



Quantitative analysis of micromorphological images in edaphosedimentary sequences of the archaeological sites of Tequendama and Aguazuque, Sabana de Bogotá, Colombia

Análisis cuantitativo de las imágenes micromorfológicas en secuencias edafosedimentarias de los sitios arqueológicos de Tequendama y Aguazuque, sabana de Bogotá, Colombia

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ABSTRACT

The Bogotá savanna is a very important site for Colombian archeology. At this site, researchers have identified the settlements of hunter-gatherers and agricultural farmers who inhabited the territory from the late Pleistocene to the late Holocene. These archaeological studies have established the ways of life, social dynamics and environmental interactions of these groups. To clarify settlement processes, this article presents a detailed micromorphological and micromorphometric analysis of sediments collected in archeological excavations conducted at the Tequendama and Aguazuque sites in the municipality of Soacha, Cundinamarca. This analysis quantifies the contents of archaeological materials, such as bone and coal, as well as carbonate remains, which are associated with various activities. The results show differences in the abundance of bones and charcoal between settlement levels. Level 7A (dated 6,897-7,001 BP) of the Tequendama site shows the highest density of occupation and activities of all levels analyzed in this study. Furthermore, based on paleoenvironmental interpretation, the presence of secondary carbonates indicates arid conditions in the Bogotá savanna matching the regional climatic records.

Keywords: micromorphometry, hunter-gatherers, geoarchaeology, settlement processes, Holocene.

RESUMEN

La sabana de Bogotá representa un sitio muy importante para la arqueología colombiana. Allí se han identificado asentamientos de grupos humanos de cazadores recolectores, horticultores y agricultores que habitaron dicho territorio desde finales del Pleistoceno hasta el Holoceno tardío. Los estudios arqueológicos han permitido establecer formas de vida, dinámicas sociales e interacciones con el medio ambiente de esos grupos humanos. Para esclarecer los procesos de ocupación, en este artículo se presenta un estudio micromorfológico y micromorfométrico detallado de los sedimentos obtenidos de las excavaciones arqueológicas realizadas en los sitios de Tequendama y Aguazuque, en el municipio de Soacha, Cundinamarca. El análisis cuantifica los contenidos de materiales arqueológicos como hueso y carbón, y restos de carbonatos, que pudieron estar asociados a diversas actividades. Los resultados muestran diferencias en la abundancia de huesos y carbón, de acuerdo con los pisos de ocupación, de manera que en el nivel 7A (datado en 6,897-7,001 AP) del sitio de Tequendama se observa la mayor densidad de ocupación y actividades, de todos los analizados. Con respecto a la interpretación paleoambiental, la presencia de carbonatos secundarios permite establecer condiciones áridas en la sabana de Bogotá, que coinciden con los registros climáticos regionales.

Palabras clave: micromorfometría, cazadores-recolectores, geoarqueología, procesos de ocupación, Holoceno.

1. INTRODUCTION

The archaeological sites of Tequendama and Aguazuque are located in the Bogotá savanna. These sites are very important because they contain evidence of the settlements of hunter-gatherers who inhabited Tequendama from the late Pleistocene to the late Holocene (12,500-2,500 BP, approximately) and Aguazuque from the middle Holocene to the early late Holocene (8,000-2,500 BP, approximately). These sites were excavated in the 1970s and 1990s (Correal and Van der Hammen, 1977; Correal, 1990) and again in 2014 in smaller columns (Triana, 2019; Triana et al., 2019). The identification of human burials, lithic artifacts and animal skeletal and macroscopic plant remains has shed light on the social dynamics of these groups; in addition, the continuous presence of such archaeological materials across different stratigraphic units suggests that humans established permanent settlements at these sites.

Features of the Tequendama section show that groups of hunter-gatherers inhabited the rock shelter during the early and middle Holocene (125,000-6,000 BP, approximately), followed by a period without data corresponding to the middle Holocene. Toward the beginning of the initial late Holocene, humans returned to the site, as documented by human skeletal remains, some ceramic fragments and animal skeletal remains (Correal and Van der Hammen, 1977). In turn, the Aguazuque section shows a permanent settlement from approximately 8,000 to 2,500 BP. Abundant human burials, lithic artifacts and animal skeletal and macroscopic plant remains provide data on potential hunter-gatherers, with a transition to farming around

4,000 BP (Correal and Van der Hammen, 1977; Correal, 1990; Triana, 2019; Triana et al., 2019; Triana et al., 2020) (Table 1).

Micromorphological analyses of sediments from both sites (Triana et al., 2019) account for different periods of occupation and reflect activities developed during those periods. Similarly, magnetic susceptibility and electrical conductivity values, sediment micromorphology and archaeological data collected by stratigraphic level show different activities of exposure to fire and long periods of occupation in each stratigraphic level at the Tequendama site during the middle Holocene. The period that reflects the most intensive occupation spans from 9,000 to 6,000 BP. At Aguazuque, soil micromorphology and the aforementioned analyses mark a peak in occupation from 4,000 to 2,500 BP. The main modifications that suggest these occupation lapses are high exposure to fire, strong compaction of stratigraphic levels and an abundance of microscopic components, such as fish spines, plant tissues and sand aggregates (Triana et al., 2019).

In turn, micromorphometric analyses performed on thin films observed under the microscope provide evidence of both ancient human impacts (marked by the presence of bone fragments, coal and other anthropic materials) and pedogenetic processes such as newly formed carbonates, soil aggregates, Fe nodules and other pedofeatures). The resulting evidence forms the “edaphic memory” (Targulian and Goryachkin, 2004) that records environmental changes and ancient human activity. The term *micromorphometry* was coined by Kubiëna to designate techniques for quantifying the soil fabric, especially changes in porosity and structure caused by soil management

Table 1. Radiocarbon dates corresponding to Tequendama and Aguazuque

Archaeological site	Stratigraphic level	Dated material	Conventional ¹⁴ C age	Calibrated ¹⁴ C age (2 sigma)	Laboratory code	Reference
Tequendama	9 grainy brown	Coal	2225 ± 35 BP	2182-2308 BP	Col 159 GrN-6536	Correal and Van Der Hammen, 1977
Tequendama	8A slightly brownish gray	Coal	6990 ± 110 BP 7090 ± 75 BP	7719-7926 BP 7844-7979 BP	Col 163 GrN-6728 Col 164 GrN-6729	Correal and Van Der Hammen, 1977
Tequendama	5B light brown	Coal	10130 ± 150 BP 10590 ± 90 BP 10920 ± 260 BP	11456-12080 BP 12327-12680 BP 12580-13111 BP	Col 176 GrN-6732 Col 167 GrN-6505 Col 170 GrN-6539	Correal and Van Der Hammen, 1977
Tequendama	7A grayish brown to brownish gray	Human bone	6080 +/- 40 BP	6897-7001 BP	Col-AAA	Triana et al., 2019
Aguazuque	5(2) dark gray loam	Human bone	2725 ± 35 BP	2789-2856 BP	GrN 14.479. Col. 594	Correal, 1990
Aguazuque	4(2) brown loam	Human bone	3850 ± 35 BP	4200-4365 BP	GrN 14.478. Col. 593	Correal, 1990
Aguazuque	4(1) sandy loam	Human bone	4030 ± 35 BP	4453-4550 BP	GrN 12.930. Col. 477	Correal, 1990
Aguazuque	3 reddish sandy loam	Human bone	5025 ± 40 BP	5713-5866 BP	GrN 14.477. Col. 1592	Correal, 1990
Aguazuque	5(2) dark gray loam	Human tooth	3600 +/- 40 BP	3865-3965 BP	Col-AAA	Triana et al., 2019

(Stoops, 2009). However, these techniques have also been successfully used to account for carbonate accumulations in soils (Bui and Mermut, 1989), to evaluate porosity (Skwortsova et al., 2000) and to determine the distribution of soil components (Gutiérrez Castorena et al., 2017).

