Archaeological and Anthropological Sciences (2022) 14:195
https://doi.org/10.1007/s12520-022-01661-9

ORIGINAL PAPER

Fuel sources, natural vegetation and subsistence at a high-altitude aboriginal settlement in Tenerife, Canary Islands: Microcontextual geoarchaeological data from Roques de García Rockshelter

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Received: 10 March 2022 / Accepted: 23 August 2022 / Published online: 17 September 2022

Abstract

High-altitude island environments, with their characteristic strong seasonal contrast and limited resources, are challenging contexts for human subsistence. However, although archaeological contexts in this kind of setting hold great potential to explore the diversity of human biological and cultural adaptations, such sites are rare. In this paper, we present the results of a microcontextual geoarchaeological study carried out at Roques de García Rockshelter, the highest altitude cave archaeological site in the Canary Islands (Spain). The site was inhabited by the aboriginal population of the island and has yielded a rich archaeological context derived from combustion activity. We carried out soil micromorphology to characterize site function and lipid biomarker analysis to investigate the natural and anthropogenic organic record. Our data indicate that the aboriginal groups that occupied the site kept goats with them (in the rockshelter) and probably used *Juniperus turbinata* (sabina) wood, a current distant fuel source. These results suggest that the aboriginal societies of Tenerife occupied the highlands regularly, taking their herds and firewood with them. Further research is necessary to explore the use and exploitation of fuel sources, the seasonality of these occupations and their differences with lowland sites.

Keywords Micromorphology · Lipid Biomarkers · Geoarchaeology · Pastoralism · Highlands · Paleoenvironment

Introduction

In this paper, we approach a high-altitude aboriginal site in Tenerife, Canary Islands, by studying its anthropogenic combustion residues using microstratigraphic geoarchaeological techniques. This approach aims to add detail to previous research on highland adaptations of the aboriginal Tenerife population (Arnay de la Rosa et al. 2011, 2017; Arnay de la Rosa and González Reimers 2006; Hernández Gómez and Galván Santos 2008; Morales et al. 2021; Vidal-Matutano et al. 2019) and contribute to our current understanding of human subsistence in highland environments as viewed from the archaeological record.

Highland settings are interesting targets of archaeological research because their environmental and geomorphological features constrain the development of human subsistence strategies. Due to the inverse correlation between temperature and elevation, agriculture tends to disappear with altitude, resulting in the usual conception of highlands as marginal human landscapes (Carrer et al. 2019; González Álvarez et al. 2016). However, as shown by recent studies

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(Arnay de la Rosa et al. 2017, 2019; Arnay de la Rosa and González Reimers 2006; Biagetti 2019; Capriles and Tripcevich 2016; Carrer 2017; Carrer et al. 2019; González Álvarez 2013; González Álvarez et al. 2016; Égüez et al. 2020; Elliott et al. 2015; Marshall and Capriles 2018; Meinekat et al. 2021; Shahack-Gross et al. 2004, 2008; Simões et al. 2020; Vidal-Matutano et al. 2019), such areas have been key for human subsistence through time, as they are linked to the development of pastoralism as an essential economic strategy. Mobile pastoralism has been shown to be an efficient activity for the seasonal exploitation of highland natural resources (Égüez et al. 2020). However, the seasonal, ephemeral nature of high mountain pastoralist settlements has hampered archaeological identification of campsites and herding areas (Égüez et al. 2018; González Álvarez et al. 2016; Shahack-Gross et al. 2008) and high-resolution multi-proxy approaches are necessary. For example, in a study of dung deposits from different pastoral rockshelters in central Italy (Monti Sibillini) using a multi-proxy approach that included botanical analysis, micromorphology and stable isotope analysis, Égüez et al. (2020) were able to reconstruct seasonality patterns linked to different vegetation belts exploited by local herders. As shown by this study, well-preserved highland archaeological sites hold great analytical potential.

Such sites have been documented in the Canary Islands, a volcanic archipelago located in the Atlantic Ocean, at approximately 300 km off the west coast of Saharan Africa. The islands were inhabited by aboriginal populations. Genetic data has shown that the archipielago was first settled by North African people (Fregel et al. 2019; Maca-Meyer et al. 2004). Recent studies employing AMS radiocarbon dating on seeds indicate that the earliest documented settlements date to the first millenium CE (Hernández-Marrero et al. 2016; Morales Mateos et al. 2017). In particular, the aboriginal population of Tenerife, known as the "Guanches," exploited highland natural resources (Arnay de la Rosa and González Reimers 2006). Tenerife's highlands, or "Las Cañadas del Teide," comprise a 190 km^2 depression at 2200 m.a.s.l. in the center of the island, at the foothill of the Teide peak (3718 m.a.s.l.) (Fig. 1). Specifically, the aboriginal occupation of Las Cañadas probably extended from the early settling stages of Tenerife (around 1600 BP) to the 16th Century, as dating has shown (Arnay de la Rosa et al. 2011, 2019; Vidal-Matutano et al. 2019).

The Guanches developed an economic system that was basically focused on mobile pastoralism and sheep/goat herding, even though activities such as plant and shell gathering, coastal fishing and agriculture have also been documented (Arnay de la Rosa et al. 2011; Diego Cuscoy 2008; Morales et al. 2021; Morales Mateos et al. 2017). In this scenario, Las Cañadas del Teide has been proposed as a seasonal, summer (May to September) habitat of shepherds and their goats (Arnay de la Rosa et al. 2017, 2011; Arnay de la Rosa and González Reimers 2006; Diego Cuscoy 2008; Vidal-Matutano et al. 2019). The exploitation of lithic resources from the area (mainly basalt and obsidian) has been previously documented (Arnay de la Rosa et al. 2017, 2019; Hernández Gómez and Galván Santos 2008). Las

