ka BP*, who settled in a tropical rainforest environment, practised a generalised subsistence, had an expedient unifacial technology, and began to paint with ochre on the walls of the mesa-top *tepuis* by at least ~*10.2* cal *ka BP*. The chronology indicates gaps in the sequence during the middle Holocene, between *5.9–4.1* cal *ka BP*, likely representing periods of abandonment.

1. Introduction

The peopling of South America, the last continental *terra incognita* (other than Antarctica) to be colonised by *Homo sapiens*, constituted a virtually unprecedented migration of modern humans across richly diverse pristine landscapes during the late Pleistocene-early Holocene (LP-EH) transition. This period is one of the most significant climatic, environmental, and subsistence regime shifts in human history, coeval with megafauna extinctions, plant cultivation and the beginnings of plant domestication, which ultimately resulted in today's remarkable diversity of South American indigenous groups and cultures.

Current archaeological and genomic data suggest that human dispersal in the Americas likely took place sometime between ~25 and 15 ka (kiloanni) BP (e.g., Braje et al., 2017; Dillehay et al., 2015; Pansani et al., 2023; Pigati et al., 2023). Although much research has been done on this process across the diverse environments of South America, the peopling of the Amazon biome remains little understood. As Patricia Lyon (1974) famously stated, South America is the least archaeologically known continent of the Americas and Amazonia is even more unknown. The dense forest creates logistical difficulties for fieldwork and impedes the identification of archaeological sites, while the acidic and clayed soils negatively affect the preservation of organic remains. As a result, the discovery and investigation of LP-EH archaeological contexts are extremely rare.

Although limited, research in recent decades is providing compelling insight into the early human history of Amazonia. The excavations at Caverna da Pedra Pintada, lower Amazon, during the 1990s, were a landmark study that proved the Amazon biome was part of the human geographic expansion of hunter-gatherer groups (Fig. 1) at the end of the Ice Age, around ~13.1 cal ka (calibrated kiloanni) BP (Roosevelt et al.,

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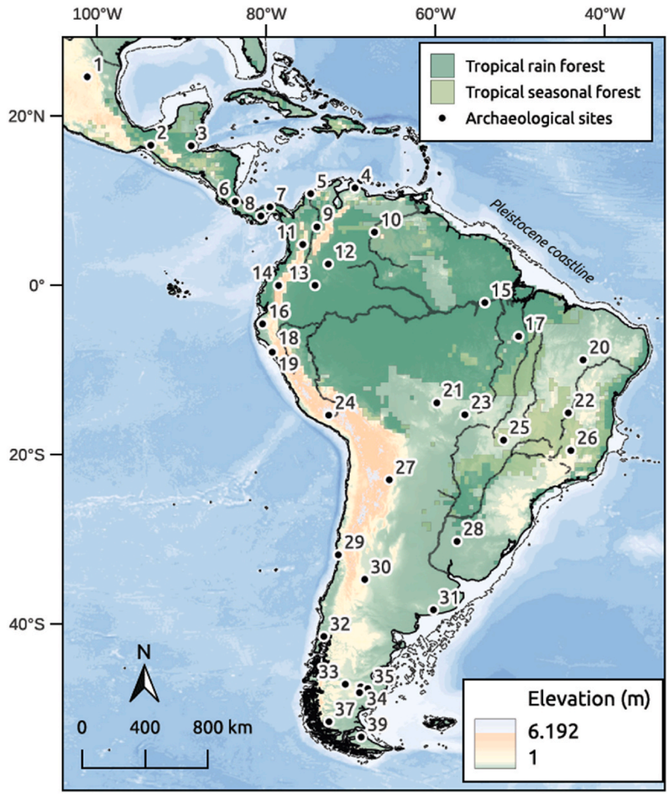

Fig. 1. Pleistocene map of tropical South America showing archaeological sites, sea levels and potential routes of entry into Amazonia. Low sea levels exposed dry land of the Atlantic and Pacific oceans during the last Ice Age. 1. Chiquihuite. 2. Los Grifos. 3. Mayahak Cab Pek. 4. Taima Taima. 5. San Isidro. 6. Turrialba. 7. Madden Lake. 8. Cueva de los Vampiros. 9. Middle Magdalena. 10. Cerro Gavilán. 11. Middle Cauca. 12. Serranía de la Lindosa. 13. Peña Roja. 14. El Inga. 15. Pedra Pintada. 16. Quebrada Jaguay. 17. Grutra do Gavião. 18. Paijan. 19. Huaca Prieta. 20. Pedra Furada/Serra da Capivara. 21. Abrigo do Sol. 22. Lapa do Boquete. 23. Santa Elina. 24. Cuncaicha. 25. Itaparica (Seranópolis). 26. Lapa Vermelha/Lagoa Santa. 27. Inca Cueva. 28. Pay Paso. 29. Quebrada Santa Julia. 30. Gruta del Indio. 31. Arroyo Seco 2. 32. Monte Verde. 33. Cueva de las Manos. 34. Los Toldos. 35. Piedra Museo. 36. Cerro Tres Tetas. 37. Cueva del Milodon. 38. Cueva del Medio. 39. Tres Arroyos.

1996). Contrary to prevailing hypotheses, the excavations demonstrated that the tropical vegetation of the Amazon was not an impassable barrier to human groups and that non-agriculturalists had successfully adapted to tropical rainforest habitats for millennia (e.g., Roberts, 2019). Mounting evidence from north-western South America further demonstrates the adaptability of early humans to the diversity of environments of the continent (Aceituno and Loaiza, 2018; Gnecco and Mora, 1997; Ranere and López, 2007; Santos et al., 2015). LP-EH archaeological sequences in north-western South America indicate that modern humans successfully traversed and adapted to sharply contrasting interior environments as well as coastal corridors, including lowland rainforest, Sub-Andean and Andean tropical forests, and savannahs, since the late Pleistocene and early Holocene (Aceituno and Loaiza, 2018; Bryan et al., 1978; Correal, 1982; Dickau et al., 2015; Gnecco and Mora, 1997; Mora, 2003; Morcote-Ríos et al., 2021; Ranere and López, 2007) (Fig. 1). In contrast to the "big game hunters" of the more open steppes and savannahs of North (e.g., Haynes, 1997) and South America (e.g., Prates and Perez, 2021), early Amazonian foragers at Caverna da Pedra Pintada had a generalised subsistence economy incorporating palm and tree fruits, small mammals, and riverine resources like fish and turtles (Pereira and Moraes, 2019; Roosevelt, 2013).

Despite these advances, there are still extensive unexplored Amazonian regions (Iriarte et al., 2020), with many archaeological gaps, especially regarding the earliest arrival and spread of human groups across the region (McMichael and Bush, 2019). Due to its relative proximity to the isthmus of Panama, Colombian Andes, and the Orinoco River, the Colombian Amazon is a strategic area for studying human dispersal of the Upper Amazon River basin.

In this paper, we present the stratigraphy and chronological framework from excavations carried out by the LASTJOURNEY project between 2021 and 2022 at the Cerro Montoya 1 and Limoncillos rock shelters, in the Serranía La Lindosa (SLL) at the fringe of the Amazon and Orinoco basins in the Colombian Amazon. Prior test excavations at these sites and excavations at Cerro Azul were previously reported in Morcote-Ríos et al. (2021).

2. Materials and methods

2.1. Study area

The SLL is formed by sedimentary rocks of the Araracuara Formation (Upper Palaeozoic). The dominant rock types in this formation are hyaline quartz conglomerates and sandstones, which give rise to the mesa-top hills known as *tepuis*. The outcrops have a tabular geometry formed from layers of sandstones (Cárdenas et al., 2008). The foothills of the *tepuis* contain deposits where sediments from the erosion of sedimentary rocks and alluvial deposits converge. These soils are acidic, have low base content, and high aluminium saturation (Cárdenas et al., 2008).

The SLL is situated within an ecotonal zone between the Orinoco savannahs, the flooded forests of the Guayabero River, and the tropical rainforests of the Amazon (Vriesendorp et al., 2018). Flooded *varzea* forests in the floodplain of the Guayabero River border the hills of the SLL. On the slopes of the mesa-top *tepuis*, tall hillside forests predominate, with high densities of palms. In the higher elevations of the *tepuis*, small tree forests and shrublands predominate on rocky outcrops. To the north of SLL, savannahs with gallery forests of the Llanos Colombianos occur. To the south of SLL, evergreen tropical forest prevails (Vriesendorp et al., 2018). Along with the diverse plant and animal resources, SLL also contains lithic raw materials in the form of chert river cobbles available in the exposed Guayabero River playas during the dry season as well as an abundance of ochre. Today's climate is warm and humid, with an average annual rainfall of ~2800 mm (Cárdenas et al., 2008).

2.2. Study sites

The rock shelters, Cerro Montoya 1 (273 m asl; 2° 32′ 0.3''N and 72° 51′ 51.3''W), Limoncillos (354 m asl, 2° 33′ 53''N and 72° 52′ 34''W), and Cerro Azul (322 m asl, 2° 31′ 47.2''N and 72° 51′ 59.0"W), are located in the SLL on the eastern bank of the Guayabero River (Guaviare Dept.) (Fig. 2a and b).

This paper focuses on the stratigraphy of Cerro Montoya 1 and Limoncillos, since the results of the excavations at Cerro Azul were recently published in Morcote-Ríos et al. (2021). We also present dates from excavations at Angosturas II (Correal et al., 1990) and Casita de Piedra, two rock shelter sites that also contain pre-ceramic occupations. Rock paintings in varying states of preservation are present on the walls of all the rock shelters described in this paper (Fig. 2c).

2.3. Excavation methodology

The excavations at Cerro Montoya 1 and Limoncillos were conducted to assess activity patterns and stratigraphic history, both inside and immediately outside of the rock shelter. Excavation followed identifiable stratigraphic layers, representing both natural and anthropogenic formation processes. Periods of more intensive human activity, resulting in identifiable horizontal compaction of sediments and artefact distribution are classified as occupation surfaces. These surfaces are typically littered with artefacts (ceramics, lithics, ochre fragments), charred plant remains (seeds and wood charcoal) and animal remains, as well as