Triana et al. (2019) performed a qualitative micromorphological study in which informative features were recorded and interpreted in both profiles. In this study, quantitative morphological methods were applied to extract a record of these features to compare them with archaeological evidence and regional environmental proxies. This document focuses on evaluating the morphological quantities and parameters of microscopic anthropic materials (microartifacts). Rosen (1989, 1991) confirmed the importance of these components for detecting the intensity and type of ancient human activity in archaeological sediments; nevertheless, micromorphometric studies of these features in sedimentary sequences are scarce.

1.1 Study area

The Bogotá savanna is located south of the *Altiplano Cundiboyacense* [Cundiboyacense highlands] in the department of Cundinamarca, which is located in the geographic center of Colombia. The municipality of Soacha is located in this region, at an average height of 2,600 meters above sea level (m.a.s.l.). Soacha is characterized by two physiographic zones: the zone of highlands and mountains, with Páramo and Subpáramo ecosystems, and the zone of dry and humid High Andean forests. The archaeological sites of Tequendama and Aguazuque are located in the municipality of Soacha. Due to their proximity, these sites have similar environmental and ecological conditions.

The Tequendama archaeological site is located in a rocky shelter on the Tequendama hacienda, near the Chusacá toll-booth, in the municipality of Soacha, Cundinamarca. Aguazuque is an open-air archaeological site located on private property known as Aguazuque Hacienda. Currently, this property is called Fute Hacienda and is located on the road to Mondoñedo (Figures 1 and 2).

In geological terms, the sediments deposited in both archaeological sites are part of the Guadalupe Formation, which corresponds to the Upper Cretaceous (Correal, 1990). Triana et al. (2019) mention evidence of a sequence of fluvial and colluvial deposits, which are described as red and brown sediments deposited during the Quaternary, in the periphery of the archaeological sites (Julivert, 1961) and a complex of black soils that define the Siecha Formation (Helmens and Van der Hammen, 1994). The presence of sandstone in the rock shelter of the Tequendama site contributes to the accumulation of sediments. In Aguazuque, additional colluvial deposits are present along with the components resulting from fluvial processes.

The landscapes that originated in both sites were shaped irregularly due to an atypical sedimentation of alluvial materials, with changes in the facies and the direction of transport, which fostered a particular accumulation and erosion that generated a diverse stratigraphy. The archaeological sites are located in rocky shelters carved in the Guadalupe Formation, which consists of fossiliferous limestones and sandstones from the Upper Cretaceous, the alteration products of which contribute to the alluvial and colluvial sediments found in Tequendama and Aguazuque. However, Triana et al. (2019) determined that only sandstone is found in the Tequendama rock shelter. Therefore, this rock shelter does not provide calcareous material to the alluvial and colluvial sediments.



Figure 1. Location map of the Aguazuque and Tequendama archaeological sites

2. METHOD

During the excavation phase, conducted in 2014, soil samples were collected from each stratigraphic level. These samples were identified and classified based on the presence of archaeological material, the characteristics of the profile and the stratigraphic levels identified by Correal and Van der Hammen (1977) and Correal (1990). Although the samples were not oriented, they were exposed as little as possible to avoid destroying the soil aggregates collected during the total sediment sampling of each level. Thus, samples from each soil level were collected in bags to preserve the original structure. Subsequently, in the laboratory, an unaltered soil aggregate—which retained the original characteristics of the outcrop and its original position, such as pores, coarse and fine particles, pedo-features and even anthropogenic materials—was impregnated with polyester resin, prepared and processed to assemble thin sections of each stratigraphic level at each site.

The soil aggregate was impregnated to prevent disintegration, thereby preserving the natural relationships between different components. These thin sections were prepared at the Soil and Sediment Thin Section Workshop of the Institute of Geology (*Instituto de Geología – IGL*), National Autonomous University of Mexico (*Universidad Nacional Autónoma de México – UNAM*) by impregnation. The impregnated blocks were cut and polished to prepare 30- μm -thick thin sections, which were observed under an Olympus optical microscope and analyzed using the 2D image analysis software Image-Pro Plus.

In total, 14 thin soil sections were prepared from the two sites using six samples from Tequendama and eight from Aguazuque. The microscopic study focused on quantifying the materials, rather than assessing their distribution. The entire slides were scanned in a high-resolution scanner to generate a complete image of the components. The thin sections were micromorphologically described using terminology from Stoops et al. (2003) and adopted by Loaiza et al. (2015). In turn, the anthropic components (microartifacts) were identified based on the work of Courty et al. (1989) and Nicosia and Stoops (2017).

The method was applied in two sections. Initially, coal, bones and carbonates present throughout the thin section were counted manually and semiautomatically to determine the percentage of coal and bones in each thin section, with respect to the solid matrix. The porous space was subtracted from the measurement because the thin sections were derived from disaggregated materials and thus could not be considered *in situ*. For this purpose, the pore space was selected using the “Color selection and area calculation” dialog box of the Image-Pro Plus software. Subsequently, this area was subtracted from the total area of the thin section. The bone fragments were selected by visual observation, in both the microscopic and scanned images, thus providing two observation and control scales. The coal and carbonate fragments of each thin section were selected, counted and measured automatically.

The second methodological part focused on identifying three soil aggregates in each thin section. These aggregates were selected after a careful analysis to identify those that re-



Figure 2. Archaeological excavations in Tequendama (a) and Aguazuque (b)

mained unchanged and contained coal, carbonates and bone fragments. Once selected, each aggregate was measured, and all coal, carbonate and bone fragments were automatically counted in detail using the “Color selection” dialog box of the Image-Pro Plus software.

3. RESULTS

The results section is divided into two subsections because, methodologically, general counts were performed in the thin sections, and detailed counts were performed in aggregates of the same thin sections.