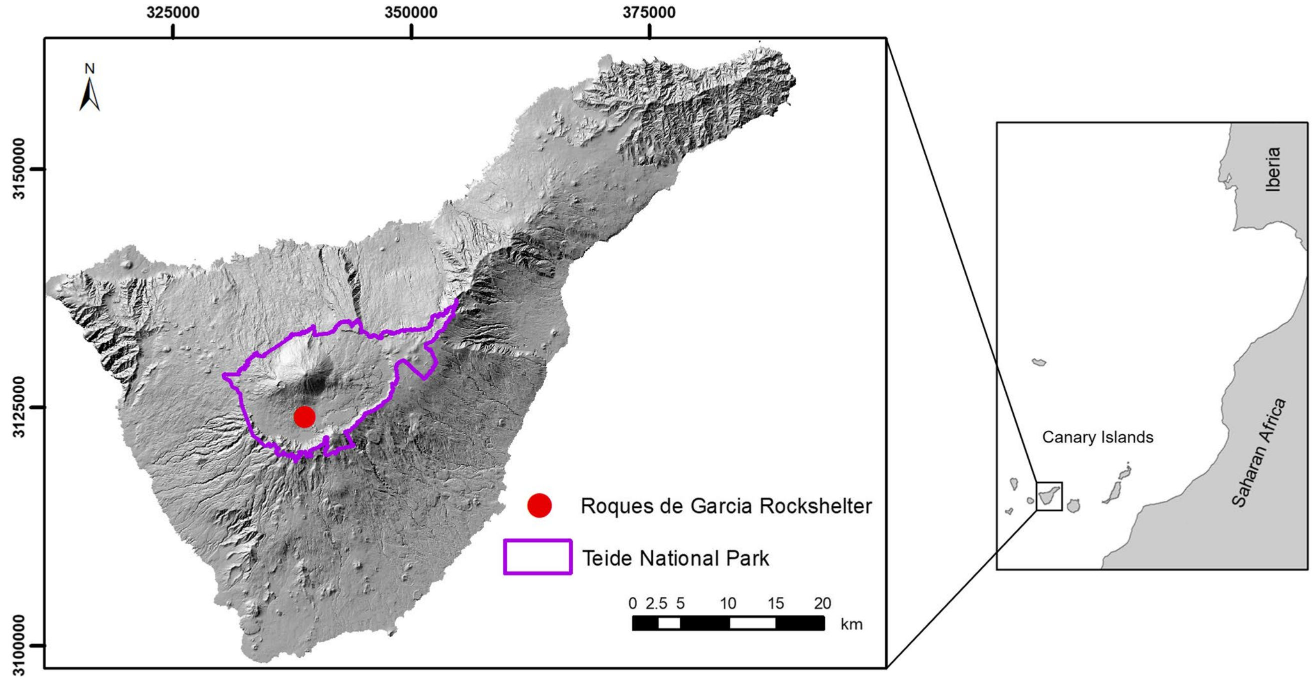


Fig. 1 Map showing the location of Tenerife, the Teide National Park and the Roques de García archaeological site

Cañadas highlands might also have represented a *refugium* for Guanche communities after the arrival of the Castillians between the 13th and the 15th Centuries (Arnay de la Rosa et al. 2011; Espinosa 1980; Aznar Vallejo 1988).

Among the different types of aboriginal archaeological contexts documented for Las Cañadas, combustion features hold high potential for the reconstruction of past human mobility and behavioral subsistence patterns. Fire has played an essential role for human societies throughout time, as several studies have shown (Aldeias et al. 2012; Berna et al. 2007, 2012; Goldberg et al. 2009; Mallol et al. 2007), and combustion structures are considered key archaeological remains to study human behavior given their exclusive anthropogenic origin (Berna et al. 2012; Mallol et al. 2013). Presence of combustion structures in archaeological contexts implies the ability to control and produce fire, and a role of fire in subsistence strategies and other behavioral domains (Mallol et al. 2013; Mentzer 2014). By studying fire we can obtain information about fuel sources and associated group mobility, intensity and functionality of fire use and domestic spatial organization (Galanidou 1997; Leierer et al. 2019; Mallol et al. 2013, 2007; Mentzer 2014; Miller 2011), and therefore, it is also a source of information about human culture and behavior (Karkanas et al. 2004; Leierer et al. 2019, 2020; Mallol et al. 2007; Schiffer et al. 2001; Vallverdú et al. 2012). Combustion structures can also be an aid in the identification and characterization of human occupation surfaces, which can be well-preserved by low-temperature burning from the fire above them (Mallol et al. 2013).

Combustion features are essentially sedimentary deposits. Thus, we can obtain relevant data by studying them from a geoarchaeological perspective (Aldeias et al. 2016; Berna et al. 2007; Berna and Goldberg 2007; Ferro-Vázquez et al. 2022; Gur-Arieh et al. 2014; Karkanas 2021; Karkanas et al. 2007, 2019; Leierer et al. 2020; Mallol et al. 2017; Miller 2011; Nicosia and Stoops 2017; Portillo et al. 2017), particularly through microstratigraphic approaches (Courty et al. 1989; Goldberg et al. 2009; Leierer et al. 2019, 2020; Mallol et al. 2013; Mentzer 2014).

Here, we present geoarchaeological data from Roques de García Rockshelter, a recently excavated Guanche site in Las Cañadas. This is the highest altitude cave archaeological site documented in the Canary Islands and the only documented inhabited cave in the area. We carried out a microcontextual study of a combustion feature coupling soil micromorphology and lipid biomarkers (compound identification and compound-specific carbon isotope analysis) of sediment samples to approach site formation processes and to characterize and assess the degree of integrity of the archaeological combustion feature. Our study included lipid and isotopic characterization of reference samples from Canarian endemic plants present in the site surroundings and identified by anthracologists in different archaeological contexts within Las Cañadas (Machado and Galván 1998; Vidal-Matutano et al. 2019). With this approach, we aim to improve our understanding of Guanche mobility patterns, resource catchment and site use, and obtain paleoenvironmental and site formation data to approach economic practices in highland archaeological contexts.

Materials and methods

Environmental and site background

Roques de García Rockshelter is an archaeological site located at 2290 m.a.s.l. in Las Cañadas del Teide, which is part of Teide National Park (Fig. 2). This highland area is characterized by a semi-arid climate with dry air, low annual rainfall and high insulation (Criado et al. 2009; Jonsson et al. 2002; Santos Guerra 1984).

The site is located in one of many *aa* and *pahoehoe* lava tubes visible on the SW slope of El Teide volcano, which dates to 27,030 ± 430 yr BP (Carracedo et al. 2007) (Fig. 1). The Teide-Pico Viejo lava flow complex rests on Lower Pleistocene deposits mainly composed of trachybasalts and plagioclasic basalts (Dorado et al. 2021; Martín and Esnaola 1984).

The rockshelter is a collapsed portion of a volcanic tube linked to the Pico Viejo (3135 m.a.s.l.) volcanic edifice. Volcanic rockshelters are formed by lava flow dynamics, and their main geomorphic features consist of collapsed lava tubes, liftup caves, blisters and inflationary caves (Mentzer 2017). Rockshelters have been occupied by human populations for a wide variety of purposes: storage, protection, natural resources management and rituals (Binford 1998; Mentzer 2017). From an archaeological perspective, rockshelters are geomorphological features that contribute to the preservation of the archaeosedimentary record deposited inside them (Mentzer 2017).

Roques de García Rockshelter has been investigated by M.A. and E.M. since 2013, as part of a broader project centering on the high-altitude aboriginal occupation of Las Cañadas. Archaeological excavations (carried out by PRORED Soc. Coop.) at the Eastern and Southern areas of the sedimentary deposit took place in 2013 and 2018, unearthing a 50-cm-thick stratified sequence comprising several layers with aboriginal archaeological remains.