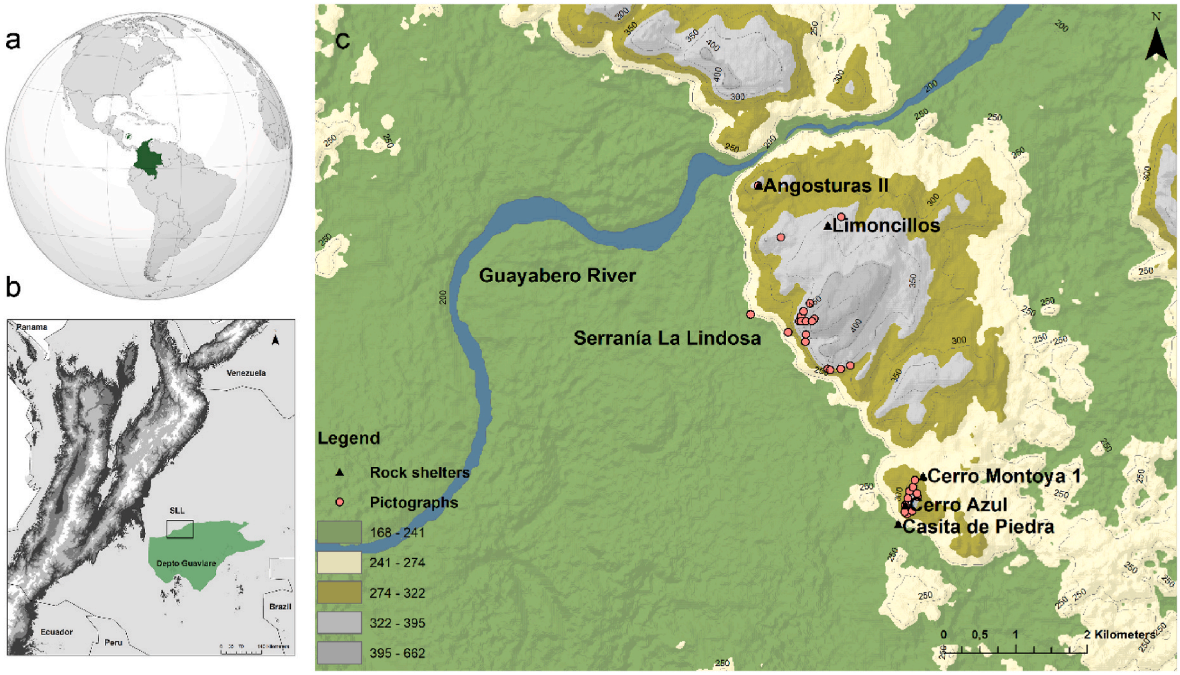

Fig. 2. a) Map of South America; b) Department of Guaviare showing the study area; c) Archaeological sites and major rock art panels in Serranía La Lindosa.

associated features, such as hearths. At both sites, sediments were collected per context for floatation and geochemical analyses. Additionally, at both sites control samples were collected from an off-site location between ~80 and ~90 m distance from the shelters. The control samples show no signs of human activity.

2.4. *Dating and bayesian modelling*

Datable organic material was collected *in situ* from well-defined occupation surfaces. When available, charred palm endocarps were selected. Dates were calibrated, modelled, and rounded to the nearest 10 years in OxCal v.4.4.4 (Ramsey, 2009). OxCal codes and calibrated dates are provided as Supplemental Data 1. Dates are reported in whole ranges to 94.5 % hpd. Given the SLL's proximity to the Tropical Low-Pressure Belt (Anacapichún, 2021), we employed a mixed SHCal20 (Hogg et al., 2020) and IntCal20 (Reimer et al., 2020) calibration curve (Marsh et al., 2018).

Bayesian modelling allows greater chronological precision to sequence the arrival of the human groups and define the different phases of occupation at the SLL (Bayliss, 2015). First, the Sum command was used to calculate the Summed Probability Distribution (SPD) for the radiocarbon dates from Cerro Montoya 1, Limoncillos, and the entire SLL, in order to identify the occupational phases within each site (Fig. 3). This calculation assumes a normal distribution, in which the

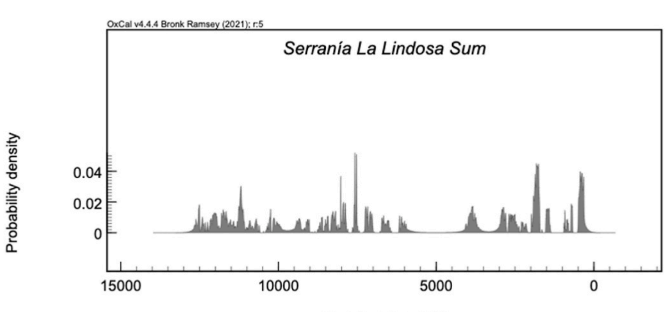

Fig. 3. OxCal plot showing the sum of the probability distributions (SPD).

probability of dates as random variables is symmetrically distributed in a Gaussian bell curve shape based on the parameters mean (μ) and standard deviation (s).

In a secondary step, we classified the SLL dates into 4 phases. Each occupation phase was plotted as a Kernel Density Estimation plot (KDE_Plot command) (Ramsey, 2017) nested within a Sequence command. Start and end boundaries were incorporated between each phase to account for hiatuses. Phase start and end dates were estimated using the median values of these boundaries, rounded to the nearest one hundred years. We also calculated hiatus lengths (Difference), phase durations (Span), and probability distributions (Sum).

3. Results

3.1. *The archaeological sites*

3.1.1. *Cerro Montoya 1*

The Cerro Montoya 1 rock shelter is an isolated rock outcrop, located in the piedmont of Cerro Azul. In 2018, the team excavated a 1 × 1 m test unit to recover datable material. Charcoal from the earliest human context was dated to 10560 ± 30 BP (Beta-509123; *12.67–12.*47 cal *ka BP*) (Morcote-Ríos et al., 2021). In 2021, two further test units were excavated to compare stratigraphy and activity patterns at the rock shelter: Unit 2 (3 × 3 m) under the overhang near the shelter wall, and Unit 3 (2 × 2 m), outside the overhang (Fig. 4). The following sections describe the stratigraphy of each excavation, from earliest context to most recent.

3.1.1.1. Cerro Montoya 1 - unit 2. Layers I-III. The deepest sediments are composed of a sandy gravel matrix formed from the eroding sandstone bedrock (Layers I-III, ~230 cm to ~180 cm below unit *datum*). Large boulders present on top of the underlying bedrock protrude through the stratigraphic layers and create irregular topography, especially in these pre-human layers (Fig. 5).

Layer IV (N profile: ~140/142–180 cm, S profile: ~154–184 cm) (Fig. 5). Sandy loam (SL) texture and dark and acidic soil. Organic matter (OM) and carbon monoxide (OC) increase from the lowest to the upper levels. Total phosphorus (TP) is very high in this layer (Table 1)

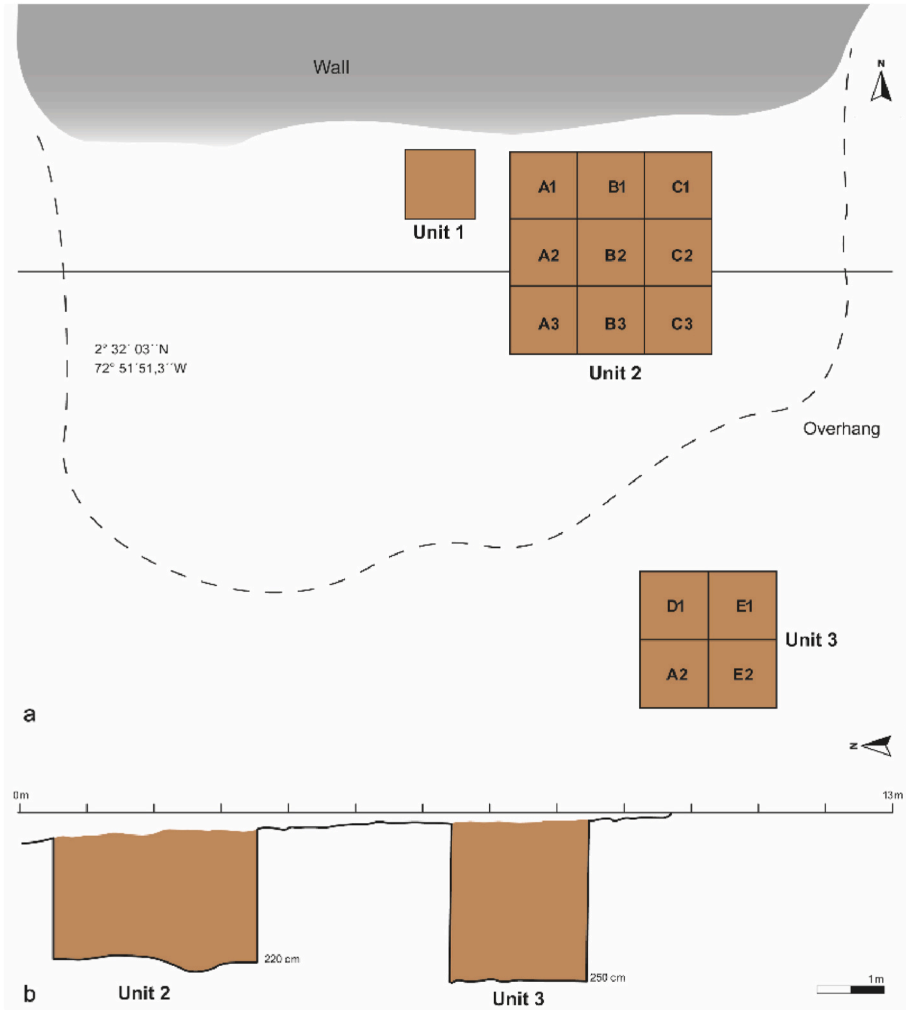

Fig. 4. Excavation plan Cerro Montoya 1. a) Excavated units; b) N–S topographic profile.

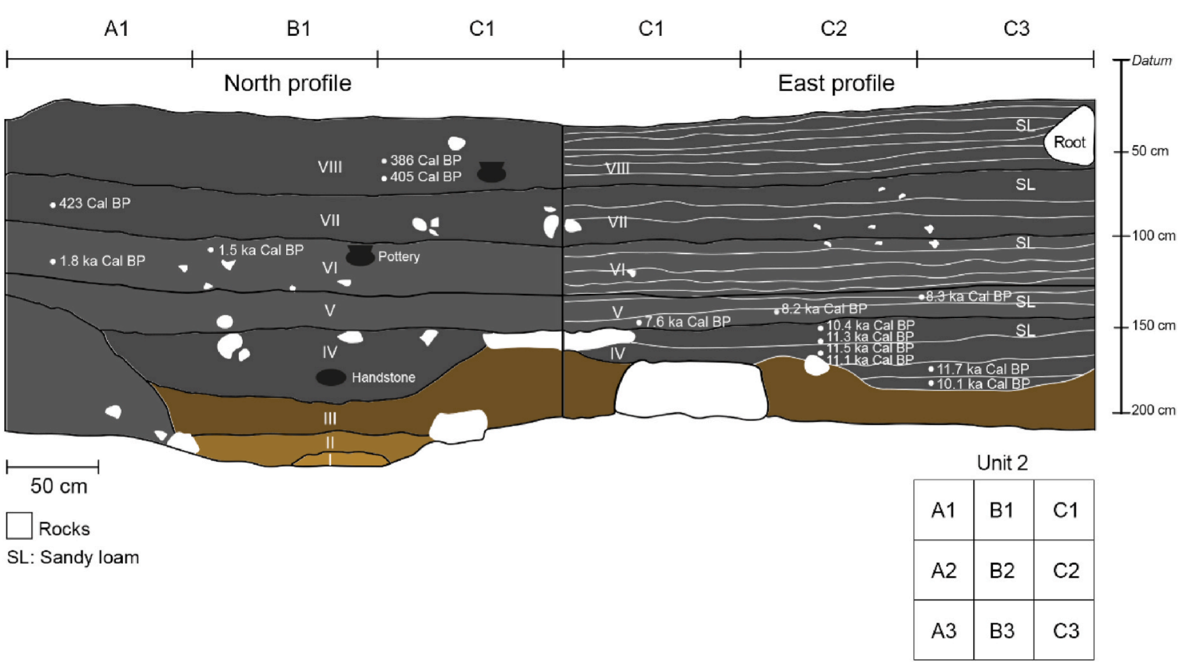

Fig. 5. Stratigraphy N and E profiles. Unit 2. Cerro Montoya 1. The east profile shows occupation contexts associated with the stratigraphic layers. The northern profile shows the appearance of grinding hand stones and ceramic.