Semiautomatic counting

The results show that bone and coal are less abundant at the Tequendama archeological site than at the Aguazuque site. The highest percentages of bone were found in the topsoil level and in stratigraphic level 7A, dated from 8,500 to 9,500 BP (Figures 3c and 4a-b). The other levels showed low proportions of bone. In stratigraphic level 7A, the burial of a woman was identified, dated at 6,897-7,001 BP (Triana et al., 2019). In addition, in the coal counts at Tequendama, only level 7A had a representative percentage of coal. These data corroborate the previously observed increase in magnetic susceptibility values related to burning (Triana et al., 2019). These findings indicate that this

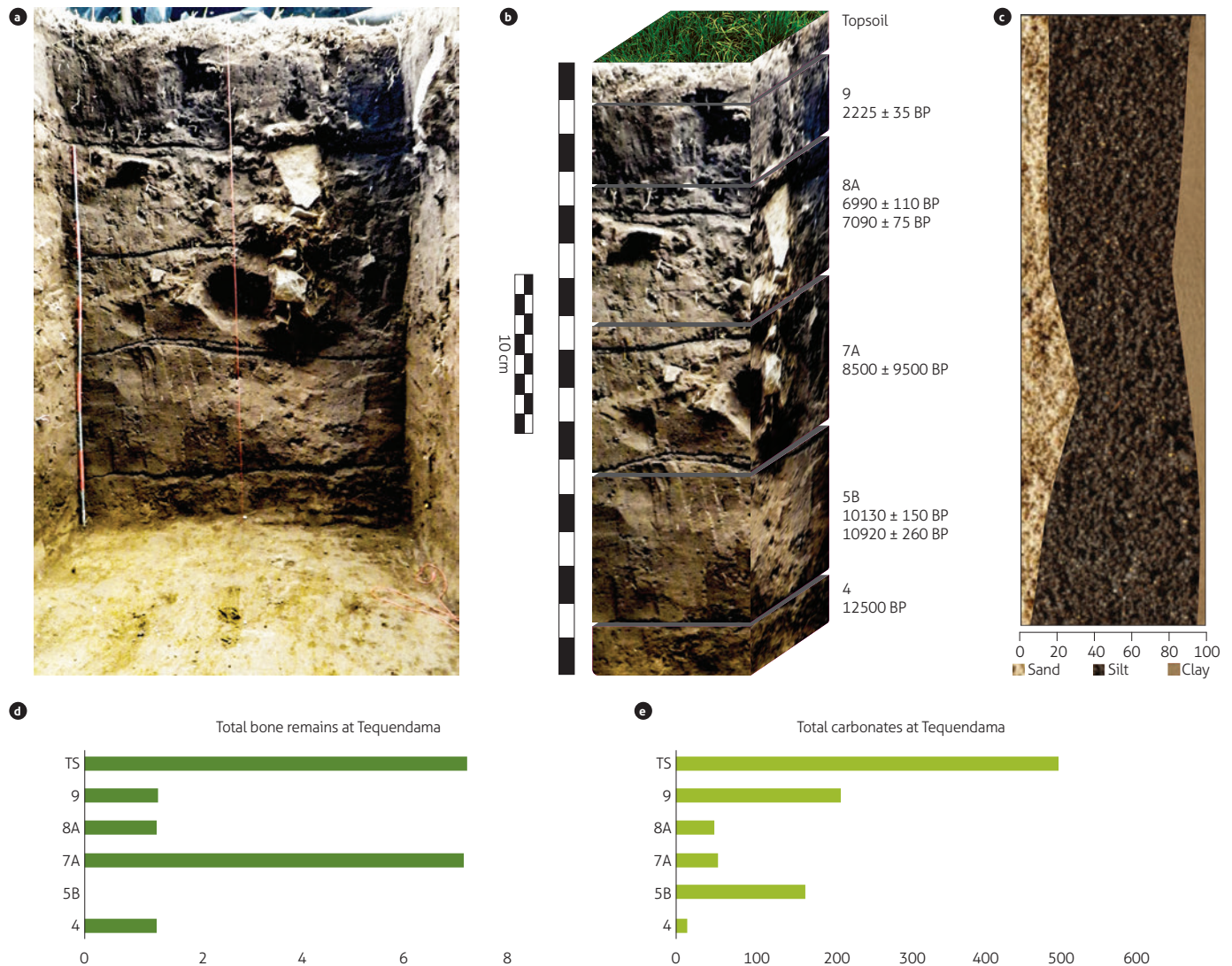


Figure 3. Stratigraphic profile (a) and micromorphological counts by stratigraphic level (b) at Tequendama; variation in texture (% sand, silt and clay fractions) across the stratigraphic profile (c) and total bone (d) and carbonate (e) remains by stratigraphic level

stratigraphic level had a high human occupation during the transition from the Lower Holocene to the Middle Holocene. The average size of the coals is 336 μm , and they present a high degree of thermal alteration.

The carbonates present at the Tequendama archeological site appear more frequently in the first stratigraphic levels, topsoil and level 9 (dated at approximately 2,500 BP) (Figures 3d and 4c-d). Similarly, though to a lesser extent, level 5B (dated at approximately 10,000 BP) also contains carbonates.

In the manual count at Aguazuque, the highest percentages of bones occur between 2,500 and 4,000 BP. In these levels, the frequency of bone remains increases, decreases and increases

again toward the earliest stratigraphic level (Figures 5c and 6a-b), in contrast to Tequendama, where the percentage of bones is not as high as that in Aguazuque. In the coal count, the highest percentages are found in the topsoil and in the first stratigraphic level, dated at 8,000 BP (Figure 5d). These values differ from those of Tequendama because the highest percentage of carbon occurs only in stratigraphic level 7A. In the carbonate count, the highest frequencies are found in stratigraphic level 6 and are associated with late periods (Figure 5e); toward the middle Holocene, the frequency decreases and then increases again in stratigraphic level 3, corresponding to the initial middle Holocene (Figure 6c-d).