The lithostratigraphic sequence is made up of five distinct layers of loose pyroclastic silty sands with variable proportions of gravel (Table 1; Fig. 3). Part of the deposit showed recent anthropogenic disturbance evidenced as localized sediment reworking and removal. The aboriginal archaeological remains are homogeneous throughout the excavated deposit and mainly consist of low amounts of scattered

Fig. 2 Photographs of Roques de García Rockshelter and its surroundings. **A**) View of Las Cañadas plateau and Roques de García, and the top of the rockshelter **B**) View of the top of the rockshelter and the Teide volcano **C**) View of the inside of the volcanic tube

Table 1 Thickness and field descriptions of the Roques de García stratigraphic units

Stratigraphic Unit	Thickness	Description
V	11 cm	Dark brown loose pyroclastic sand
IV	8 cm	Brown layered pyroclastic sand and clay
III	10 cm	Very dark brown loose pyroclastic sand and gravel
II	6 cm	Light brown compact pyroclastic sand
I	13 cm	White loose silt

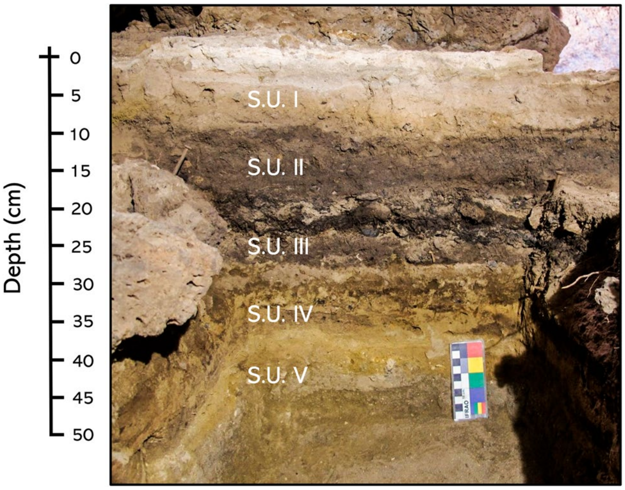


Fig. 3 Roques de García lithostratigraphic sequence indicating the five different units (I-V) that were identified in the field

sheep/goat burnt and calcined bone fragments, basalt and obsidian flakes and pottery fragments.

Archaeological soil micromorphology

Archaeological soil micromorphology is a geoarchaeological technique with great potential for analyzing and understanding site formation, specific sedimentary components, paleoenvironment, depositional and postdepositional processes, as well as microcontextual features (Courty et al. 1989; Goldberg and Berna 2010; Nicosia and Stoops 2017).

For the analysis, three intact and oriented sediment blocks (Fig. 4) from two Northeast profiles of the site were taken, and then processed into 8 petrographic thin sections in two different laboratories. Block 1 was processed by Thomas Beckmann (Schwülper-Lagesbüttel, Germany) into three thin Sects. (9 cm × 6 cm × 30 μm). The remaining blocks were processed at the Archaeological Micromorphology and Biomarkers Lab (AMBILAB, University of La Laguna, Tenerife, Spain) by Caterina Rodríguez de Vera, following the procedure described by Leierer et al. (2019). This included drying the blocks for 48 h at 60 °C and impregnating them with a 7:3:0.1 v/v/v ratio mixture composed of polyester resin (palatal cast resin UN1866, TNK compounds), styrene (styrene monomer (CAS: 100–42-5) UN2055, TNK compounds) and catalyst (methyl ethyl ketone (Luperox, CAS: 78–93-3), TNK compounds). Then, the hardened blocks were cut into 1-cm-thick slabs using a Euro-Shatal M31100 radial saw and glued onto 9 × 6 cm glass slides. Their depth was reduced to 1 mm using a Uniprec ATA Brilliant-220

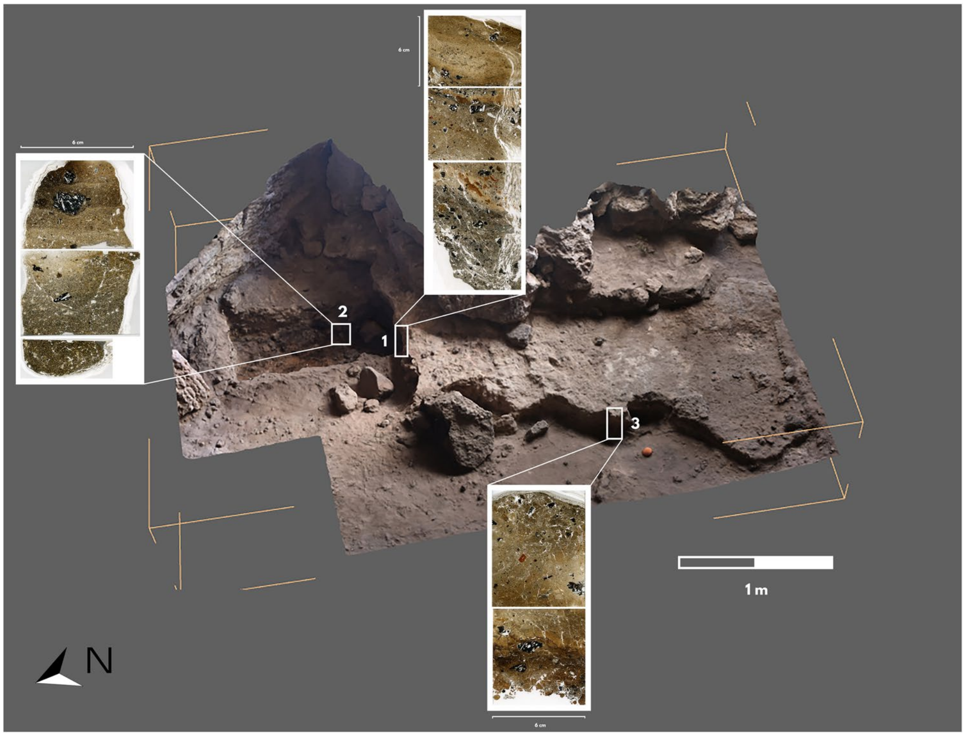


Fig. 4 Plan view of the excavated area showing the location of the micromorphological samples included in this study. Lipid biomarkers sediment samples were collected in association with Samples 1 and 2

precision cutting machine and polished down to 30 µm using a G&N MPS-RC-Geology grinding machine.

For the micromorphological analysis, we used two petrographic microscopes, Nikon E600-POL and Nikon AZ100 with epifluorescence module, located at AMBILAB. Microphotos were taken using a Nikon DS-Ri2 camera.

The thin sections were described following standard guidelines from Stoops (2003) and Nicosia and Stoops (2017). To describe the thin sections, we employed the concept of sedimentary microfacies (sensu Courty 2001 or Karkanas et al. 2015) and classified micromorphological features into Microfacies Units (MFU) and Microfacies Types (MFT) to facilitate the identification of depositional and postdepositional processes (sensu Goldberg et al. 2009). For our purposes, Microfacies Unit (MFU) is a stratigraphically and spatially discrete combination of micromorphological features and a Microfacies Type (MFT) denotes the processes represented by particular groups of Microfacies Units.