Table 1
Physico-chemical characteristics of the stratigraphic layers of Cerro Montoya 1.

			%					%		mg/kg
Unit	Layer	Colour	Sand	Silt	Clay	Texture	pH	OM	OC	TP
2	IV	10 YR2/2	85	6	9	SL	4.9	1.91	1.11	8400
	V	10 YR2/2	84	7	9	SL	4.7	3.03	1.76	4510
	VI	10 YR2/2	85	6	9	SL	4.7	3.04	1.76	8836
	VII	10 YR2/2	83	6	11	SL	4.5	3.48	2.02	17.044
	VIII	10 YR2/2	83	6	11	SL	4.3	3.61	2.09	3562
3	II	10YR4/3	67	22	11	LS	5.0	0.71	0.41	2829
	III	10YR3/3	81	10	9	SL	4.9	1.31	0.76	210
	IV	10YR3/1	79	10	11	LS	4.7	1.44	0.84	105
	V	10YR2/2	79	10	11	LS	4.8	2.0	1.15	2357
	VI	10YR2/1	82	9	9	SL	4.8	1.81	1.05	28
	VII	10YR2/1	82	10	8	SL	4.7	1.69	0.98	199
	VIII	10YR2/2	85	8	7	SL	3.9	2.36	1.37	760

coinciding with higher frequency of lithic artefacts (Supplemental Figs. 1a,c,d). Fragments of red ochre are also found in several levels. Nine radiocarbon dates were obtained from different surfaces of this layer that range between 10130 ± 30 BP (Beta-489156; *11.88–11*.50 cal *ka BP*) (level 32) and 8920±30[1] BP (Beta-611107; *10.20-10*.11 cal *ka BP*) (surface of level 33).

Layer V (N profile: ~126–143 cm, S Profile: ~126–140 cm) (Fig. 5). SL texture, same colour and slightly more acidic than Laver IV. The values of OM and OC show an increase in relation to the underlying layer, while TP shows a significant decrease (Table 1). Although lithic artefacts are abundant, they tend to decrease in the upper levels of this layer (Supplemental Figs. 1a,c,d). Three dates corresponding to the middle Holocene were obtained in this layer: 6690 ± 30 BP (Beta-625032; *7.61–7*.48 cal *ka BP*) (surface of level 23), 7400 ± 30 BP (Beta-625031; *8.34–8*.03 cal *ka BP*) (surface of level 22), 7460 ± 30 BP (Beta-625030; *8.35–8*.18 cal *ka BP*) (surface of level 18).

Laver VI (N profile: ~84–126 cm, S Profile: ~82–126 cm) (Fig. 5). SL texture. Similar values of OM and OC to the underlying level. TP increases strongly (Table 1; Supplemental Figs. 1c and d). Upper Levels mark the appearance of ceramics in this unit, and lithic artefacts decrease slightly in relation to the Layer V (Supplemental Figs. 1a and b). Two dates were obtained in this layer: 1870 ± 30 BP (Beta-625029; *1.87–1*.70 cal *ka BP*) (surface of level 15), and 1580 ± 30 BP (Beta-625027; *1.53–1*.38 cal *ka BP*) (surface of level 10) (Fig. 2).

Layer VII (N profile: ~68–84 cm, S profile: ~64–82 cm) (Fig. 5). SL texture, dark colour and slightly more acidic soil than the underlying layer. Increase in OM and OC. At the base of this layer, the highest value of TP of all occupations was obtained, coinciding with the peak density of lithic material (Table 1; Supplemental Figs. 1c and d). The general trend in this layer is an increase of lithic artefacts and ceramics in its upper levels. The layer also shows a sharp increase in the density of ceramic fragments (Supplemental Figs. 1a and b). A date of 410 ± 30 BP (Beta-625026; *0.52–0*.32 cal *ka BP*) (surface of level 7) was obtained.

Layer VIII (N profile: ~64–68 cm, S profile:~46 cm) (Fig. 5). Same colour and texture as Layer VII. The layer is the most acidic and has the highest content of OM and OC of the entire profile (Table 1; Supplemental Fig. c,d). In this layer, lithic artefacts decrease, while ceramics show the highest frequency (Supplemental Figs. 1a and b). This layer was dated to 320 ± 30 BP (Beta-625025; *0.47–0*.30 cal *ka BP*) (surface of level 3) and 360 ± 30 BP (Beta-625028; *0.49–0*.31 cal *ka BP*) (surface of level 5).

3.1.1.2. Cerro Montoya 1 - unit 3. Layer II (N profile: ~224–250 cm, S profile: ~238–250 cm). Brown colour, loam sandy (LS) texture. This layer contains the earliest human occupation (Fig. 6). It overlies a yellowish, sandy, very moist stratum with no archaeological material (Layer I). Layer II has the least acidic soil of the profile, the lowest percentages of OM and OC, and the highest TP values of the entire profile, similar to Layer II of Unit 2 (Table 1; Supplemental Figs. 2, c,d). Lithic artefacts were recovered from the southern profile (Supplemental Fig. 2a). This layer was dated to 9620 ± 30 BP (Beta-633116; *11.17–10*.77 cal *ka BP*) (surface of level 46, S profile) and 9488 ± 30 BP (Beta-642564; *11.07-10*.58 cal *ka BP*) (surface of level 49, S profile).

Layer III (N profile: ~204–224 cm, S profile: ~210–238 cm) (Fig. 6). The soil is darker than the underlying layer. Soil shows an increase in sands (SL texture), marking a lithological discontinuity. OM and OC values almost double compared to the basal layer, while TP decreases sharply (Table 1; Supplemental Figs. 2c and d). Lithic artefacts slightly increase compared to Layer II (Supplemental Fig. 2a). This layer was dated to 7460 ± 30 BP (Beta-625030; *8.26-8*.35 cal *ka BP*) (surface of level 45, N profile) and 7070 ± 30 BP (Beta-633115; *7.97–7*.79 cal *ka BP*) (surface level 40, N profile).

Layer IV (N profile: ~172–204 cm, S profile:~190–210 cm) (Fig. 6). Texture change to LS. Soil colour is dark. OM and OC remain similar to the underlying layer, while TP slightly decreases (Supplemental Figs. 2c and d). Lithic artefacts increase slightly compared to the underlying layer (Supplemental Fig. 2a). This layer has a single date of 7130 ± 30 BP (Beta-633114; *8.02–7*.86 cal *ka BP*) (surface of level 33, N profile).

Layer V (N profile: ~148–172 cm, S profile:~34-24 cm) (Fig. 6). Similar texture to Layer IV (LS). Soil colour remains dark and has a similar pH. The TP reaches the second highest value in the stratigraphic sequence. This Layer also experiences an increase in values of OM and OC (Table 1; Supplemental Figs. 2c and d)). Lithic artefacts are more abundant compared to Layer IV (Supplemental Fig. 2a). This layer has two discordant dates: 5280 ± 30 BP (Beta-642566; *6.19–5*.93 cal *ka BP*) (surface of level 26) and 2500 ± 30 BP (Beta-642565; *2.73–2*.42 cal *ka BP*) (surface of level 29).

Layer VI (N profile: ~110–148 cm, S profile: ~118–144 cm) (Fig. 6). Texture turns to SL, with an increase in sands and a decrease in fine particles. Similar colour and pH to Layer V OM and OC decrease slightly. TP decreases sharply (Table 1; Supplemental Figs. 2c and d). This layer is characterised by a stone fill consisting of cobblestones, which is not observed in Unit 2. The density of lithic debris increases sharply (Supplemental Fig. 2a). Two radiocarbon dates are available for this layer: 1920 ± 30 BP (Beta 633113; *1.93–1*.73 cal *ka BP*) (surface of level 23) and 2470 ± 30 BP (Beta-633112; *2.71–2*.26 cal *ka BP*) (surface of level 15).

Layer VII (N profile: ~75–110 cm, S profile: ~82–118 cm) (Fig. 6). SL texture. Same colour as Layer VI. The soil is slightly more acidic. From the oldest to the more recent levels, OM and OC decrease, TP increases, and there is a sharp decrease in the density of artefacts (Supplemental Figs. 2a–d). This layer contains the oldest pottery of the unit. No radiocarbon dates were obtained from this layer.

Layer VIII (N profile: ~75 cm –*datum*, S profile:~82 cm –*datum*) (Fig. 6). The colour is slightly darker than Layer VII. SL texture. OM and

[1] This unsynchronised date is probably due to bioturbation.

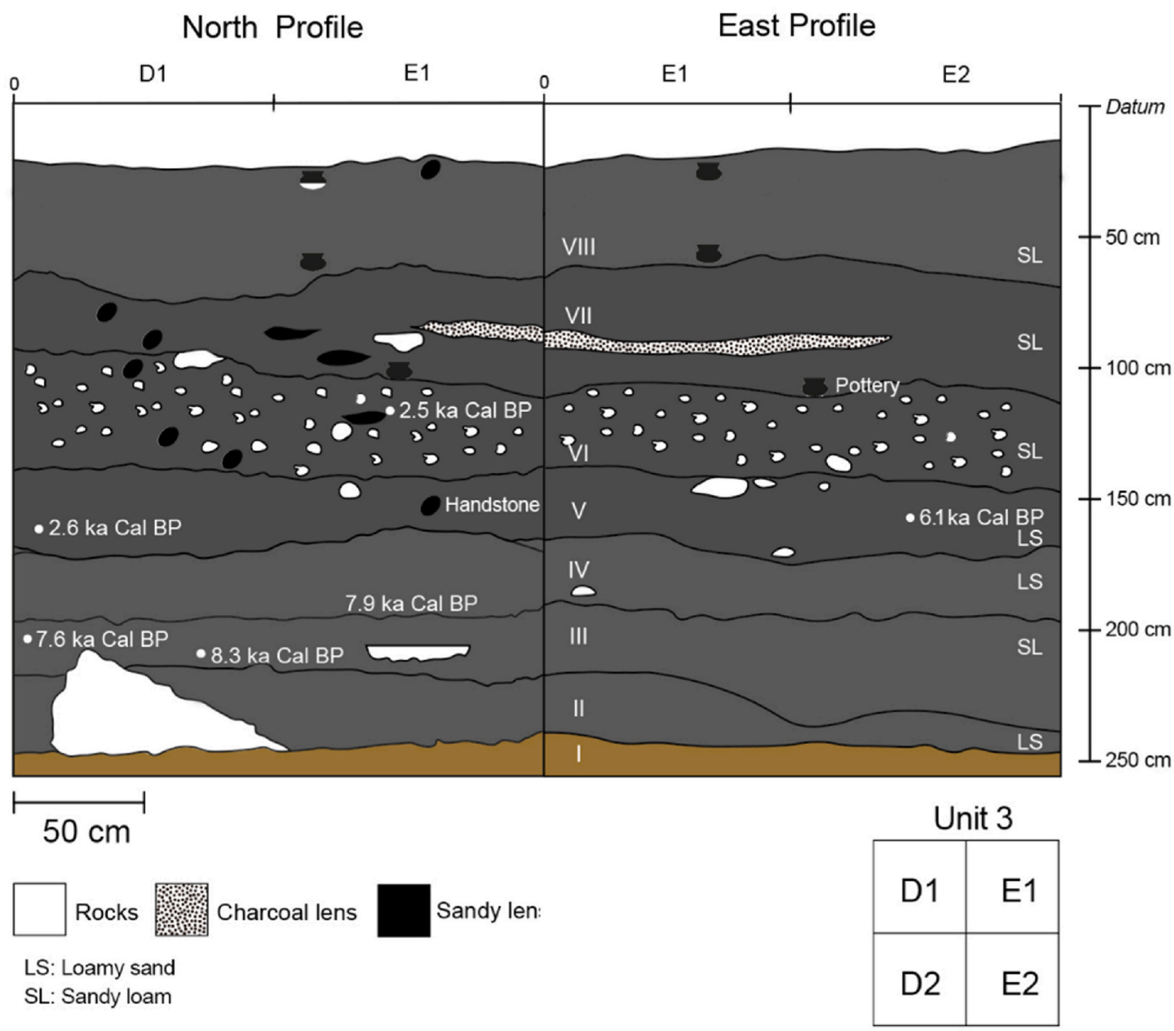

Fig. 6. Stratigraphy northern and eastern profiles. Unit 3. Cerro Montoya 1. Both profiles show the stratigraphic appearance of grinding hand stones and ceramic.