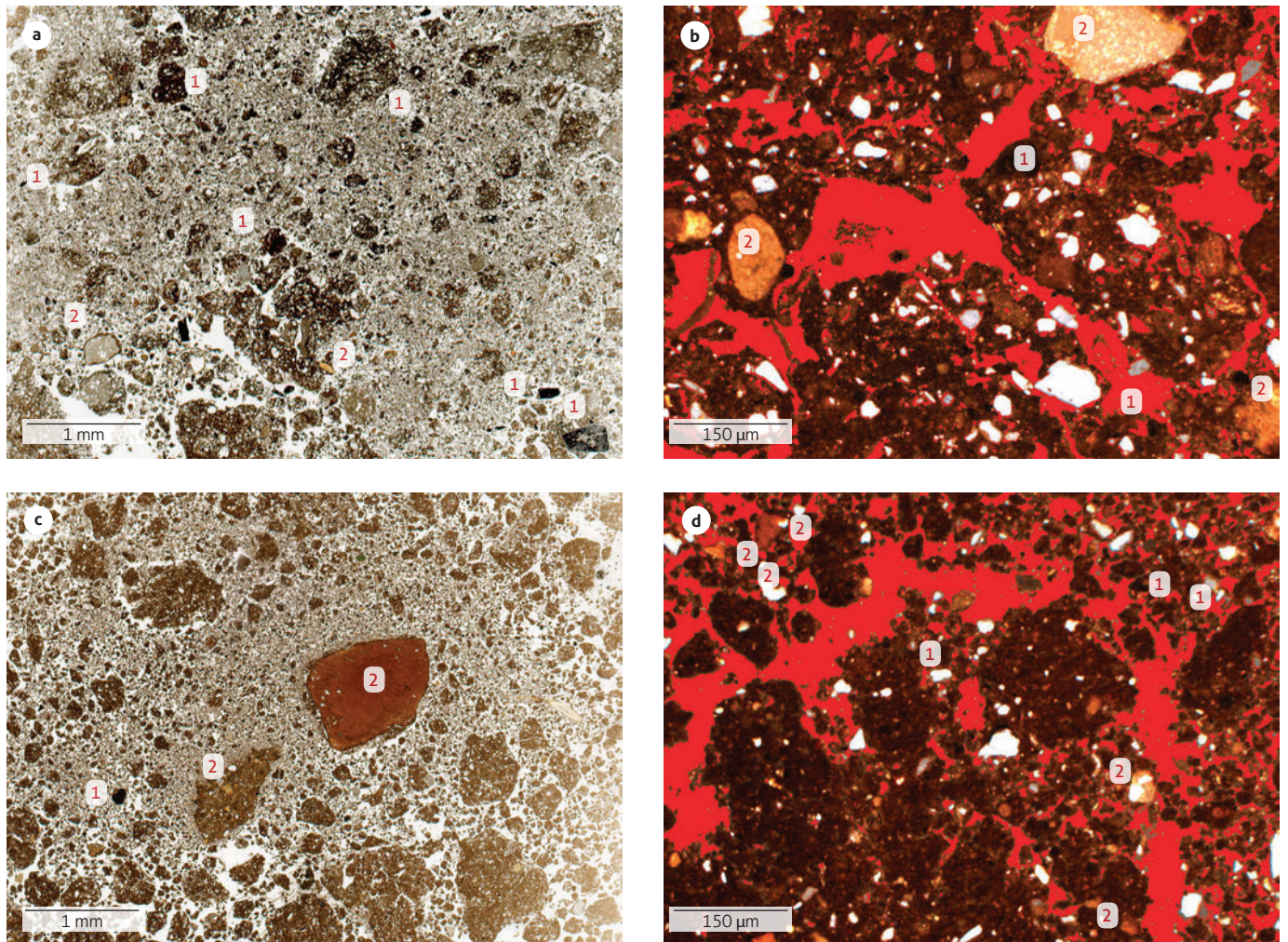


Figure 4. Semiautomatic count at Tequendama; a) thin section of stratigraphic level 7A; b) total coal (1) and bone remains (2) at level 7A (Image-Pro Plus); c) thin section of stratigraphic level 9; d) total coal (1) and bone remains (2) at level 9 (Image-Pro Plus)

Detailed counts in aggregates

In the counts performed in three soil aggregates of each thin section, coals, bones and carbonates were also identified. These counts were performed using the Image-Pro Plus software. At Tequendama, 1,638 bone fragments with medium-to-small sizes and an average size of 32.59 μm were detected in the topsoil (Figure 7a). Coals were abundantly found in aggregates from level 9 (2,500 BP, approximately) and level 7A (8,500-9,500 BP, approximately). Levels 8A (6,000-7,000 BP, approximately) and 4 (12,500 BP) also showed carbon fragments, but in lower proportions than in the previous levels (Figures 7b and 8b). The

percentages of coals in the counts performed using the software are higher than in those performed manually.

The percentage of carbonates present in aggregates at Tequendama increases in the earliest periods, that is, in levels 8A, 7A and 5B, which represent the transition from the early to the middle Holocene (Figures 7c and 8c). Carbonate sizes are larger in the later levels, averaging 30 μm , and decrease toward the earliest levels.

At the Aguazuque archeological site, the aggregate counts by stratigraphic level showed that bone remains were only present in stratigraphic level 3 (associated with 5,025 BP), in which 3,657

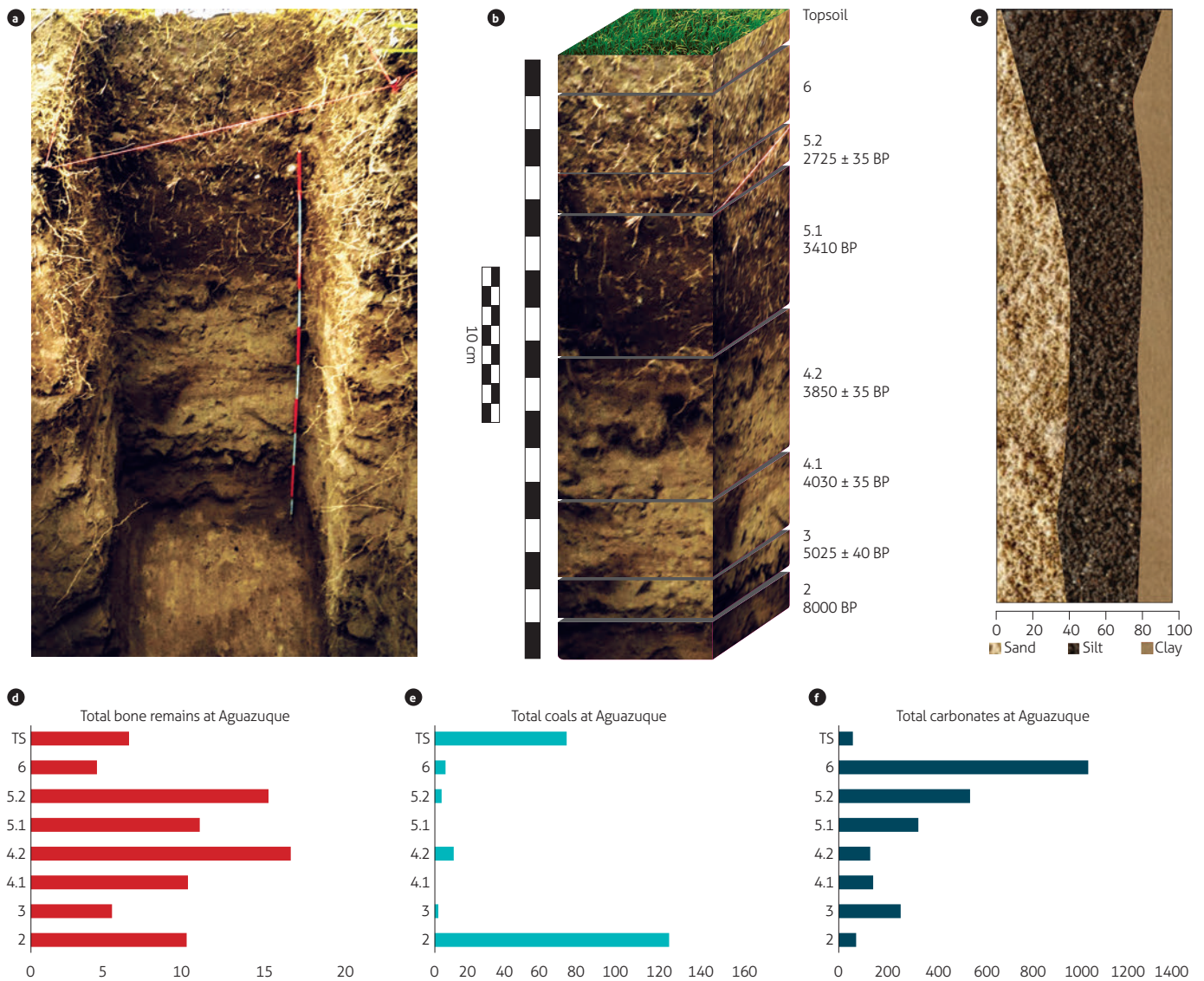


Figure 5. Stratigraphic profile (a) and micromorphological counts by stratigraphic level (b) at Aguazuque; variation in texture (% sand, silt and clay fractions) across the stratigraphic profile (c) and total bone (d), coals (e) and carbonates (f) by stratigraphic level

very small fragments were counted (Figure 9a), in contrast to Tequendama, where the bone counts showed a lower proportion in the latest levels and were not as early as those at Aguazuque. The average size was $0.32\ \mu\text{m}$. The coal counts showed that the frequency of occurrence is high in the earliest level, subsequently decreases, slightly increases toward the middle Holocene (between 4,000 and 2,500 BP), then decreases toward late periods and finally increases in the topsoil (Figures 9b and 10b). The coals found in Aguazuque had higher counts and larger average sizes than those found in Tequendama.