Lipid biomarkers

Lipid biomarkers are organic molecules that are representative of specific biota sources which hold a great potential for conservation in soils and sediments (Gaines et al. 2009; Peters et al. 2007), because they are hydrophobic complex molecular fossils (composed of carbon, hydrogen and other elements) derived from past living organisms (Peters et al. 2007). They have been widely studied in archaeological contexts, providing useful information about diet or past technology and mainly focusing in ecofacts and artifacts, such as pottery (Lucquin et al. 2007; Namdar et al. 2009; Rafferty 2006); rocky surfaces (Buonasera 2016), mummies and human remains (Evershed et al. 1995; Gülacara et al. 1990) and natural bitumens, plant resins and plant pyrolysis products (Dudd and Evershed 1999; Regert et al. 2003; Pollard et al. 2017). The study of lipid biomarkers in archaeological sedimentary contexts is more recent (Birk et al. 2012; Buonasera et al. 2015; Collins et al. 2017; Connolly et al. 2019; Égüez et al. 2020; Leierer et al. 2019, 2020; Sistiaga et al. 2011, 2014; Prost et al. 2017) and is starting to show its potential as a geoarchaeological tool for approaching past human societies and their environments.

Lipid extraction, analysis and quantification

Twelve bulk sediment samples were collected from the Northeast profile of the site, adjacent to the micromorphology blocks (Fig. 4). One of the bulk sediment samples (sample 6) contained thin (3 mm ⌀), cm-sized, unidentified charred twigs that were analyzed separately (see supplementary material). We also collected fresh samples from endemic plant species currently present in the site's surroundings as reference to compare their lipid profiles. We sampled summer and winter specimens of six species: *Spartocytisus supranubius* (retama), *Juniperus cedrus spp. canariensis* (Canarian cedar), *Juniperus turbinata* (sabina), *Pterocephalus lasiospermus* (rosalillo de cumbre), *Adenocarpus viscosus* (codeso de cumbre) and *Arrhenatherum calderae* (mazorrilla del Teide). The *Juniperus cedrus spp. canariensis* (Canarian cedar) and *Juniperus turbinata* (sabina) samples were collected at lower altitudes.

All the samples were collected using sterilized metal tools and nitrile gloves, then packed in aluminum foil to avoid phthalate contamination, and stored at –20 °C. Plant samples (twigs) were cleaned with Milli-Q® ultrapure water and dried at 60 °C for 24 h (Jambrina-Enríquez et al. 2018), whereas sediment samples were dried at 60 °C for 48 h (Leierer et al. 2019, 2020). We processed each sample in a fresh and burnt state to control for changes in the lipid profile through charring. For the fresh samples, we cut 1 g of branches of each species. For the burnt ones, twigs of each species were cut into 1-cm-long pieces, and then burnt in a crucible of 4,2 cm diameter and 2,5 height, covered with aluminum foil to limit O_2 supply during the process (Wiedemeier et al. 2015). Each sample was burnt for 1 h at 350 °C in a muffle furnace, at a ramp of 26 °C / min (Kuo et al. 2008). When the combustion had taken place, samples were left to cool inside the furnace for 24 h, and then homogenized and subsampled into ~ 1 g samples.

The plant and sediment samples were processed and analyzed at AMBILAB, following the procedure already employed by Jambrina-Enríquez et al. (2018), Leierer et al. (2019) and Connolly et al. (2019). 1 g of cut and homogenized twigs (fresh and burnt) and 2 g of homogenized sediment were taken from each sample to extract their Total Lipid Content (TLE). Lipids were extracted three times using a 20 mL 9:1 v/v mixture of dichloromethane (DCM)/methanol (MeOH) under ultrasonic irradiation for 30 min (USC 600th from VWR International, Barcelona, Spain). The mixture was then centrifuged at 4700 rpm for 10 min (Mega Star 1.6 from VWT International) and filtered through pyrolized glass wool. The final extracts were combined and evaporated using a Nitrogen evaporator at 40 °C (RapidVap® Vertex Evaporator from Labconco, Missouri, USA).

Once the TLE was obtained, it was fractionated using a chromatographic column made of 1 g of calcined silica gel (70–230 mesh) and 0.1 g of sterilized sand (50–70 mesh). Fractions 1 (*n*-alkanes), 2 (aromatics), 3 (ketones), 4 (alcohols) 5 (fatty acids) and 6 (other compounds) were extracted for each sample (Table 2), evaporated under nitrogen flow and finally stored at –20 °C until the analysis.

For the alcohols, we added 100 µL of N, O-Bis (trimethylsilyl) trifluoroacetamide (BSTFA) and trimethylchlorosilane (TCMS) 99:1 v/v to obtain trimethylsilyl esters (TMS). The mixture was derivatized at 80 °C for 1 h, then dried and reconstituted with 50 µL of DCM. The fatty acids and other polar compounds, on the other hand, were derivatized to methyl-esters by adding 5 mL of MeOH and 400 µL of de H_2SO_4, then heated at 70 °C for 4 h. The mixture was then neutralized with a sodium bicarbonate saturated solution and extracted three times using 3 mL of *n*-hexane. The samples were finally dried under nitrogen flow and reconstituted with 50 µL of DCM. Reconstitution for each fraction employed 50 µL of DCM per sample.

Before measuring employing gas chromatography (GC), we added the internal standard (IS) to each fraction according to the data presented in Table 2, and then reconstituted them using solvent (DCM). Every fraction was analyzed employing GC. To determine and quantify the compounds present in plants and sediments, an Agilent 7890B gas chromatograph was used, attached to a 59774A single quadrupole (Q) MSD with an electron impact interface and equipped with an automatic injector and a multimode injector (Agilent Technologies, Waldbronn, Germany). The MassHunter Workstation Software was used to control the system, as well as to acquire and process the data.

The equipment conditions were similar to the ones described by Jambrina-Enríquez et al. (2018), Herrera-Herrera and Mallol (2018) and Leierer et al. (2019). A ((5% phenyl) -metipolysiloxane, length: 30 m, ID: 250 µm, 0.25 µm thickness; Agilent Technologies) fused silica capillary column was used for analyte separation. Helium flux was set at 1.0 mL/min. The GC oven was initially programmed at 70 °C, and this temperature was maintained for 2 min. Subsequently, the temperature increased to 140 °C (at a heating rate of 12 °C/min), and, finally, it reached 320 °C (at a heating rate of 3 °C/min), holding it for 15 min. The multimode injector (MMI) was maintained in the 5: 1 split ratio at an initial temperature of 70 °C for 0.85 min, and heated to 300 °C, at the configured rate of 720 °C/min. Regarding the MS, the transfer line, the ion source and the quadrupole were adjusted to 280 °C, 230 °C and 150 °C, respectively.

Table 2 Solvents and elution volumes, and internal standards used to extract each lipid fraction

Fraction	Solvents and elution	Internal Standard (IS)
1 *n*-alkanes	3/8 dead volume (DV) *n*-Hexane	5α-androstane
2 aromatics	2 DV 8:2 v/v *n*-Hexane/DCM	5α-androstane
3 ketones	2 DV DCM	5α-androstane
4 alcohols	2 DV 1:1 v/v DCM:EtOAc	5α-androstan-3β-ol
5 fatty acids	2 DV EtOAc	Methyl C19:0
6 other compounds	2 DV MeOH	Methyl C19:0

The electron ionization energy level was -70 eV, and the analyzer was used in full scan mode (m/z 40–580).