OC values increase considerably, and pH becomes very acidic at the top of the layer. TP increases from the base to the top (Table 1; Supplemental Figs. 2c and d)). This layer is also associated with the most recent ceramic occupations. In general, lithic artefacts sharply decrease, similar to Unit 2, and ceramics decrease slightly in relation to Layer VII (Supplemental Figs. 2a and b). No radiocarbon dates were taken from this layer.

3.1.1.3. Cerro Montoya 1 chronology and site formation processes. Chronologically, the period of occupation of Cerro Montoya 1 is ~*12.19 ka* (*Span Cerro Montoya 1, 12.06-12.33 ka*, 95.4 % hpd). Radiocarbon dates indicate the earliest occupation of Cerro Montoya 1 occurred by ~*12.*52 cal *ka BP* and archaeological abandonment happened after ~*0.*39 cal *ka BP* (Fig. 7a). The site was not constantly occupied, as shown by the discontinuous distribution of the radiocarbon dates. The SPD implies five phases of human activity, separated by chronological hiatuses (Fig. 7b). 1) ~*12.5* to *9.*9 cal *ka BP*; 2) ~*8.3* to *7.*5 cal *ka BP*; 3) ~*6.2* to *5.*9 cal *ka BP*; 4) ~*2.7* to *1.*4 cal *ka BP*; and 5) ~*0.48* to *0.*30 cal *ka BP.*

The homogeneity of lithological composition between layers

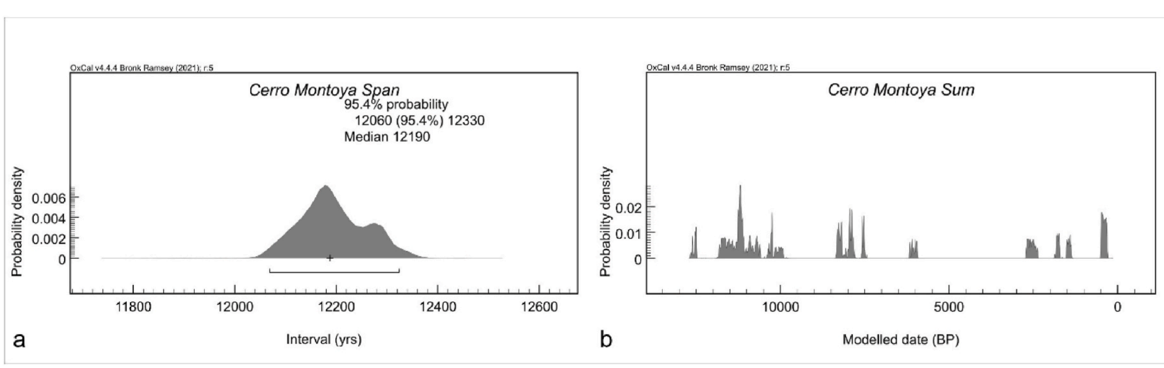

Fig. 7. Chronological model for the Cerro Montoya 1 rock shelter. A) Total duration of occupations; b) SPD showed the five moments of occupation.

demonstrates continuity in sediment formation processes; however, there are stratigraphic discordances, i.e. an absence of stratigraphic record shown in sedimentary and chronological hiatuses. In Unit 2, the first chronological hiatus is between ~*10.0* and *7.*8 cal *ka BP* (~*2.2 ka*), between ~144-34 cm below the *datum*. If we apply the observed sedimentation rate (78 yr/cm) *vs.* the expected one (20 yr/cm) (Supplemental Fig. 3a), a higher accumulation rate would be needed to explain the ~2000 years difference. The second hiatus is more pronounced, bracketed between ~*7.8* and *2.*0 cal *ka BP* (~*5.8 ka*); it occurs between ~134-20 cm depth, where again the deep gap indicates an irregular accumulation rate. In Unit 3 the hiatus occurs between ~*8.0* and *2.*0 cal *ka BP* (~*6.0 ka*), if we accept the intercalated date of ~*6.*0 cal *ka BP*, between ~186 and 171 cm below the *datum* (~10–12 cm depth) (Supplemental Fig. 3b). If we compare the observed sedimentation rate (~68 years/cm) *vs.* the expected rate (50 years/cm), a higher rate of accumulation would have been required, which indicates that the rate of accumulation was irregular at the site.

Two processes may explain these hiatuses: periods of site abandonment or erosion. The first is that the rate of sediment accumulation was unstable, because sedimentation processes were episodic, with periods of heavy sedimentation associated with human occupations interspersed with times of very low sedimentation associated with the abandonment of the site. The second hypothesis is that there was natural or anthropogenic erosion that affected the stratigraphic integrity of the site. Signs of erosion are not perceptible in the stratigraphy. For example, in the layers excavated in both units, we have not identified strong textural changes in the sedimentation regime, nor natural fills mixed with the occupation surfaces that would indicate physiogenic processes of post-depositional alteration. Nor are strong colour changes evident in the same stratigraphic unit, because of soil removal (Posada et al., 2010).

During the excavation of both units, multiple pre-ceramic and ceramic contexts or occupation surfaces were defined. In general terms, these occupation surfaces show good integrity, as indicated by the presence of hearths in different levels (23/21/18/16/5/7) (Supplemental Fig. 4) evidenced by thermal features (abundant charcoal) associated with stone circles, the re-fitting of flakes in two contexts, the layer of cobbles from Layer VI (Unit 3) or the recovery of an entire vessel from Layer VI (Unit 2). However, this does not mean that these surfaces have remained intact in the face of post-depositional processes, as suggested by the total absence of animal remains, which were preserved in other contexts like Cerro Azul, or the inversion of some radiocarbon dates. The latter indicates translocation processes in the soil, due to factors such as bioturbation or anthropic use of the space. In these sites, with space very restricted to the overhang of the shelter and regularly occupied, there is an increased likelihood of post and pre-depositional actions causing the mobility of small items (ecofacts and artefacts) due to the effect of anthropic reoccupation of the site or other natural causes.

In pedogenetic terms, Cerro Montoya 1 is a soil of sedimentary origin that has evolved in a series of very deep A horizons, melanised by the impregnation of organic matter in the soil mass (Flórez and Parra, 2001). The soil in both profiles is highly acidic (pH $\leq$ 5). The high acidity favours the concentration of Al and the loss of soluble bases, such as Ca, K, Mg, S, N, Zn, and Cu, because of the excess drainage of these soils (Posada et al., 2010). FE values (~35 mg/kg) were similar to the natural soil sample (34 mg/kg) (Palomares, 2021; Peña-Venegas and Vanegas, 2010; Sánchez, 2000).

OM, OC and TP values are good indicators of human activities (Holliday and Gatner, 2007; Zlateva et al., 2018). TP is an allopatric element that can enter soils through human activity (Holliday and Gatner, 2007; Peña-Venegas and Vanegas, 2010; Valdés, 1995). In addition, TP is also an indirect indicator of bone decomposition, since the inorganic matrix (hydroxyapatite) is one of the main sources of P in soils (Valdés, 1995). High TP values in Unit 2, together with soil acidity and high moisture, are three factors present at the site that could potentially explain the absence of animal remains (Kibblewhite et al., 2015), although this cannot be fully contrasted, since TP includes phosphates of both organic and inorganic origin (Holliday and Gatner, 2007).

Broadly speaking, in both units, with the exception of one sample from Unit 2, the OM and OC values throughout the stratigraphy are higher than the control sample adjacent to the site (OM, 1.35 %; OC, 0.78 %) and regional soils (~1.45 %), which we relate to the anthropogenic conditions under which the layers were formed (Palomares, 2021). Furthermore, a statistical correlation by Spearman's Rho coefficient of 0.964 with a P value less than 0.05, was found between OM and Al in unit 2, indicating that Al contributed to the stabilisation and fixation of OM in the soil (Posada et al., 2010). On the contrary, in unit 3 the Spearman correlation (0.560) was low, coinciding with slightly lower OM values. In both units, ceramic occupations show the highest percentage of OM and OC. This may be due to higher anthropogenic activity levels at the site, as well as the fact that they are the shallowest levels. These differences between units 2 and 3 in OM and OC are also observed in TP.

TP also shows anomalous values compared to the reference samples, especially in the inner sector of the shelter overhang (Unit 2). In Unit 2, the average value (8462 mg/kg) is much higher than that of the control sample (740 mg/kg) and reference values for Amazonian soils (~200 and 600 mg/kg) (Palomares, 2021). On the contrary, in the external part, although the average TP (868.4 mg/kg) is slightly higher than the values of the control sample, with the exception of three samples, the rest shows lower values (Table 1). This strong contrast is an indicator of a spatial use pattern of the shelter that is maintained throughout its occupation.

High TP values are related to multiple activities such as preparation (cooking), processing (animal butchering areas) and consumption of food, such as meat, fish, and plants (Barba and Ortiz, 1992; Holliday and Gatner, 2007). It is important to note that most of the hearths found are located in Unit 2. In contrast, the low TP values in Unit 3 suggest either that past activities were restricted to the inner sector of the shelter overhang, or that it was an area cleared of organic residues, like the transit areas (Barba and Ortiz, 1992). This contrast between the two areas is also reflected in the OM and OC values and the lithic artefacts, especially lithic debris that are much more abundant in the internal part, which corroborates the differences in the use of space in the rock shelter.

In summary, Cerro Montoya 1 shows a cultural stratigraphy, with a non-constant occupation of the site, exhibiting chronological and sedimentary hiatuses. The site shows a good integrity of the archaeological record and geochemical elements, such as TP, OM and OC show differences in the use of space that were maintained throughout the occupation of the shelter. Of course, the formation of the site was also subject to natural and cultural post-depositional disturbances, which may explain or be the cause of the absence of bone remains or the translocation of dates.

3.1.2. *Limoncillos*

The Limoncillos rock shelter is located 4 km from Cerro Azul. In 2018, a test pit excavated in front of some faded rock paintings, established there to be an intact stratigraphy with an initial late Pleistocene occupation. Three units have been excavated at Limoncillos, two under the overhang (Unit 4 and Unit 2) and one outside the rock shelter (Unit 3) (Fig. 8). Unit 4 is a cleaning of the profile of the test pit excavated in 2018 to collect new samples. Unit 2 (2 × 2 m) was also placed under the overhang. Unit 3 (2 × 2 m) was placed in the outer part of the rock shelter, about 3 m away from Unit 2, outside of the overhang.