At Aguazuque, the carbonates values are low in the earliest levels; however, they rise and fall during the middle Holocene, between 4,000 and 2,500 BP. In level 6, toward the late period, carbonates considerably increase (Figures 9c and 10c); although the presence of carbonates is higher at Tequendama, the variation is similar, with values increasing toward later periods. At Tequendama, the carbonates show an average size larger than $10\ \mu\text{m}$ and are thus larger than the carbonates found in Aguazuque.

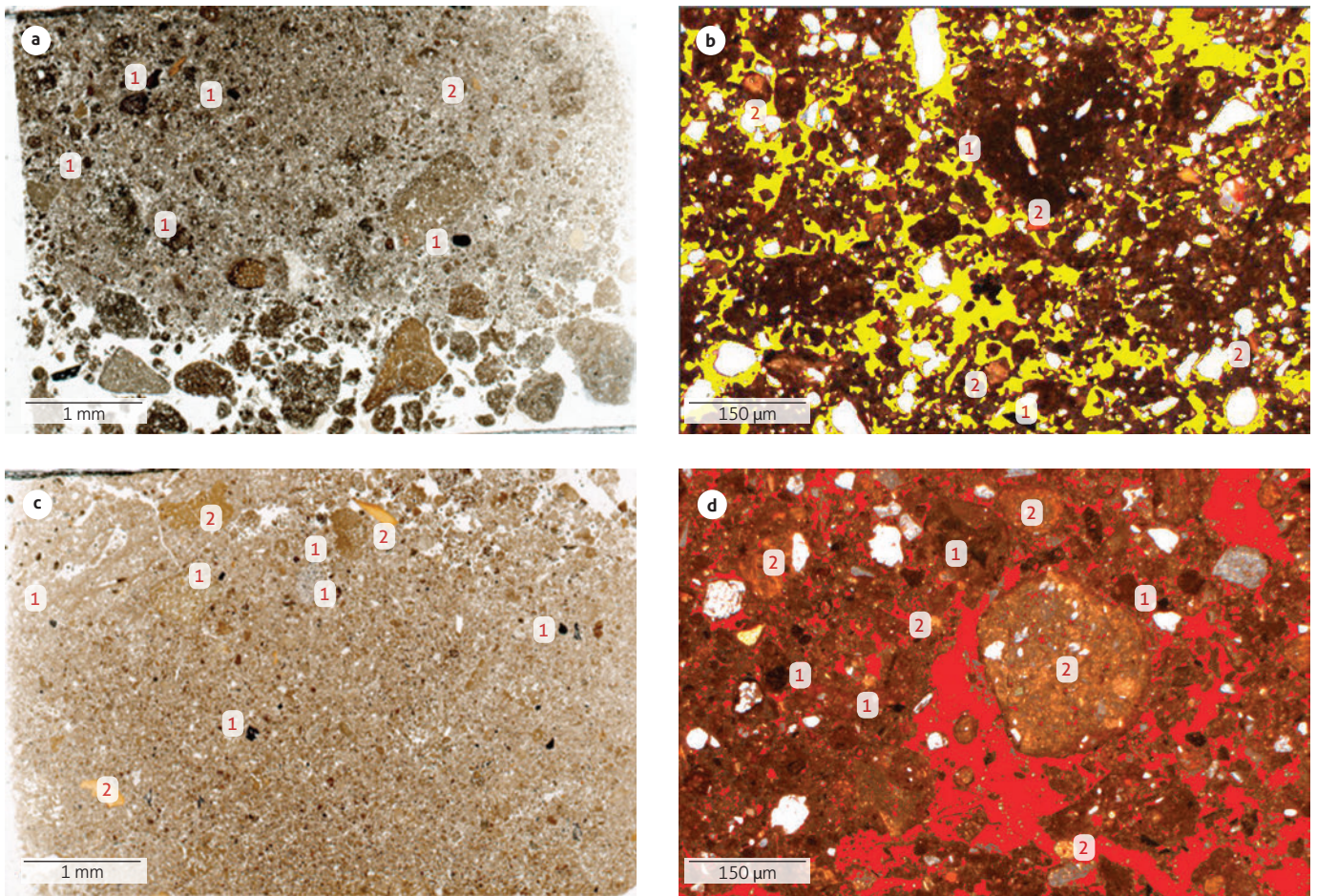


Figure 6. Stratigraphic profile and micromorphological counts at Aguazuque; a) thin section of stratigraphic level 5.2; b) total coal (1) and bone remains (2) at level 5.2 (Image-Pro Plus); c) thin section of stratigraphic level 2; d) total coal (1) and bone remains (2) at level 2 (Image-Pro Plus)

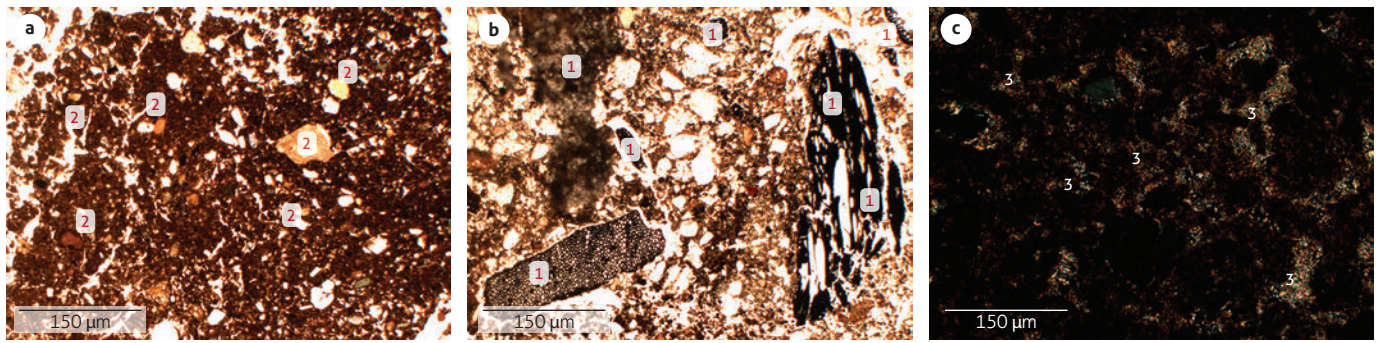


Figure 7. Detailed count by aggregate at Tequendama; a) topsoil level; total bone remains (2); b) level 7A; total coals (1); c) level 5B, total carbonates (3)