The compounds were identified by comparing their retention times and reference spectra from pure standards (see supplementary material from Rodríguez de Vera et al. 2020), as well as using the NIST Mass Spectrum Library. The *n*-alkanes were quantified using calibration curves obtained by plotting the Area/AreaIS ratio against the concentration of reference standards. In addition, the four most intense fragment ions were taken in the mass spectra for quantification (m/z 43, 57, 71, and 85 for alkanes; m/z 67, 81, 95, and 245 for the IS internal standard). The concentrations for the other compounds were estimated by comparison with the IS area. Concentrations are presented in µg per gram of dried sample (µg/gds).

To facilitate the interpretation of the data from Fraction 1, we calculated the following indexes and ratios employing the *n*-alkane quantifications obtained through calibration curves:

- OEP 27–31 (odd-over-even predominance), formulated by Hoefs et al. (2002), for determining the preservation degree of organic matter.
- ACL 25–31 (average chain length), the weighted average of the various lengths of the carbon chain formulated by Freeman and Pancost (2014), which allows the evaluation of the characteristics of the biomass.
- Ratios $nC_{31}/nC_{29}+nC_{31}$ and $nC_{31}/nC_{27}+nC_{31}$, which allow the identification of the predominance of terrestrial and shrub flora *vs* woody flora (Cranwell 1973; Meyers and Ishiwatari 1993).

Compound-specific carbon isotope analysis (CSIA)

Compound-specific carbon isotope analyses of *n*-alkanes and fatty acids were carried out at AMBILAB (Tenerife, Spain) following the steps described by Jambrina-Enríquez et al. (2018, 2019), Connolly et al. (2019) and Leierer et al. (2019). This was carried out using a Thermo Scientific Isotope Ratio Mass Spectrometer Delta V Advantage joint to a GC Trace 1310 through a Conflo IV interface with a GC Isolink II. Plant and bulk sediment samples were injected employing a Programmer Temperature Vaporizing injector (PTV) in splitless mode. The initial temperature, 60 °C (held for 0.05 min), was followed by an evaporation stage in which temperature increased to 79 °C (held for 0.5 min) and a transfer stage, with temperature increasing to 325 °C (held for 3 min) and a 10 °C/s rate. In the last stage, temperature reached 350 °C (held for 3 min and with a 14 °C/s rate) for cleaning. GC was fitted with a Trace Gold 5-MS (Thermo Scientific) fused silica capillary column ((5%-diphenyl)-dimethylpolysiloxane) of 30 m length × 0.25 mm and 0.25 µm film thickness. Helium flowed at a rate set of 1.5 mL/min, and the oven temperature increased to 70 °C (held for 2 min) to 140 °C (12 °C/min), from 140 °C to 320 °C (held for 15 min, rate 3 °C/min). Finally, the temperature of the combustion reactor was maintained at 1000 °C.

Isodat 3.0 software (Thermo Scientific) was used for data processing, repeating measurements three times. The $\delta^{13}C$ values were normalized with a *n*-alkane Schimmelmann-type A6 mixture (from nC_{16} to nC_{30}) to the Vienna Pee Dee Belemnite (VPBD) scale. Carbon isotope measurements showed a standard deviation below 0.5 ‰. For fatty acids, a FAME F8 standard mixture (from C14:0 methyl ester to C20:0 ethyl ester, Arndt Schimmelmann

Table 3 Description of the main components identified in the micromorphological samples

Components	Description
Charcoal	Very abundant in the middle of the sequence Variable size, from silt to coarse sand Variable shape, from angular to rounded
Charred plant material	Very abundant throughout the whole sequence Silt sized Rounded, crumbly
Phytoliths	In the central area of the sequence, grouped
Orange-colored bone fragments	Abundant Variable size and shape, from rounded to angular Some burnt and fissured
Sheep/goat tooth fragments	Few, in the middle of the sequence Angular shape
Lithic artifacts	Few, in the middle of the sequence Angular shape Obsidian and basalt
Herbivore coprolites	Few, in the middle of the sequence Fibrous Some burnt
Sheep/goat dung	Very abundant in the middle of the sequence Spherulitic Some burnt