3.1.2.1. Limoncillos – unit 4. This excavation unit measures 2 × 1 m and is an extension of the 2018 test pit, which yielded a basal anthropogenic date of 10340 ± 40 BP (Beta-509124; *12.47–11.*93 cal *ka BP*. In total, five broad strata, with internal occupation levels, were defined (Fig. 9a).

Layer I (~130–180 cm) (Fig. 9a). Lies on top of bedrock SL texture

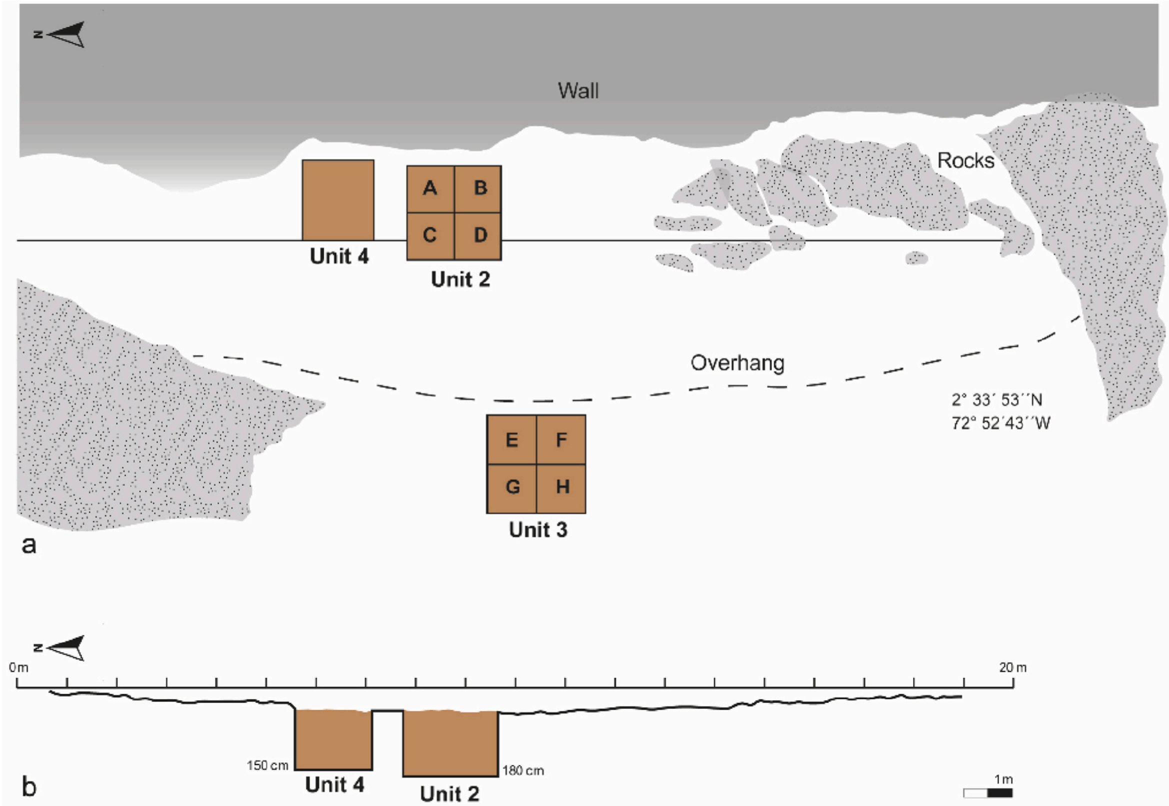

Fig. 8. Excavation plan Limoncillos. A) Excavated units; b) Topographic profile N–S.

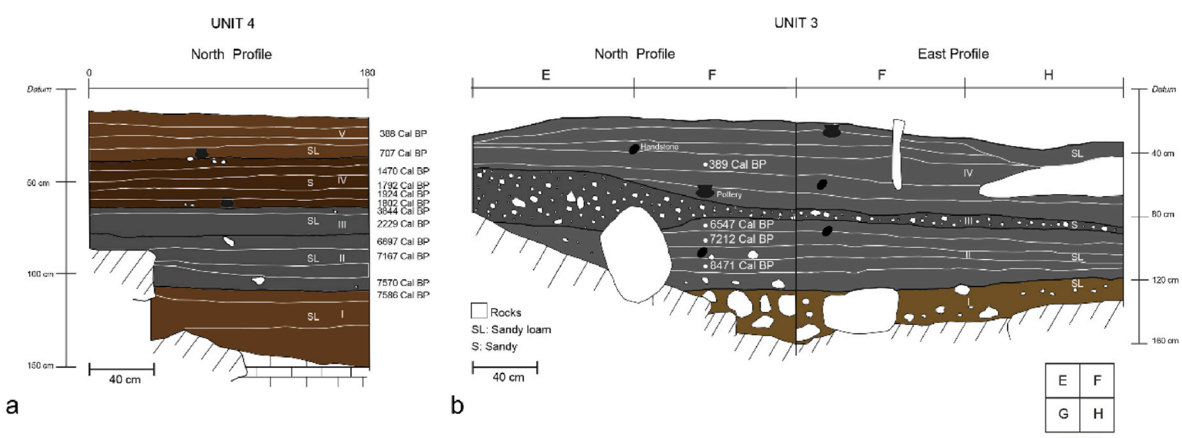

Fig. 9. Limoncillos stratigraphic profiles. A) North profile of Unit 4; b) North and east profiles of unit 3. Both profiles show the appearance of pottery and in Unit 3 the grinding hand stones.

Table 2
Physico-chemical characteristics of the stratigraphic layers of Limoncillos.

			%					%		mg/kg	
Unit	Layer	Colour	Sand	Silt	Clay	Texture	pH	OM %	OC %	TP	FE
4	I	5 YR 4/3	79	14	7	SL	5.1	0.61	0.36	3458	104
	II	7.5 YR 2.5/2	83	10	7	SL	5.2	1.27	0.73	6217	302
	III	7.5 YR 2.5/2	87	8	5	SL	5.1	2.22	1.29	6811	243
	IV	10YR3/3	89	6	5	S	5.5	1.48	0,86	3388	191
	V	10YR4/3	85	8	7	SL	5.4	1.55	0.90	8836	99
3	II	10YR2/2	85	10	5	SL	4.6	2.32	1.34	9500	103
	III	10YR2/1	89	6	5	S	4.8	1.57	0.92	14.215	51
	IV	10YR2/2	82	10	8	SL	4.3	2.55	1.48	1610	62

reddish brown colour and acidic. Values of OM and CO are lower than in natural soil. High TP which is much higher than the control sample (349 mg/kg) (Table 2; Supplemental Figs. 5a and b). A date of 6720 ± 30 BP (Beta-642569; *7.67–7.*50 cal *ka BP*) was obtained on the upper part (surface of level 17).

Layer II (~90–130 cm) (Fig. 9a). SL texture is similar to Layer I. Very dark brown colour, and acidic soil similar to layer I, with a significant increase in OM and OC compared to Layer I. TP increases strongly (Table 2; Supplemental Figs. 5a and b). The layer dates to the mid-Holocene: 6700 ± 30 BP (Beta-642570; *7.62–7.*48 cal *ka BP*) (level 16), 6240 ± 30 BP (Beta-642569; *7.26–7.*00 cal *ka BP*) (level 14), and 5870 ± 30 BP (Beta-642572; *6.78–6.*56 cal *ka BP*) (level 14) (Fig. 9a).

Layer III (~72–90 cm) (Fig. 9a). SL texture with a slight increase in sands. Same pH as layer II, while OM and OC increase (Table 2; Supplemental Figs. 5a and b). The layer has two inverted late Holocene dates: 2210 ± 30 BP (Beta-642573; *2.33–2.*11 cal *ka BP*) (level 12) and 3550 ± 30 BP (Beta-642574; *3.96–3.*71 cal *ka BP*) (level 11).

Layer IV (~40–72 cm) (Fig. 9a). Sandy (S) texture showing an increase in sands, while OM, OC and TP decrease (Table 2; Supplemental Figs. 5a and b). Three dates from the late Holocene show inversions: 1900 ± 30 BP (Beta-642575; *1.89–1.*72 cal *ka BP*) (level 10), 1990 ± 30 BP (Beta-642576; *2.00–1.*83 cal *ka BP*) (level 9), 1890 ± 30 BP (Beta-642577; 1.89–1.72 cal *ka BP*) (level 8) and 1600 ± 30 BP (Beta-642578; *1.54–1.*39 cal *ka BP*) (level 7). Between layers III and IV there is a clear chronological discordance, also manifest in this case in the geochemical values and in the colour (Dark yellowish brown).

Layer V (~40 cm –*datum*) (Fig. 9a). SL texture with a decrease in sands. Brown soil colour. Compared to Layer IV, pH, OM and OC are similar, while TP shows a sharp increase (Table 2; Supplemental Figs. 5a and b). Level 5 was dated at 800 ± 30 BP (Beta-642579; *0.74–0.*66 cal *ka BP*) and Level 3 at 330 ± 30 BP (Beta-642580; *0.47–0.*30 cal *ka BP*).

3.1.2.2. Limoncillos – unit 3. Four strata with their different human occupations were defined in Unit 3. Layer I (bedrock/~155 cm) (Fig. 9b). The unit is dominated by a large boulder that slopes from ~61 cm below *datum* in the north, to ~110 cm in the south. The boulder continues below the level of the basal rocks of the bedrock. No artefacts were recovered in association with the rocks, suggesting these were not exposed when the first humans occupied the area.

Layer II (~74–110 cm) (Fig. 9b). This layer is restricted to the eastern profile, bounded by a large boulder that occupies a large part of the unit. SL texture. Very dark colour and acidic. OM and OC values above the natural soil of the area (OM, 1.69 % and OC, 0.98 %). The TP is much higher than the natural soil (349 mg/kg) (Table 2; Supplemental Figs. 6c and d). Three dates were obtained from this level: 7690 ± 30 BP (Beta-642555; *8.55–8.*40 cal *ka BP*) (surface of level 18) associated with a lithic assemblage of chert flakes resembling a lithic cache, 6300 ± 30 BP (Beta-642556; *7.31–7.*15 cal *ka BP*) (surface of level 17), and 5750 ± 30 BP (Beta-642557; *6.64–6.*44 cal *ka BP*) (surface of level 15).

Layer III: (~65–74 cm) (Fig. 9b). Gravel and a small rock layer cover the surfaces of this layer. The matrix covers the large boulder and appears to be a construction fill, atop of which a sediment surface was laid. Dating of charcoal from the gravel layer may be complicated by the presence of midden fill, which can contain debris and trash from older contexts. Therefore, any charcoal within the gravel layer may not be *in situ*. S texture OM and OC decrease. TP is very high (Table 2; Supplemental Figs. 6c and d).

Layer IV (~65 cm depth –*datum*) (Fig. 9b). SL texture and the most acidic of this unit. OM and OC increase again with values similar to the older occupations. TP is the lowest in the unit, indicating a change from the underlying layer (Table 2; Supplemental Figs. 6c and d). Surface of level 5 was dated at 340 ± 30 BP (Beta-642558; *0.48–0.*31 cal *ka BP*).