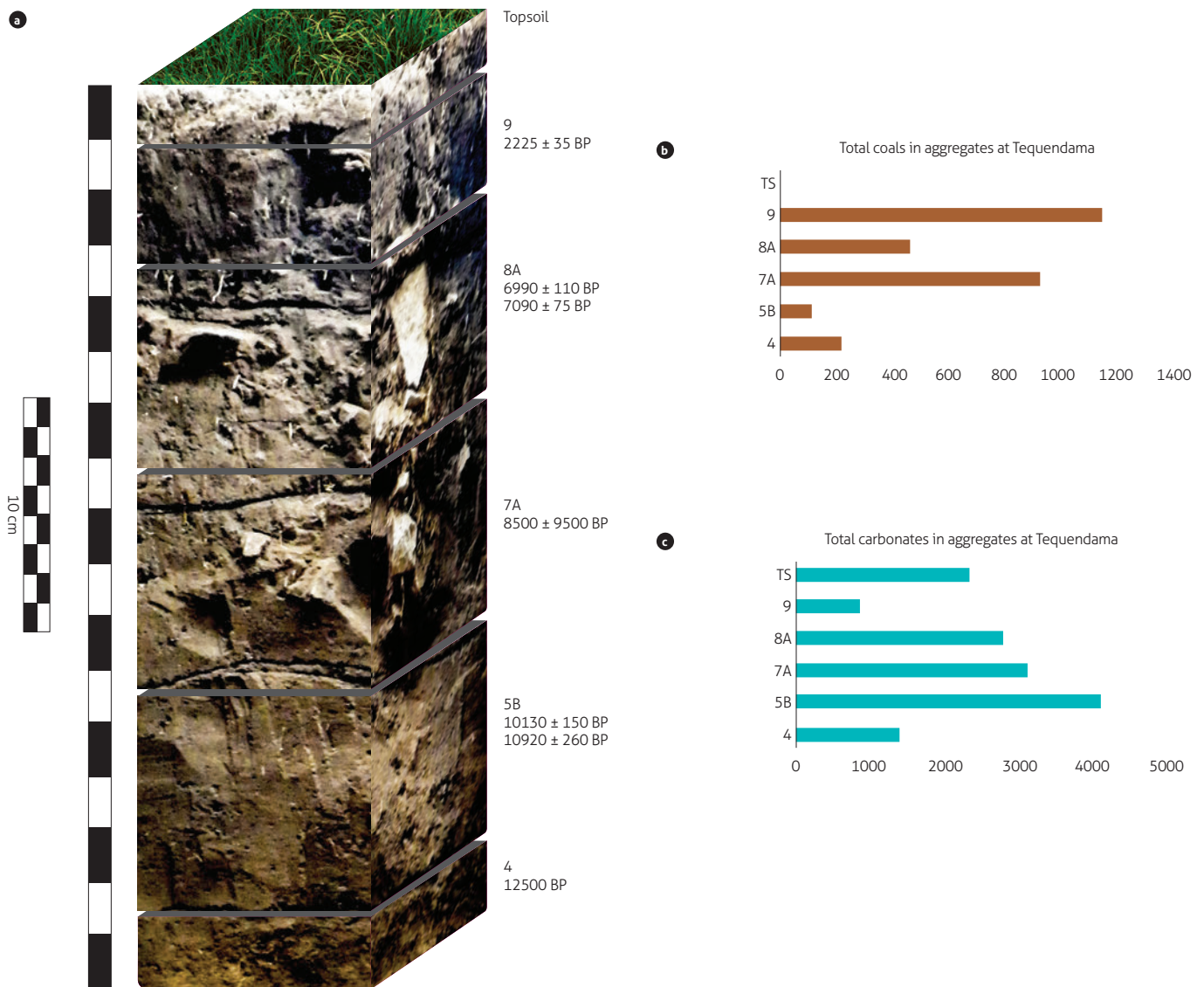


Figure 8. Stratigraphic profile (a) and total aggregate counts at Tequendama with total coals (b) and carbonates (c) by stratigraphic level

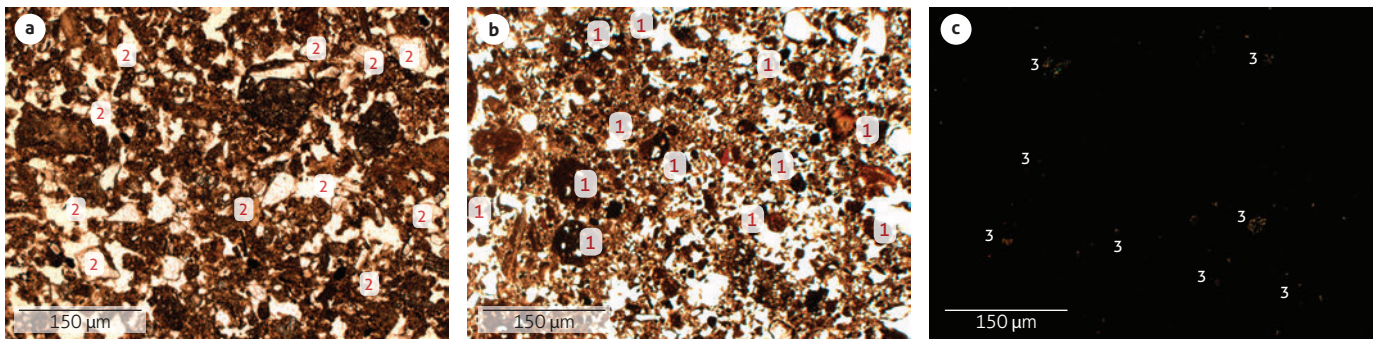


Figure 9. Detailed count in aggregates at Aguazuque
 a) level 3, total bone remains (2); b) level 2, total coals (1); c) level 6, total carbonates (3)