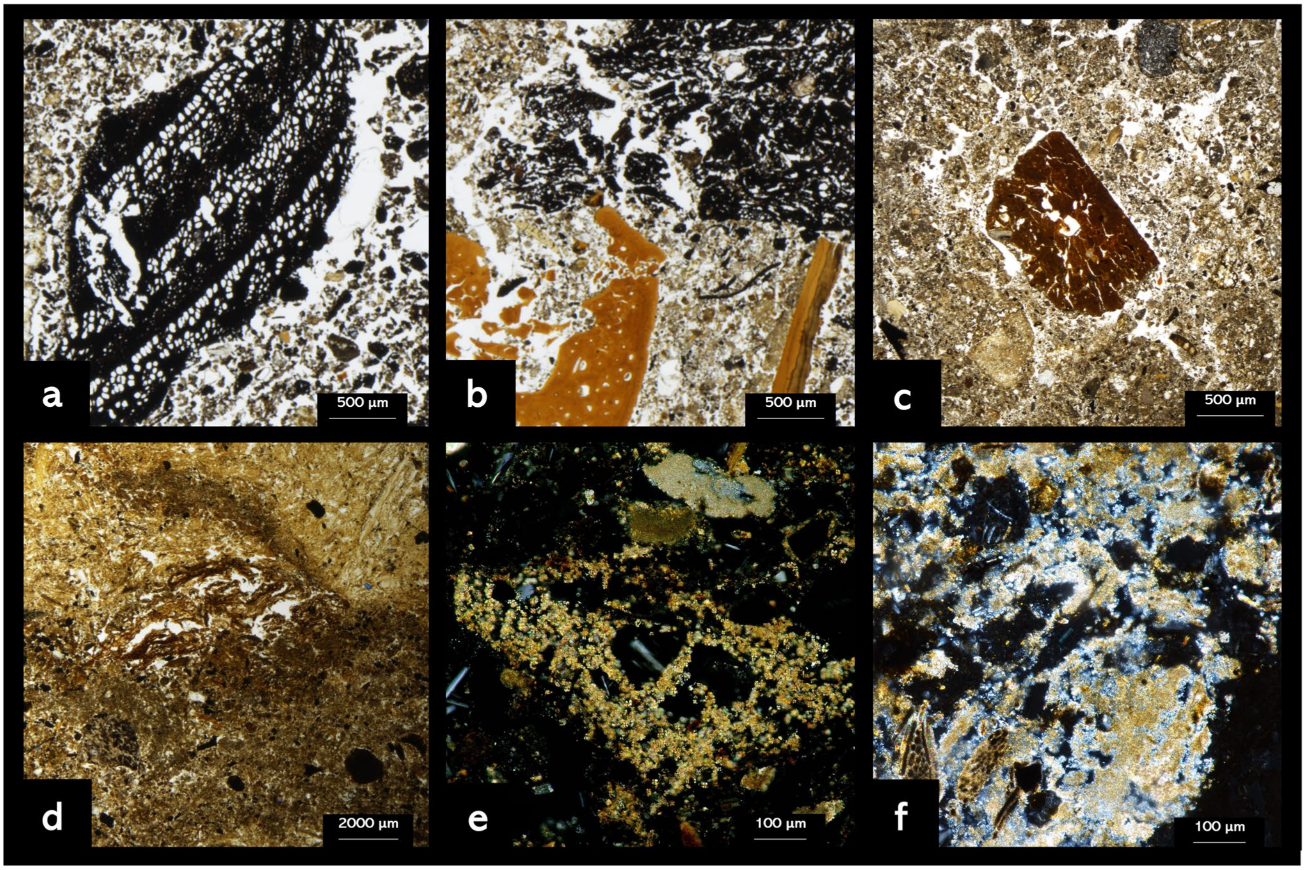


Fig. 5 Microphotographs of the most representative microscopic components identified throughout the sedimentary sequence. **A**) Charcoal. It is commonly found both rounded and angular. **B**) Burnt herbivore coprolite and bone fragments, abundant in the middle of the sequence **C**) Pottery fragment **D**) Sheep/goat dung. It is found burnt and unburnt **E**) Dung spherulites **F**) Calcitic wood ash

Biogeochemical Laboratories, Indiana University) was run prior to the analyses, and the standard deviation of the FAMEs mixture was for each analysis equal or better than ±0.5‰.

The mass balance equation employed by Goodman and Brenna (1992) was used to correct all the free fatty acids results from the isotopic signature of the introduced methyl groups. The $\delta^{13}C$ values for modern plant samples were corrected by + 1.9‰ to match archaeological values (Jambrina-Enríquez et al. 2019), due to the decrease in atmospheric $^{13}CO_2$ associated with ^{13}C. This corrected value is based on the assumption of a preindustrial atmospheric $\delta^{13}C$ value of 6.4‰ (McCarroll and Loader 2004) and the δ^{13}Catm value at the time of sampling (8.3‰) (Keeling et al. 2010).

Total organic and inorganic carbon

To determine the organic and inorganic carbon presence in the archaeosedimentary sequence, total carbon (TC), total organic carbon (TOC) and total inorganic carbon (TIC) were analyzed from subsamples of each of the twelve bulk sediment samples using a LECO SC 144DR furnace at Instituto Pirenaico de Ecología (IPE-CSIC), Spain.

Statistical analyses

Statistical analyses, Shapiro–Wilk test (p-value 0.0003631), one-way ANOVA (alpha level of 0.05, F = 5.7458, p-value = 0.005852), Tukey's test (95% family-wise confidence level), and confidence ellipses of a two-dimensional dataset, were performed on R Studio v.1.4.1106. We used analysis of variance to compare isotopic signatures and to determine probable differences between groups: archaeological samples, reference samples dataset (Jambrina-Enríquez et al. 2019) and the collected modern plants. 95% confidence ellipses of $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ were also calculated for the different groups, to test the variability of bivariate group means.

Results

Archaeological soil micromorphology

We identified 23 Microfacies Units (MFU) associated with 13 biomarker samples (Fig. 6; Table 4).

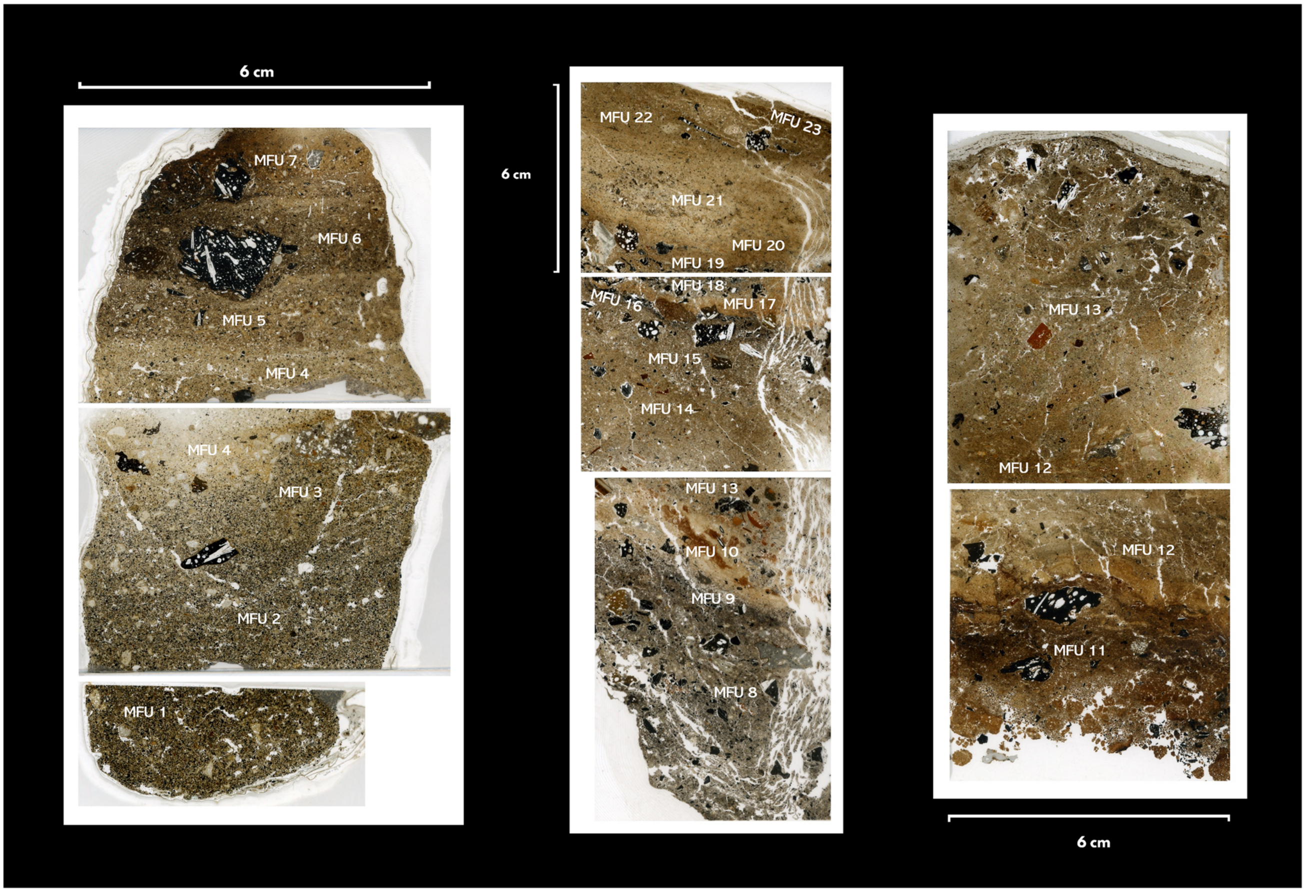


Fig. 6 Microfacies units (MFU) identified in the micromorphological samples. A more detailed description of the microfacies units and their stratigraphic position is presented in Table 4

All the samples show the same lithological composition consisting of sand-to-gravel-sized basalt and pumice fragments, silt-sand-sized obsidian fragments and igneous mineral grains. We also documented the presence of silt-sized eolian quartz in very small amounts.