3.1.2.3. Limoncillos chronology and site formation processes. Similar to Cerro Montoya 1, the archaeological layers were formed above a stratum of angular stone blocks amid sandy sediments accumulated on the underlying rock of the rock shelter. The soil is largely homogeneous across the stratigraphy and is characterised as moist, sandy, acidic, well-drained, with low soluble bases and high in Al.

Chronologically, the period of occupation of Limoncillos is *~11.70* ka (*Span Limoncillos, 11.51–12.08 ka,* 95.4 % hpd) (Fig. 10a), but with a discontinuous distribution, which indicates that the occupation of this shelter was not constant. It exhibits large intervals without dates that *a priori* are interpreted as periods of abandonment of the shelter. Except for the extreme date of 10340 ± 40 BP (Beta-509124; *12.47–11.*93 cal *ka BP*), the two main occupation intervals of Limoncillos coincide with Cerro Montoya 1. The first corresponds to the middle Holocene, between *~8.3* and *6.*5 cal *ka BP*. The second between *~2.5* and *0.*3 cal *ka BP* corresponds to the late Holocene. The first chronological interval of Cerro Montoya 1 is not present at Limoncillos (Fig. 10b). Both sites, just 2 km apart, are broadly contemporaneous and exhibit similar archaeological sequences.

Similar to Cerro Montoya 1, at Limoncillos there are stratigraphic discordances, because the depositional rate was not constant. In Unit 4, the hiatus (*~2.8 ka*) occurs between ~80 and ~70 cm depth, which according to the calculation of the expected rate (100 yr/cm) *vs.* the observed rate (280 cm/year), sedimentation should be larger than the 10 cm observed in the stratigraphy (Supplemental Fig. 7a). In Unit 3, the case is similar, with a hiatus of *~6.4 ka*, for an observed accumulation rate of 152 yr/cm *vs.* the expected rate of 100 yr/cm, although in this case the difference is smaller, bringing both observed and expected rates closer together (Supplemental Fig. 7b).

At Limoncillos, the excavation units exhibit differences in their soils' chemical elements composition. In Unit 4, in the inner part of the overhang, OM and OC values are generally lower than the control sample (1.69 %), except for level 12, with values above 2 %. However, the high Fe values found throughout the layers are remarkable, with an average of 188 mg/kg, significantly higher than the control sample (25.94 mg/kg) (Supplemental Fig. 5c). TP also shows high values (average 5742 mg/kg), above the control sample (349 mg/kg). This unit was the only one with a less acidic pH (~5). In Unit 3, OM and OC values tended to be higher than in Unit 4, and there is a strong correlation between OM and OC values and Al and TP, with Spearman correlation coefficients of 0.97 and 0.98, with a P-value less than 0.01, respectively. In this unit, the soil is slightly more acidic with a pH below 5, similar to Cerro Montoya 1. TP values throughout the sequence are very high, averaging 6733 mg/kg. In the outer part of the rock shelter overhang, the Fe values were lower, with an average of 69 mg/kg, which is still high compared to the control sample.

These data show that the contrast between the inner and outer areas is less pronounced in Limoncillos compared to Cerro Montoya 1, suggesting different use of space in the two shelters. For example, TP values are high in both units, indicating that the activities that generated high TP values were not restricted to a particular part of the shelter. However, they were slightly higher in the outer part. At Limoncillos, unlike Cerro Montoya 1, the highest TP value of the whole series (~14,000 mg/kg) is associated with the layer of stones. Like in Cerro Montoya 1, this human-made feature is associated with the stratigraphic unit that marks the transition with the ceramic occupations. A characteristic feature of this shelter is the high Fe values compared to the control sample and the average values of Cerro Montoya 1 (35 mg/kg). One way to explain this anomaly is that high values of Fe in Limoncillos could be related to the processing of mineral ochre rich in haematite.

3.2. Chronological framework for the serranía de La lindosa

The SLL chronological sequence, based on 62 radiocarbon dates from five rock shelters, covers ~12.3 thousand years of human history ranging from the Younger Dryas (YD) period to the 17th century CE (late Holocene) (Fig. 11).

The first phase (17 radiocarbon dates) corresponds to the arrival of

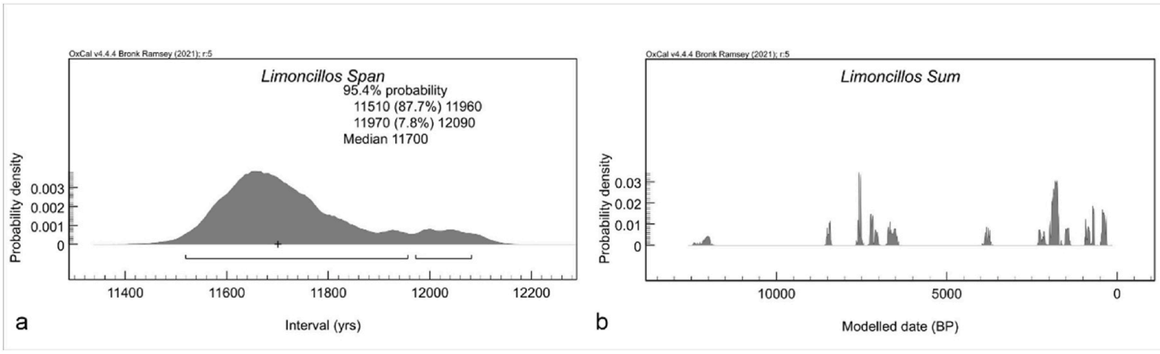

Fig. 10. Chronological model for the Limoncillos rock shelter (a) The total duration of occupations; (b) SPD showed the moments of occupation.

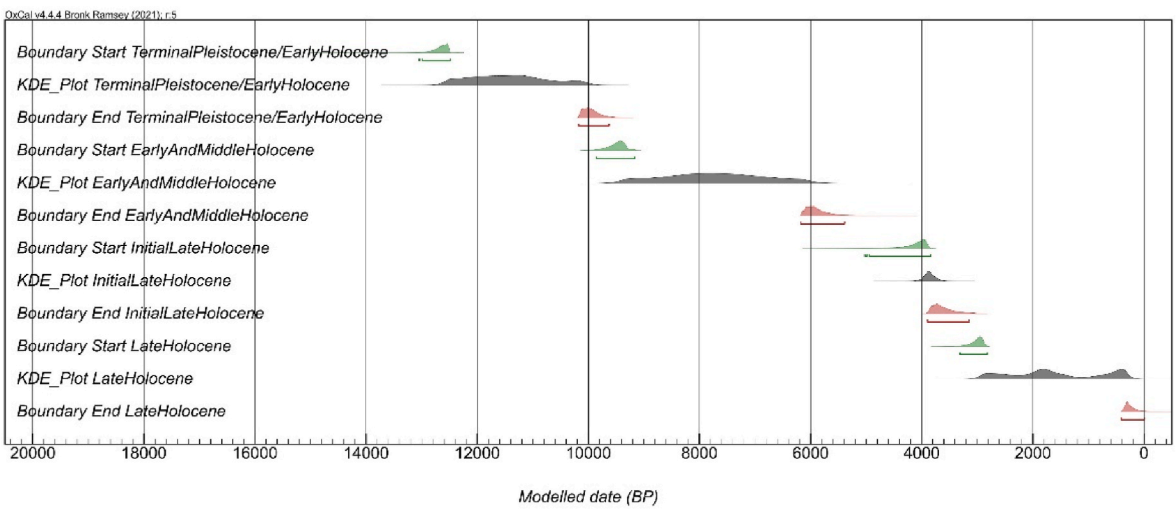

Fig. 11. OxCal Plot showing the chronological sequence, indicating the start and end and the KDE and SPDs (sum) for each phase.

the first human groups in the SLL. The model projects an onset between *12.99–12.*48 cal *ka BP* (median *~12.*63 cal *ka BP*) during the YD. This first phase ends in the early Holocene between *10.18–9.*63 cal *ka BP*, with a duration of *~2.45 ka*.

The hiatus between Phase 1 and 2 lasted *~0.46 ka* (0.0*2–0.79 ka, 95.4 % hpd*). The second phase (18 radiocarbon dates) which corresponds to the early and middle Holocene, began between *9.86–9.*17 cal *ka BP* and ended between *6.18–5.*38 cal *ka BP*, lasting *~3.25 ka*.

Following a hiatus of *~1.79 ka* (*0.78–2.26 ka*, 95.4 % hpd), Phase 3 (3 radiocarbon dates) began between *4.97–3.*83 cal *ka BP*. This is the shortest occupational phase, coinciding with the initial late Holocene and lasting *~0.17 ka*.

Finally, Phase 4 (24 radiocarbon dates) began between *3.28–2.*81 cal *ka BP*, following a hiatus of *~0.64 ka* (*0.10–0.97 ka,* 95.4 % hpd). This phase of occupation continued for *~2.56 ka* until *~0.*27 cal *ka BP*, coincident with the period of European conquest.

In summary, the radiocarbon dates obtained in five rock shelters have allowed us to define a *~12.3 ka* chronological sequence for the SLL, disrupted by several hiatuses, which we have divided into four phases from the YD to the late Holocene (Fig. 12).

4. Discussion

4.1. Site formation processes

The excavation of Cerro Montoya 1 and Limoncillos reveals multicomponent stratigraphies. Radiocarbon dates indicate that both sites were occupied since the late Pleistocene, albeit not continuously. Both sites exhibit stratigraphic discordances, associated with non-constant accumulation rates. This may indicate two scenarios: a) sediment erosion or b) low sedimentation rates in the absence of human occupation. The fact that the same phenomenon is repeated at both sites

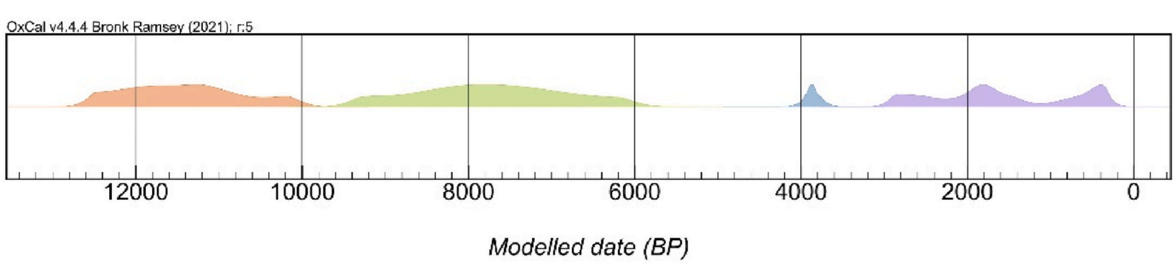

Fig. 12. OxCal Plot stack graph showing a summary of the chronological sequence of the SLL showing the four phases defined by KDE.

leads us to favour the hypothesis of low sedimentation rates associated to moments of abandonment of the site or short-lived occupations.

The stratigraphy of both sites was formed by the accumulation of largely quartzite sandy sediments that originate from the sandstone outcrops and base geology surrounding the sites, separated by identifiable occupation surfaces. Both sites show a stratigraphic sequence formed by the superposition of black, sandy, moist, very acidic, base-poor soils with high Al values, which are correlated with high OM and OC values. These soil characteristics are common to the pedogenesis of the soils in the area.