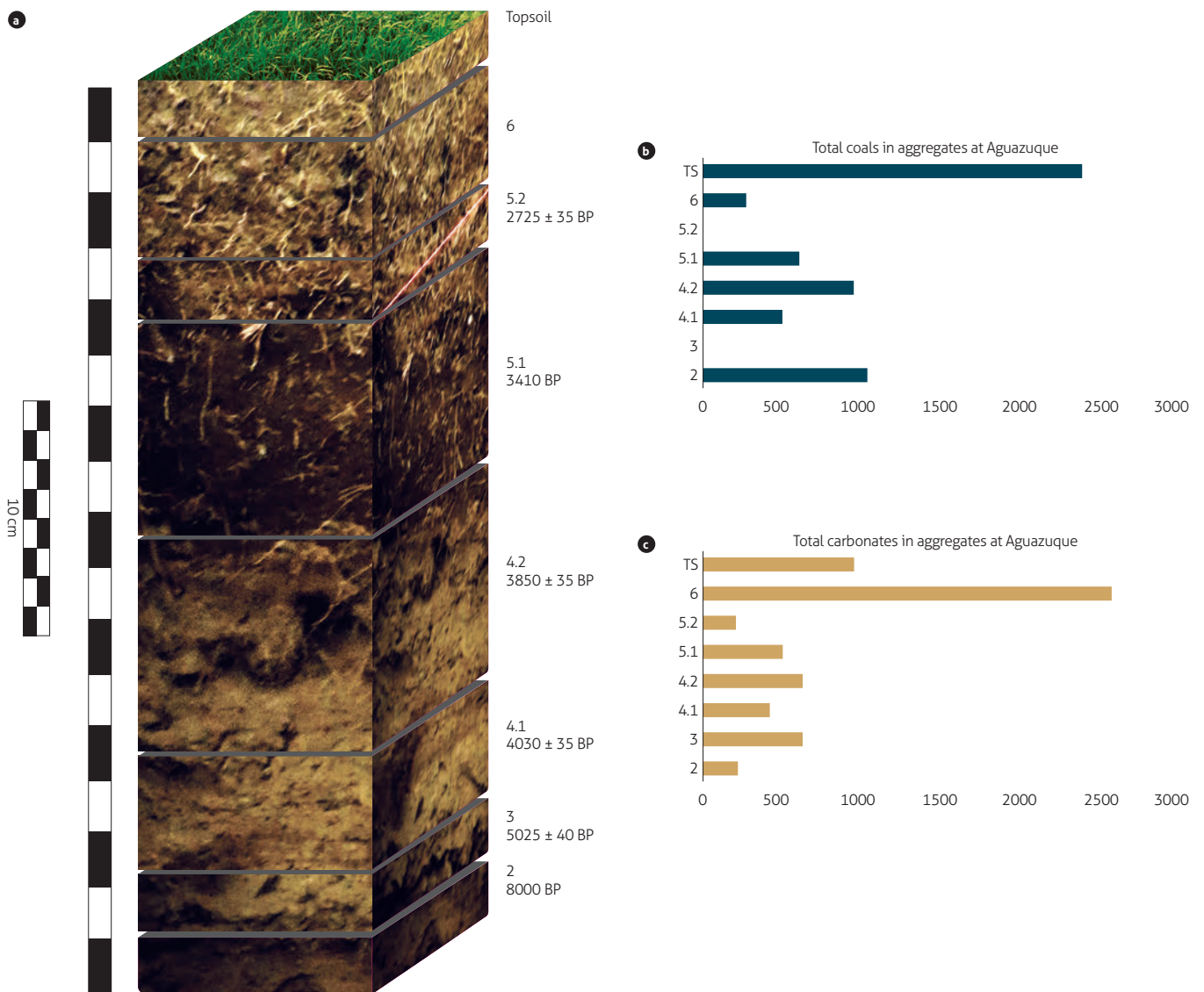


Figure 10. Stratigraphic profile (a) and counts in aggregates at Aguazuque with total coals (b) and carbonates (c) by stratigraphic level

4. DISCUSSION

Activities of the groups that inhabited the Bogotá savanna in the Holocene

The manual counts show that the topsoil and 7A levels of the Tequendama site contain bone remains in abundance. In turn, coals are only identified in level 7A, whereas carbonates are highly prevalent in the topsoil, in level 9 and, to a lesser extent, in level 5B, thus matching the periods of highest human occupation of the site (Correal and Van der Hammen, 1977).

Conversely, at the Aguazuque site, the percentage of bone remains increases and then decreases over the occupation of the site (Correal, 1990; Triana, 2019; Triana et al., 2019; Triana et al., 2020), although it sporadically and considerably increases from approximately 3,800 to 2,500 BP (initial late Holocene). Coals are only evident in the topsoil and in the first level of occupation. Carbonates behave similarly to coals: they are present in the latest levels, such as 6, and in the earliest levels, such as 3, dated at 5,025 BP.

The automatic counts at the Tequendama site show that bone remains are only present in the topsoil. Coals are present in almost all stratigraphic levels, except in the topsoil; however, levels 7A and 9 show high values. Lastly, carbonates increase toward the earliest periods, dated from approximately 6,000 to 10,000 BP (levels 8A, 7A and 5B). The automatic counts at Aguazuque show that bone remains are only present in level 3 (5,025 AP). Coal fragments are present in all stratigraphic levels, but the topsoil has the highest values, followed by level 2, the earliest level of occupation. Carbonates are present in the latest levels, such as level 6.

The results from both counts at the Tequendama site indicate that bone remains are present in the latest levels, such as topsoil; however, general micromorphological counts (Triana et al., 2019) and the frequency of the material during excavation (Triana, 2019) have shown that bone remains are present in all stratigraphic levels, although primarily in levels 9, 8A and 7A (early and middle Holocene), and decrease toward the late Holocene. This indicates that, in late levels, such as topsoil, the frequency of microfragments is high, which can be observed and quantified in both manual and automatic counts. The frequency of bone remains in level 7A is in line with the abundance of bone remains observed during the excavation phase and with micromorphological observations. The above findings support the hypothesis that the highest period of occupation of the Tequendama site is level 7A, with an absolute

date of approximately 6,897-7,001 BP (Triana, 2019; Triana et al., 2019; Correal and Van der Hammen, 1977).

The data from the coal counts show a higher presence of microfragments in the automatic counts, and levels 7A and 9 have the highest values. These data indicate that occupation is again identified in level 7A. In addition, level 9 (dated at 2,500 BP) also contains coals, which has not been identified in micromorphological observations or even in manual counts. This level contained a stone floor in that period of occupation, associated with the late Holocene (Correal and Van der Hammen, 1977), as well as ceramic fragments. The body of evidence suggests that some activities were performed during this period in which human groups were possibly developing farming practices; similarly, the presence of coals at this stratigraphic level may be associated with food processing and cooking practices that could have been conducted at the site.

This information can be complemented with reports on changes in the social dynamics of the groups that occupied the Bogotá savanna. More specifically, some authors have argued that the populations were more sedentary, that agriculture markedly outlined a subsistence economy and that the population density would have increased around 2,500 BP. Accordingly, different studies on individuals from this period confirm these hypotheses because they show dietary changes that suggest a dependence on crops, such as maize, and variable percentages in protein intake (Van der Hammen et al., 1990; Cárdenas, 2002; Delgado, 2018; Triana, 2019; Triana et al., 2020).

The manual counts of Tequendama show that carbonates tend to decrease in the latest levels (topsoil and layer 9) and toward the earliest periods. However, level 5B (dated at 10,000 BP) shows an increase in these components. The automatic counts are different because they show a significant increase in carbonates; similarly, the latest levels, such as the topsoil and layer 9, do not show a higher frequency of carbonates; apparently, the frequency of these components increases toward the earliest levels, especially in level 5B, where carbonates peak, which corresponds to the transition from the end of the Pleistocene to the early Holocene. These carbonates are newly formed pedogenic phases, as explained below; as such, they indicate the driest environmental conditions of that period.

Conversely, the peak of carbonates in level 5B at Tequendama matches the presence of lithic artifacts, bone fragments and coals identified in micromorphological observations during the excavation phase. This suggests the presence of human groups in the Bogotá savanna during the transition from the

Pleistocene to the early Holocene, in an environment with conditions very different from those of the late Holocene (Triana et al., 2019; Triana, 2019; Correal and Van der Hammen, 1977; Aceituno et al., 2013; Correal, 1993 and 1981; Correal et al., 2005). The counts of bone remains at the Aguazuque site are consistent with the frequency of archaeological material found during the excavation phase; however, they differ from the automatic counts because bone remains are only identified in level 3 (dated at 5,025 BP; that is, the results show a high presence of previously undetected microfragments).

The occupation of Tequendama lacks data toward the middle Holocene, and the stratigraphic levels with abundant coals at Aguazuque are levels 5.1, 4.2 and 4.1 of this period. These findings suggest that, during the middle Holocene, the social dynamics of the human groups were not limited to hunting and gathering. The archaeological evidence—lithic artifacts such as anvils, hammers, metates and quern stones used for plant processing; dietary changes reported based on different analyses of stable isotopes; burial patterns and diseases of individuals who lived during this period—suggests that the inhabitants of the Bogotá savanna went from hunter-gatherers to potential crop farmers. These data are complemented by the presence of charred plants at Aguazuque from around the same period (Correal 1990; Cárdenas, 2002; Delgado, 2018; Triana et al., 2019, Triana 2019).