We identified two different types of microstructures throughout the sequence: 1) An intergrain microaggregate microstructure prevails in the lower and middle third of the sequence (MFU 1, 2, 3, 4, 5, 8, 9, 13, 14, 15, 19 and 20); 2) a compact, fibrous microstructure prevails in the upper part (MFU 6, 7, 11, 12, 17, 21, 22 and 23). The predominant c/f-related distribution patterns are enaulic and porphyric, and complex packing voids were observed throughout the whole sequence.

The main anthropogenic and biogenic components observed are charcoal fragments and unidentified charred plant material. Other components include: phytoliths, orange-colored bone fragments, sheep/goat teeth fragments, lithic artifacts, unidentified herbivore coprolites (burnt and unburnt) and sheep/goat dung (see Table 3 and Figs. 5 and 6).

Based on the recurrence of different combinations of coarse components, level of compaction, c/f-related distribution, micromass features and microstructures, we classified the Microfacies Units into 10 Microfacies Types (MFT; Fig. 7; Table 4).

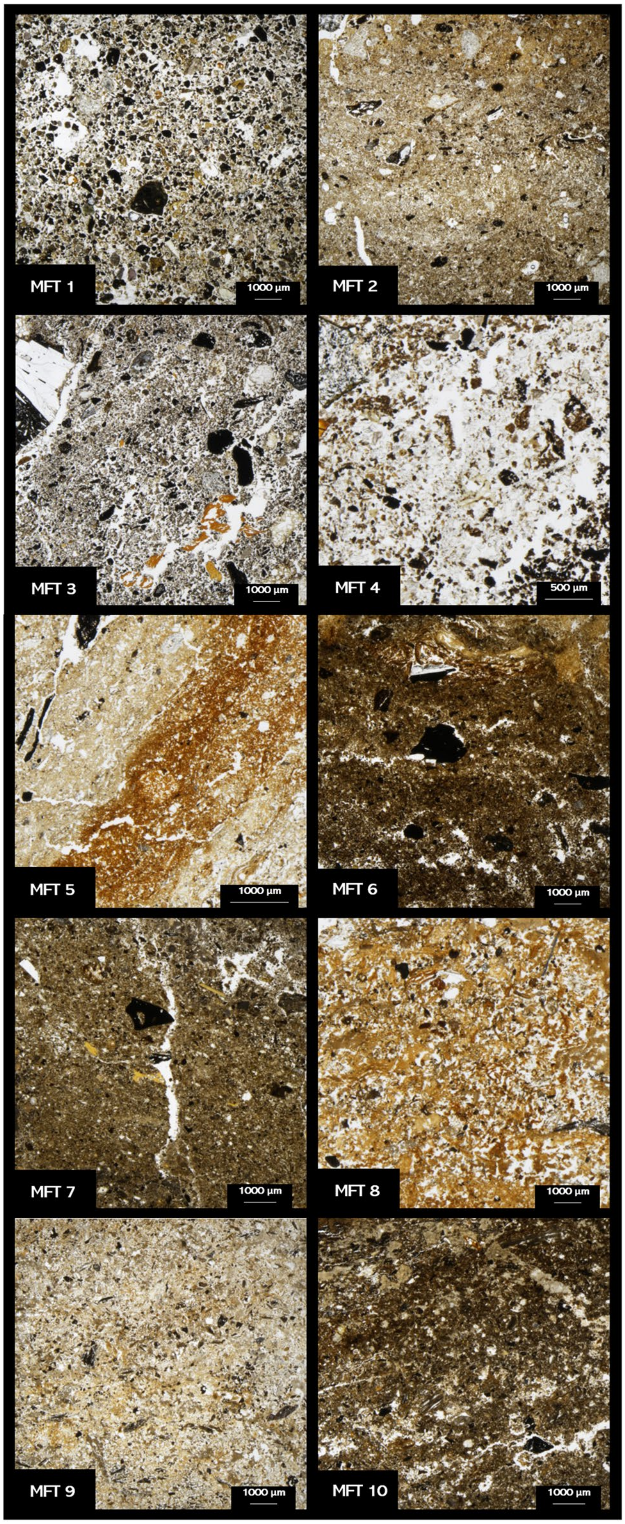
Lipid biomarkers, CSIA and total organic and inorganic carbon

Archaeological samples

n-Alkane data was obtained from 9 of the 13 archaeological samples. The *n*-alkane distribution ranges from $n\mathrm{C}_{18}$ to $n\mathrm{C}_{31}$, and *n*-alkane concentration varies between 0.02 to 5.21 µg/gds (Fig. 8). *n*-Alkane indexes and ratios (OEP, ACL, $n\mathrm{C}_{31}/n\mathrm{C}_{29}+n\mathrm{C}_{31}$ and $n\mathrm{C}_{31}/n\mathrm{C}_{27}+n\mathrm{C}_{31}$) were calculated on the samples with significant *n*-alkane content (Fig. 9). OEP values oscillate between 7.24 and 1.34, while ACL ranges from 29.70 to 26.00. Aromatics, alcohols, acids, terpenoids and other compounds were also identified and estimated in 11 of the 13 samples (see supplementary material).

δ^{13}C values of $n\mathrm{C}_{29}$ and $n\mathrm{C}_{31}$ alkanes were measured in the 13 archaeological samples. δ^{13}C values of $n\mathrm{C}_{29}$ range

Fig. 7 Microfacies types (MFT) identified in the micromorphological ▶ samples. **MFT 1)** Geogenic pyroclastic sand deposit mixed with silt-sized, unidentified charred particles. **MFT 2)** Laminated pyroclastic sandy-clayey deposit with iron staining. **MFT 3)** Pyroclastic detritic sandy deposit mixed with silt-sized, unidentified charred particles, subrounded charcoal fragments and horizontally bedded bone fragment concentrations. **MFT 4)** Geogenic volcanic sand. **MFT 5)** Phytolith-rich fibrous clayey deposit with charcoal fragments at the top. **MFT 6)** Fibrous, horizontally bedded, spherulite-rich, unburnt sheep/goat excrements mixed with reworked calcitic-crystalitic wood ash. There are common horizontal planes. **MFT 7)** Fibrous, spherulite-rich sheep/goat excrements (mostly unburnt but some burnt) mixed with reworked calcitic-crystalitic wood ash. There are common vertical planes. **MFT 8)** Reworked calcitic-crystalitic wood ash with charcoal and bone fragments. **MFT 9)** Calcitic-crystalitic wood ash. **MFT 10)** Silty-clayey crust



between –30.5‰ and –28.2‰, while $\delta^{13}C$ values of nC_{31} oscillate between –29.6‰ and –27.2‰ (Figs. 9, 10, 11, supplementary material). $\delta^{13}C$ values of palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) acids were also measured in 7 of the 13 archaeological samples (see supplementary material).

TIC and TOC values were obtained for the 12 loose sediment samples (Fig. 9). TIC ranges between 4.27% and 0.00%, whereas TOC values oscillate between 21.23% and 0.11%.