Importantly, some soil traits, such as high values of OM, OC, and particularly TP compared with natural soils samples, are associated with the human occupation of the rock shelters. TP is one of the most reliable chemical elements for the identification of areas of activities related to the processing of food and especially animals (terrestrial and aquatic) (Holliday and Gatner, 2007; Kulkova, 2022; Zlateva et al., 2018). TP is the element with the highest values in comparison with the natural soils (control samples), except some samples for Unit 3 of Cerro Montoya 1. In turn, the high TP values, together with being moist and very acidic soils, at these sites is likely related to the decomposition of bone remains.

Activity patterns, artefact discard, and soil chemistry indicate that both rock shelters were used as domestic spaces through time. In addition to the differences in the distribution of the radiocarbon dates' curves, there are dissimilarities in soil chemical elements, as well as density of lithic and ceramic artefacts. In general, Cerro Montoya 1 maintains a similar pattern throughout the stratigraphic sequence. In the inner part of the rock shelter overhang, hearths are concentrated (N = 7), which coincides with the highest TP values and the highest density of lithic and ceramic artefacts. In the outer part of the rock shelter overhang, the frequency of lithic artefacts, ceramics, number of hearths (N = 2) and the TP values were lower across the entire stratigraphic sequence. In the outer part of the overhang, the most relevant change in the stratigraphic sequence is the stone fill (Layer VI), which marks the transition to the ceramic occupations of the site. The stone fill is anthropic, but its function is unclear. One possibility is that they represent stone ovens commonly found in early sites in the Americas (e.g., Black and Thorns, 2014). However, the TP value is very low, as are the K values (0.02 cmol(+)/kg), a chemical component that increases in soils with ash (Bintliff and Degryse, 2022; Kulkova, 2022). K values in the stone fill were similar to the control samples (0.01 cmol(+)/kg). Likewise, the pH value remains low, contrary to what happens in the hearths where pH increases due to ash and charcoal concentrations (Braadbaart et al., 2020; Muñoz and Chacama, 2007). The low TP, K, and pH values do not allow us, *a priori*, to associate the stone fill with an area of food preparation and consumption.

Limoncillos shows relevant differences in some of the soil elements and distribution of artefacts that indicate a different occupation pattern than Cerro Montoya 1. At Limoncillos the highest frequency of lithic artefacts was recovered in unit 3, while ceramics were slightly more abundant in unit 2. The TP values were high both in the internal and external part of the rock shelter overhang. Contrary to Cerro Montoya 1, the highest values were found in the external part of the shelter and are associated with the stone fill (Layer III), a feature that was also found in Cerro Montoya 1 in the same stratigraphic position, below the ceramic layers. In Limoncillos, the K values (0.02 cmol(+)/kg) were also low and the soil continues to be acidic. Therefore, we cannot associate the stone fill with a hearth area either. Due to the high TP values, we suggest that the stone fill is likely related to a food consumption area or trash dump area (Muñoz and Chacama, 2007). The other difference in elements present in the soil is the high levels of Fe compared to the control sample, which could be related to intense ochre preparation at this site. Macrofragments of ochre pigments (0.5–50 mm) were recovered in all levels at both sites, but the average values of Fe from Cerro Montoya 1 (34.2 mg/kg) were similar to the natural soil adjacent to the site (34.02 mg/kg).

In summary, the stratigraphy of both sites shares common features (natural and anthropic) but there are differences that indicate different occupation patterns at each site, which will be a matter of future research.

4.2. Phase 1: late pleistocene-early holocene (12.6–10.0 cal ka BP)

4.2.1. Chronology

The earliest dating established at three distinct rock shelter sites indicates that human groups arrived at the SLL between approximately *13.00–12.*50 cal *ka BP* (*median* ~*12.*63 cal *ka BP*).

4.2.2. Paleoenvironment

Palaeoclimate records show that the Last Glacial Maximum (LGM) (23-19 cal ka BP) was a pronounced cold/dry episode (Urrego et al., 2009) with temperatures approx. 7.8 °C lower in the northern Andes and 3–5 °C lower at sea level, while sea levels were 120 m lower than today (Groot et al., 2011). Following the LGM, gradual warming was punctuated by an abrupt cold/dry episode between ~17 and 16 ka BP corresponding to the H1, and the Bølling-Allerød warm period between ~14 and 12.8 ka BP (Van Der Hammen and Hooghiemstra, 1995). A rapid return to glacial conditions during the YD period saw temperatures across the Neotropics at least 6 °C lower and precipitation reduced by about 30–50 % compared to late Holocene conditions (Piperno, 2011). Regional studies indicate a shift from cool, wet YD conditions to a warmer climate and moderately dry early to middle Holocene for the Colombian Andes and for western Amazon (Cheng et al., 2013; Muñoz et al., 2017).

Currently, there is no palaeoenvironmental evidence specific to the SLL area, and relying on regional records alone cannot accurately capture the unique ecotonal characteristics of the SLL. The pollen record of Loma Linda, in the edaphic savannahs of the Colombian Llanos, ~150 km to the north of SLL, shows the presence of grass savannah with gallery forest since the oldest extrapolated dates of the core, ~9.6 cal ka BP (Behling and Hooghiemstra, 2000). To the southeast, in what is today a tropical evergreen forest, in the Middle Caquetá River, the Pantano de Mónica pollen record shows the presence of evergreen tropical forest with a few Andean elements since the earliest extrapolated date of 11.15 ka BP (Behling et al., 1999).

The macrobotanical record from the SLL excavations provides insight into local plant availability (Morcote-Ríos et al., 2021). Charred palm remains are present from the start of human occupation, including *Astrocaryum chambira*, *Attalea maripa* and *Attalea racemosa*, *Bactris* sp. and *Syagrus orinocensis*. These species of palm can currently be found growing in various locations in the region, such as *terra firme*, seasonally flooded *varzea* forests, and rocky outcrops of the Guiana Shield. Remains of *Mauritia* sp. likely *M. flexuosa* and *M. carana* were also identified. These species are commonly found in areas that are permanently or periodically flooded, as well as near small streams (Galeano and Bernal, 2010; Henderson et al., 2019). *Brosimum* cf. *lactescens,* which currently grows in *terra firme* forests of Amazonia (Berg, 1972), has also been identified in the early archaeological contexts. Collectively, the macro-botanical assemblage from the earliest levels of these rock shelters indicates that tropical forest elements were established within the SLL at the time of human arrival; however further research is required to precisely establish the palaeoenvironmental conditions and the boundaries of the ecotone during the occupation sequence.

4.2.3. Settlement pattern

At present, the early sites in SLL are limited to rock shelters. However, it is important to acknowledge that our survey efforts have focused on rock shelters, and the preservation and identification of open-air sites is extremely challenging. The variations in the archaeological record indicate differences in the activities carried out at each of the sites. Broadly speaking, SLL contains small sites located in different sectors of the landscape.

Cerro Azul and Limoncillos are located at rock shelters featuring even surfaces situated on the hillsides of *tepuis*, while Cerro Montoya 1 and Casita de Piedra are located in the foothills of the *tepuis*, which in some way, pending analysis, determined the activities carried out at each site, as part of an integrated natural resource management strategy (biotic and abiotic).

4.2.4. Subsistence

Our previous analysis of plant and animal bone from the excavations at Cerro Azul show that the early settlers of SLL had a generalised subsistence economy. Plant remains reveal the consumption of a diversity of palms, including *Astrocaryum chambira*, *A.* sp., *Attalea racemosa*, *A. maripa*, *Euterpe precatoria*, *Mauritia flexuosa*, *Oenocarpus bataua*, *Syagrus orinocensis*, *Socratea exhorriza*, and *Bactris* sp., from the time of the initial occupation (Morcote-Ríos et al., 2021; Robinson et al., 2021). The diet of the early inhabitants of SLL was complemented by a diversity of animals (Morcote-Ríos et al., 2021). Fish included cachama (*Piaractus* sp.) and piranha (*Pygocentrus* sp.). Mammals such as deer (Cervidae), agouti (*Dasyprocta* sp.), capybara (*Hydrochoerus hydrochaeris*), and armadillo (*Dasypus* sp.) were also consumed. Reptiles included turtles (Testudines), iguanas (*Iguana* sp.), snakes (Boidae and Viperidae), crocodiles and caimans (Crocodylia). The diverse zooarchaeological assemblage indicates the management of a broad spectrum of animals associated with different ecosystems that converge in the SLL.

This generalised economy is similar to other late Pleistocene sites across the Amazon. For example, Caverna da Pedra Pintada shows the consumption of tree and palm fruits, including *Hymenaea*, Brazil nut (*Bertholletia excelsa*), *Sacoglottis guianensis*, *Talisia esculenta*, *Mouriri apiranga*, *Coccoloba pixuna*, and muruci (*Byrsonima crispa*), *Attalea macrocarpa*, *A. spectabilis* and *Astrocaryum vulgare* (Roosevelt et al., 1996). Similar records of tree and palm fruits, along with small animals and fish, are recorded in early Holocene contexts at Gruta do Gavião associated with nut-breakers ~11.6–8.5 cal ka BP (Magalhães et al., 2019). A broad-spectrum diet of river fauna and forest tree fruits is recorded at the Itaparica Tradition sites dating to the early Holocene, ~13-11 cal ka BP (Schmitz et al., 2004) along the Cerrados in the southern rim of the Amazon.

4.2.5. Material culture

4.2.5.1. Lithics. The lithic assemblages of SLL are composed of cores, debris, unifacially retouched and non-retouched tools, with a microlithic tendency, mostly manufactured in chert and to a lesser extent quartz, which were both locally sourced. In addition, lithic technology includes plant-processing tools (handstones) which appear from Phase 1 at Cerro Montoya 1 (early Holocene). Unlike Pedra Pintada, which contains both unifacial and bifacial technology elements (Rodet et al., 2023; Roosevelt et al., 1996), only unifacial lithic assemblages constitute the SLL. Also contrasting with the early sites on the montane forests of the Cauca River or the Middle Caquetá River, the SLL material repertoire does not exhibit waisted hoes or axes, so typical of the early records of the aforementioned regions. On the other hand, the predominance of charred palm remains from the earliest human occupation of these sites indicates the potential role of perishable wood and fibre-based technologies (Ford, 2017). The more detailed analysis of plant remains, animal bones and stone tool technology from Limoncillos and Montoya 1 is currently underway and will be the subject of future research outputs.

4.2.5.2 Rock art. Rock art, in the form of both paintings and engravings, is ubiquitous in the Colombian Amazon. The SLL is characterised by the diversity and quantity of rock painting throughout the entire extension of the hill chain (Supplemental Fig. 8). All sites dating to the late Pleistocene at the SLL contain ochre pigments since the earliest levels of human occupation. Ochre tablets with evidence of grinding and rubbing have been recovered in contexts dating to 10.050 ± 40 (Beta-625037; *11.75–11.*32 cal *ka BP*). A fragment of exfoliated rock wall exhibiting traces of ochre paint has been recovered in Cerro Montoya 1 in a context dated to circa 9150 ± 30 (Beta-625033; *10.41–10.*22 cal *ka BP*) providing evidence that humans were using ochre to paint the walls of this rock shelter at least since this time. We have also suggested that some paintings could be representations of the large Ice Age mammals that became extinct by about 10.0 ka BP (Iriarte et al., 2022a). Direct dating of the paintings is needed to confirm these hypotheses. If these early dates are confirmed, SLL walls could well record the origins of an Amazonian cosmovision and way of viewing and living in the world. This may well be the beginning of a very Amazonian tradition of 'writing in the landscape', a way of embedding history and cosmological conceptions in the landscape (Santos-Granero, 1998). These findings should not come as a surprise since numerous late Pleistocene/early Holocene archaeological sites across South America occur in rock shelters associated with rock paintings that include naturalistic images of animals, geometric designs and hand negatives (Iriarte et al., 2022b; Prous, 2012; Troncoso et al., 2017). A detailed description of these materials will be provided in a forthcoming article.