Paleoenvironment in the Bogotá savanna based on the counts

An important result is the presence of carbonates at both sites, the morphology of which is related not to primary carbonates, but to secondary carbonates, formed in the soil environment. In the region, the Guadalupe Formation is composed of fossiliferous limestones from the Upper Cretaceous; however, in the thin sections, none of the carbonates match the petrography of a fossiliferous limestone (Figure 11). In turn, the carbonates are related neither to lacustrine calcareous sediments, the morphology of which is linked to bodies of water, with lamellae or nodules with tangentially distributed crystals (Gutiérrez Castorena et al., 1998), nor to coarse textures, such as sand or gravel (which would show an alluvial or colluvial origin), but they are instead micritic carbonates. Micrite and microsparite form nodules or incrustations of plant tissue fragments, which is typical of newly formed pedogenic carbonates (Triana et al., 2019). These carbonates are formed by dissolution and reprecipitation processes when the substrate is calcareous

and a primary carbonate source, serving as the basis for the initial dissolution. At Tequendama, the rock shelter is formed by sandstone without carbonates (Triana et al., 2019).

Consequently, the genesis of these carbonate accumulations requires more complex processes: 1) the formation of carbonic acid from CO_2 , a product of plant respiration; 2) the formation of soluble bicarbonates (HCO_3^-)₂ from the weathering of primary, calcium-rich minerals, such as plagioclase and amphibole, which were identified in the thin sections (Triana et al., 2019), as well as the dissolution and migration of primary carbonates present in local rocks, and 3) the precipitation of carbonates. This precipitation process is conditioned by the loss of water, as the main mechanism (Rabenhorst et al., 1984); therefore, high ambient temperatures and low levels of rainfall are required because carbonate leaches under humid conditions. Therefore, its presence indicates arid and semiarid conditions (Tanner, 2010). Importantly, no carbonates were identified in the basal layers of the Tequendama section (Triana et al., 2019).

Based on the above, the carbonates present in the thin sections indicate arid conditions starting from the transition from the Pleistocene to the early Holocene (12,500-10,000 BP). This shift represents a notable climate change at the beginning of the Holocene, a period for which cold-humid conditions have been documented, with Subpáramo and forest vegetation (Delgado, 2018; Marchant et al., 2002; Van der Hammen, 1992). Toward the beginning of the early Holocene (10,000 BP) a temperature change is recorded: the environmental conditions became more temperate, in line with the presence of ferruginous nodules and Aristeidae and Gramineae phytoliths, which are

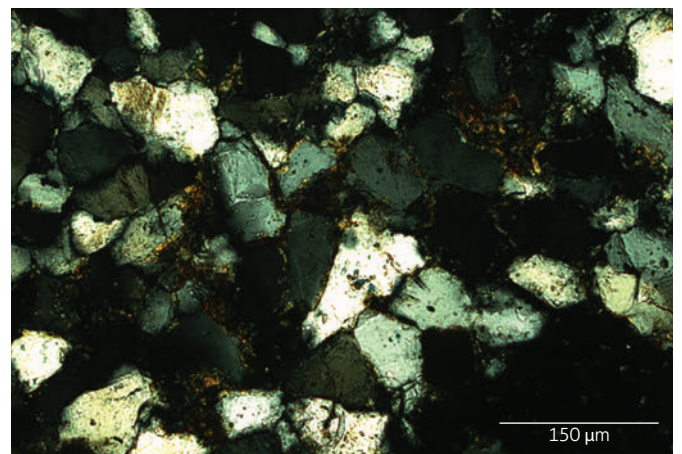


Figure 11. Thin section of rock from the rock shelter of the Tequendama archaeological site showing no evidence of carbonates

generally associated with temperate-to-warm environments, in the lower stratigraphic levels of the study sequences (Triana et al., 2019; Triana, 2019). From the initial early Holocene (10,000-7,000 BP), the environmental conditions were warmer and drier and gradually became more arid toward the middle Holocene (Helmens and Van der Hammen, 1994; Torres et al., 2005; Van Geel and Van der Hammen, 1973; Van der Hammen, 1992). Lastly, toward the late Holocene, the climate became more humid on a regional scale. These climatic trends match the presence of carbonates in the study sections.

At the Bogotá savanna, in the middle Holocene, from approximately 8,000 to 6,000 BP, the climate was dry and cold, with dry and open areas and abundant *Quercus* plants throughout the savanna. From 5,000 to 2,500 BP, the water level of the lakes decreased, and the forest variety increased; species of the genera *Quercus*, *Podocarpus*, *Urticaceae* and *Cecropia* were identified in this period (Triana et al., 2019; Delgado, 2018; Marchant et al., 2002; Van der Hammen, 1992). The above is confirmed by the pH, electrical conductivity and phytolith values from this period, which corroborate the permanent settlement at the Aguazuque site; similarly, the high concentrations of silica skeleton phytoliths, which were apparently deposited in the soil without being altered and were observed in both the thin sections and the sediments, confirm the constant occupation of the site during these periods (Triana, 2019; Triana et al., 2019; Nicosia and Stoops, 2017).

5. CONCLUSIONS

The data collected during the present study confirm that human groups settled at Tequendama and Aguazuque. At Tequendama, the longest period of occupation spans from approximately 8,500 to 6,000 BP, while that at Aguazuque spans from 4,000 to 2,500 BP. Interestingly, the differences between the manual and automatic counts show the high numbers of anthropogenic components that had not been identified when using qualitative micromorphological techniques. The Image-Pro Plus software more clearly defines the presence of anthropogenic elements that are not visible to the naked eye. These computer techniques enable us to determine features related to early human settlements (transition from the Pleistocene to the early Holocene) in levels such as 5B at Tequendama.

On the one hand, at Aguazuque, low concentrations of bone remains were found during the excavation and qualitative analysis phases (Triana et al., 2019). Those counts were

redefined during the present study. Thus, high percentages of bone fragments were detected in level 3 (5,025 BP), thus indicating an intensification of human activities in the middle Holocene. Most likely, this high concentration of bone fragments is related to the processing of faunal resources. On the other hand, variables related to environmental conditions, such as the presence of pedogenic carbonates, can be identified at the microscopic level.

Consequently, quantitative analysis in archeological contexts identifies elements related to human occupation. In the study of the Tequendama and Aguazuque sites, the implementation of this technique highlights the importance of approaching data from different multidisciplinary perspectives by integrating the data and more clearly understanding the contexts of each floor of occupation, as well as the corresponding social and cultural dynamics. The information on the Tequendama and Aguazuque sites has been expanded thanks to quantitative microscopic techniques, which provide very important data on the occupation and environmental changes that may have occurred at these sites.

ACKNOWLEDGMENTS

The present study was made possible thanks to collaboration with Universidad Nacional Autónoma de México, especially the Instituto de Geología, Edaphology Group, Paleosols Laboratory and Lamination Workshop. Support and funding were also provided by the Fundación Nacional de Investigaciones Arqueológicas, the Instituto Colombiano de Antropología e Historia (ICANH), the Fundación CeiBA, which granted a doctoral scholarship, and the Universidad de los Andes. The authors also thank the owners of the Tequendama and Fute haciendas, who endorse and support archaeological research in Colombia.

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