4.2.6. Routes of human dispersal in the colombian amazon

Given the presence of humans in the cool rainforests of south-central Chile by at least ~14.6 cal ka BP (Dillehay, 2000; Pansani et al., 2023), ~12.1 cal ka BP in the highlands of Peru (Rademaker et al., 2014), and possibly between ~23.1 and 18 cal ka BP in the Cerrado' savannahs along the southern rim of the Amazon (Boëda et al., 2014; Vialou et al., 2017), it is probable that people arrived to northwestern South America well before 15 ka BP and by 13 ka BP human groups had adapted to a diversity of environments and exhibited distinct lithic technologies (Dillehay, 2000).

Multiple human dispersals across what is today Colombia, including the settlement of the SLL, occurred during the YD period (Aceituno and Uriarte, 2019; Aceituno et al., 2013). Based on geographical proximity, a similar unifacial lithic technology, and the presence of pictographs (Tequendama and El Abra) the Bogota plateau is a potential place of origin for the SLL settlers. Archaeological sites, such as El Abra and Tibitó, date back to ~15 ka BP, share an unifacial lithic tradition lacking projectile points and are just ~330 km from the SLL (Correal, 1982, 1993; Correal et al., 1977). The middle Magdalena River chert lithic tradition, associated with lowland and riverine environments dating to around 12.5 ka BP, could be another potential place of origin (López, 2019). The many watercourses that originate in the eastern Andean cordillera later becoming large tributaries of the Orinoco River, such as the Guayabero and Ariari rivers, may have facilitated the descent of these forager groups into the lowlands of Colombia.

In the Amazonian and Orinoco lowlands, there are neighbouring more recent (early Holocene) sites that share common elements but whose geographic connection is still unknown. The Gavilán 2 rock shelter, located northeast of SLL in the middle Orinoco region of Venezuela, dates to around 10.4 cal ka BP. Gavilan 2 has similar lithic technology, plant and animal remains reflecting a generalised economy and is also associated with rock paintings (Scaramelli and Scaramelli, 2017). To the south of SL, along the Caquetá River is the Peña Roja site, dated ~10.4 cal ka BP (Mora, 2003), which contains similar unifacial technology with plant-processing handstones and where thousands of palm seed fragments were recovered as at SLL. It is also important to note that the SLL dates are broadly contemporaneous with the early tropical forest occupation at Caverna da Pedra Pintada in the lower Amazon at ~13.1 cal ka BP (Roosevelt et al., 1996), and Manachaqui cave in the montane forest of Peru which dates to ~12.2 cal ka BP) (Church, 2021).

4.3. Phase 2: early to middle-holocene (9.5–5.9 ka cal BP)

4.3.1. Chronology

Phase 2 shows a very good continuity with the first phase and is associated with the early and middle Holocene (*~11.7 and ~6.*0 cal *ka BP*). The end of this phase concludes with a significant hiatus in the chronological sequence.

Like the SLL, some parts of Amazonia with early human occupations experienced gaps in occupation during the mid-Holocene. This is the case, for example, between about the seventh and the fourth to second millennium BP in the Central Amazon (Neves, 2007), Lower Amazon (Gomes, 2011), and the Cerrados of Central Brazil (Araujo et al., 2005). A recent analysis of archaeological radiocarbon (Riris and Arroyo-Kalin, 2019) suggests a decline in population throughout South America, including Amazonia, after 8.6 cal ka BP. These authors (Riris and Arroyo-Kalin, 2019) note that this population decrease is coeval with the onset of more arid conditions and marked precipitation variability across South America (Deininger et al., 2019). Several factors may be responsible for the decline in radiocarbon dates in these regions, including lack of archaeological work, geomorphic processes such as a very dynamic late Holocene that may have buried sites under alluvium (Lombardo et al., 2019), and rising middle Holocene sea levels that may have covered low-lying archaeological sites. Regardless, these hiatuses are not widespread. Other regions of Amazonia and tropical South America, such as sectors of the Bolivian and Brazilian Amazon (Lombardo et al., 2020; Pugliese et al., 2018) and NW South America show continuous occupations. At present, the lack of palaeoclimate and palaeoenvironmental data at a regional scale in the SLL prevents us from examining the role that climate change may have played in these local hiatuses. Understanding why people abandoned these rock shelters for thousands of years during the mid-Holocene will be an important topic for future research.

4.3.2. Paleoenvironment

The early to middle Holocene is the driest period in the Amazon since humans arrived in the basin (McMichael and Bush, 2019). However, recent data suggests that the decrease in precipitation in the western Amazon was less severe compared to the eastern Amazon (Cheng et al., 2013). For this period, the Laguna Loma Linda pollen record indicates a dry period and more extensive savannahs than at present (Behling and Hooghiemstra, 2000). Preliminary analysis of the macrobotanical remains from the rock shelters does not show any changes in the identified taxa that could be related to changes in vegetation around these sites.

4.4. Phase 3: initial late holocene (4.1–3.7 cal ka BP)

4.4.1. Chronology

Between the second and third phases, the sequence shows a break in the archaeological record of about ~*1.79 ka (0.76–2.26 ka,* 95.4 % hpd*)* for which we do not know the reasons at present.

4.4.2. Palaeoenvironment

In environmental terms, the end of Phase 2 (middle Holocene) coincided with a regional shift towards wetter conditions (Behling and Hooghiemstra, 2000) that is accentuated during the last 4000 years (late Holocene), when the climate throughout Amazonia was wetter than during the early and middle Holocene (Behling and Hooghiemstra, 2000; Della Libera et al., 2022; McMichael and Bush, 2019). The Laguna Loma Linda pollen record agrees with these data, as it generally shows a continuous expansion of tropical forest from ~3.59 ka BP to the present, indicating wetter climatic conditions (Behling and Hooghiemstra, 2000).

4.5. Phase 4: late holocene (3.0 cal ka BP-1680 CE)

4.5.1. Chronology

Phase IV shows good continuity with Phase 3, representing the late Holocene and the appearance of ceramics. In both Limoncillos and Cerro Montoya 1, the first ceramics appear in the levels above the layer of stones. Interpretation of these rock layers is not straightforward. One possibility is that these stone layers are the remains of stone ovens so common across lowland South America (e.g., Iriarte et al., 2008).

4.5.2. Palaeoenvironment

Although in general terms they coincide with a wetter climate, the beginning of this phase at the global Amazonian level occurred under drier conditions, between approximately 1.25–0.75 ka BP (~700 and ~1200 CE) (Della Libera et al., 2022), although the Loma Linda column does not show such conditions (Behling and Hooghiemstra, 2000).

4.5.3. Settlement pattern

During this period, we have the first evidence of open-air habitation contexts, associated with Amazonian Dark Earths, located in the foothills of the rocky outcrops (Finca Limoncillos). These sites date between *2.70–2.*34 cal *ka BP* and are associated with lithics, ceramics, carbonised palm seeds and maize phytoliths (Kosztura, 2020).

4.5.4. Subsistence

Preliminary analysis of plant remains shows that maize cultivation is very recent. Maize macro remains were recovered from Phase 4, associated to the dates 410 ± 30 BP (Beta-625026; *0.52–0.*32 cal *ka BP*) and 360 ± 30 BP (Beta-625028; *0.49–0.*31 cal *ka BP*). These dates are several millennia later than the earliest evidence of maize (pollen) in the Colombian Amazon, with a date of ~*5.*5cal *ka BP* (Mora et al., 1991).

4.5.5. Material culture

In Cerro Montoya, Unit 2, the first ceramics appear in level 10/11 (context 217) associated with a date of 1580 ± 30 BP (Beta-625027; *1.87–1.*70 cal *ka BP*). At the Limoncillos unit 2 ceramics appear about 1970 ± 30 BP (Beta-642562; *1.99–1.*82 cal *ka BP*), similar to the dates of Montoya.

5. Conclusions

The archaeology of the first modern humans to populate the diverse landscapes of South America, and especially Amazonia remains understudied. Our recent excavations at the SLL help fill this gap and provide novel insights into the first human groups to arrive in the Colombian Amazon and their historical trajectories during the Holocene.

The excavation of multi-component rock shelters exhibiting rock paintings (Cerro Azul, Cerro Montoya 1, Limoncillos, Angosturas II) firmly establishes that the human occupation of the SLL began in the late Pleistocene, during the YD period, about *12.*6 cal *ka BP* and continued until the 17th century CE. SLL dates are broadly contemporaneous with other early sites of the Lower Amazon, such Caverna da Pedra Pintada around ~13.1 cal ka BP.

The exceptional number of rock shelters found in the SLL region with evidence of human habitation during the late Pleistocene and early Holocene periods suggest that this area was an attractive landscape for forager groups. The SLL was a productive ecotone, where early foragers had access to palm-dominated tropical forest, savannah, and riverine resources. The early foragers appear to have privileged the occupation of rock shelters that provided protection and visibility. However, it should be noted, as mentioned before, that this could be a bias of our survey efforts only directed to rock shelters. Future surveys in the region will look for open-air sites.

Current data show that these groups had a broad-spectrum economy, unifacial lithic tool technology manufacture on local chert cobbles. All the rock shelters exhibit ochre paintings. Ochre fragments are present in all the sites since the earliest occupations. Ochre tablets with use-wear indicating grinding and rubbing are present since at least the 10th millennium BP. The recovery of a fragment of exfoliated rock with ochre painting dating to ~*10.*28 cal *ka BP* is indirect evidence that people were painting these walls of this rock shelter with ochre since at least that time.

Rock shelters in SLL sites were abandoned during the mid-Holocene between ~*6.0 and 4.*0 cal *ka BP*, similar to other Amazonian regions (see section 4.3.1). The reason for this abandonment is currently unclear. After these hiatuses, all sites were reoccupied, coinciding with the appearance of stone fills in the outer part of the rock shelters, Phase IV saw the introduction of ceramics (~*2.*8 cal *ka BP*), (Morcote-Ríos et al., 2021), maize (*Zea mays*) macro and micro-botanical remains (*0.*45 cal *ka BP*), and anthrosols in the foothills (*2.7-2.*3 cal *ka BP*).

Several specific studies on recovered material are underway including soil analysis, lithics, animal bones, plant remains, and ochre. So far, our results allow us to define a chronological reference framework for the process of human occupation of the SLL, which includes the initial settlement and the effective occupation of the territory (*sensu* Borrero, 1989–90). This effective occupation is evidenced by the long-term chronological sequence and by a landscape that was humanized with thousands of rock paintings (Iriarte et al., 2022b) similar to other Amazonian locations, such as the Serranía de Chiribiquete (Colombian Amazon) (Castaño-Uribe, 2019) or the Monte Alegre region, where Caverna Pedra Pintada is located (Roosevelt, 2013).

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jose Iriarte reports financial support was provided by European Research Council. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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