Reference samples

n-Alkanes**,** aromatics, alcohols, acids, terpenoids, aldehydes and other compounds were identified and quantified or estimated in all the plant reference samples, fresh and burnt (350 °C) (see supplementary material). $\delta^{13}C$ values of nC_{29} and nC_{31} alkanes were measured for all the samples. $\delta^{13}C$ of nC_{29} ranges from –25.8‰ and –31.1‰ in the summer specimens, and between –24.9‰ and –31.7‰ for the winter samples. $\delta^{13}C$ of nC_{31} values, on the other hand, oscillate between –25.5‰ and –30.2‰ for the summer samples, and between –22.7‰ and –29.7‰ for the winter ones (corrected values) (Figs. 9, 10, 11, supplementary material). $\delta^{13}C$ values of palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) acids were also measured in all the samples (see supplementary material). The ANOVA (alpha level of 0.05) and Tukey's test performed on the $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ values from the different sample groups showed that the means of summer and archaeological samples were similar, as opposed to the winter-archaeological pairwise that showed significant differences (diff = 1.5305109, lwr = 0.2866333 upr = 2.774388 p-value = 0.0118919).

Discussion

The main goal of this study was to characterize an archaeological combustion feature from the Roques de García Rockshelter site through a microcontextual approach. Our lipid and micromorphological results show that the sequence preserves reworked residues from at least two overlapping combustion structures (MFT 3, 8, 9) associated with two diachronous human occupation events (MFT 6, 7). Our data has allowed us to identify the fuel source employed

Table 4 Description of the microfacies units (MFU) that were determined through micromorphological analysis (see Fig. 6). Their correlation with microfacies types (MFT), stratigraphic units (S.U.) and the associated biomarker (BM) samples is also indicated

S.U	MFU	MFT	BM sample	Upper contact	Microstructure	C/f-related distribution	Compaction	Micromass	Components *	Other relevant features
I	23	10	1		Massive/fibrous	Porphyric	Compact	Calcitic-crystalitic brown, in situ ash	- Abundant charcoal and charred plant material - Gypsum crystals	
	22	9	2a	Diffuse	Fibrous	Porphyric	Compact	Calcitic-crystalitic, in situ ash	- Abundant charcoal and charred plant material - Few orange bone fragments	
	21		2b	Diffuse	Fibrous	Porphyric	Compact	Calcitic-crystalitic, in situ ash	- Abundant charcoal and charred plant material - Few orange bone fragments - Anorthic micritic nodules	
	20		3	Diffuse	Intergrain micro-aggregate	Porphyric	Compact	Calcitic-crystalitic, in situ ash	- Abundant charcoal and charred plant material - Few orange bone fragments	
	19	7		Diffuse	Intergrain micro-aggregate	Enaulic	Loose		- Abundant charcoal and charred plant material	
II	18		4	Diffuse	Intergrain micro-aggregate	Enaulic	Loose		- Horizontal layer formed by abundant charcoal fragments and charred plant material	
	17	8		Sharp	Fibrous	Enaulic	Loose	Calcitic-crystalitic micromass, abundant reworked ash	- Abundant charcoal and charred plant material - Few orange bone fragments, some burnt	
	16	7		Diffuse	Intergrain micro-aggregate	Enaulic	Loose		- Horizontal layer formed by charcoal and burnt herbivore coprolites	
	15		5	Sharp	Intergrain micro-aggregate	Enaulic	Loose	Calcitic-crystalitic brown micromass with reworked ash	- Abundant charcoal and charred plant material - Abundant orange bone fragments, some burnt	
	14			Diffuse	Intergrain micro-aggregate	Enaulic	Compact	Calcitic-crystalitic brown micromass with reworked ash	- Abundant charcoal and charred plant material - Abundant orange bone fragments, some burnt - Fissured and burnt sheep/goat excrements (spherulites), some burnt	- Subangular blocky peds - Vertical planes
	13		5	Diffuse	Intergrain micro-aggregate	Porphyric	Compact	Calcitic-crystalitic micromass with reworked ash	- Abundant charcoal and charred plant material - Frequent sheep/goat excrements (spherulites) - Abundant orange bone fragments, some burnt - Fissured and burnt sheep/goat tooth - Anorthic clay nodule	
	12	6	-	Diffuse	Fibrous	Porphyric	Compact	Orange calcitic-crystalitic micromass, reworked ash	- Abundant charcoal and charred plant material - Abundant sheep/goat excrements (unburnt spherulites, some burnt) - Abundant phytoliths - Frequent pottery remains	- Subangular/subrounded blocky peds - Horizontal and vertical planes
	11			Diffuse	Fibrous	Porphyric	Compact	Brown calcitic-crystalitic micromass, reworked ash	- Abundant charcoal and charred plant material - Abundant sheep/goat excrements (unburnt and burnt spherulites) - Abundant phytoliths - Few orange bone fragments	- Subangular blocky peds - Horizontal and vertical planes

Table 4 (continued)

S.U	MFU	MFT	BM sample	Upper contact	Microstructure	C/f-related distribution	Compaction	Micromass	Components *	Other relevant features
III	10	5	6	Sharp	Fibrous	Enaulic	Compact	Clayey isotropic micromass	- Abundant charcoal and charred plant material (upper contact) - Abundant phytoliths - Obsidian knapping remains (upper contact) - Few orange bone fragments - Herbivore coprolite	
	9	4		Diffuse	Intergrain microaggregate	Enaulic	Loose		- Frequent charcoal and charred plant material	
	8	3	6 Archaeological fuel	Diffuse	Intergrain microaggregate	Enaulic	Loose		- Abundant charcoal and charred plant material - Orange bone fragments, some burnt	
Upper contact III-IV	7	2	7	Sharp	Fibrous	Porphyric	Compact	Light brown clayey micromass, isotropic	- Abundant charcoal and charred plant material - Few small brown/orange bone fragments	- Horizontal layering
	6			Sharp	Fibrous	Porphyric	Compact		- Abundant rounded charcoal and silt-sized charred plant material - Few small brown bone fragment - Few burnt herbivore coprolites	
IV	5		8a	Sharp	Intergrain microaggregate	Porphyric	Compact		- Abundant rounded charcoal and silt-sized charred plant material	- Horizontal layering
	4			Sharp	Intergrain microaggregate	Porphyric	Compact		- Abundant rounded charcoal and silt-sized charred plant material - Few small brown and orange bone fragments	- Horizontal layering
	3	1	8b	Diffuse	Intergrain microaggregate	Porphyric	Compact	Clayey micromass, isotropic	- Abundant silt-sized charred plant material	
V	2		9	Diffuse	Intergrain microaggregate	Porphyric	Loose		- Abundant silt-sized charred plant material - Few small orange bone and charcoal fragments	
	1		10	Diffuse	Intergrain microaggregate	Porphyric	Loose		- Abundant silt-sized charred plant material - Few small charcoal fragments	

*Lithological components of all the samples consist of sand-to-gravel-sized basalt and pumice fragments, silt-sand-sized obsidian fragments and igneous mineral grains

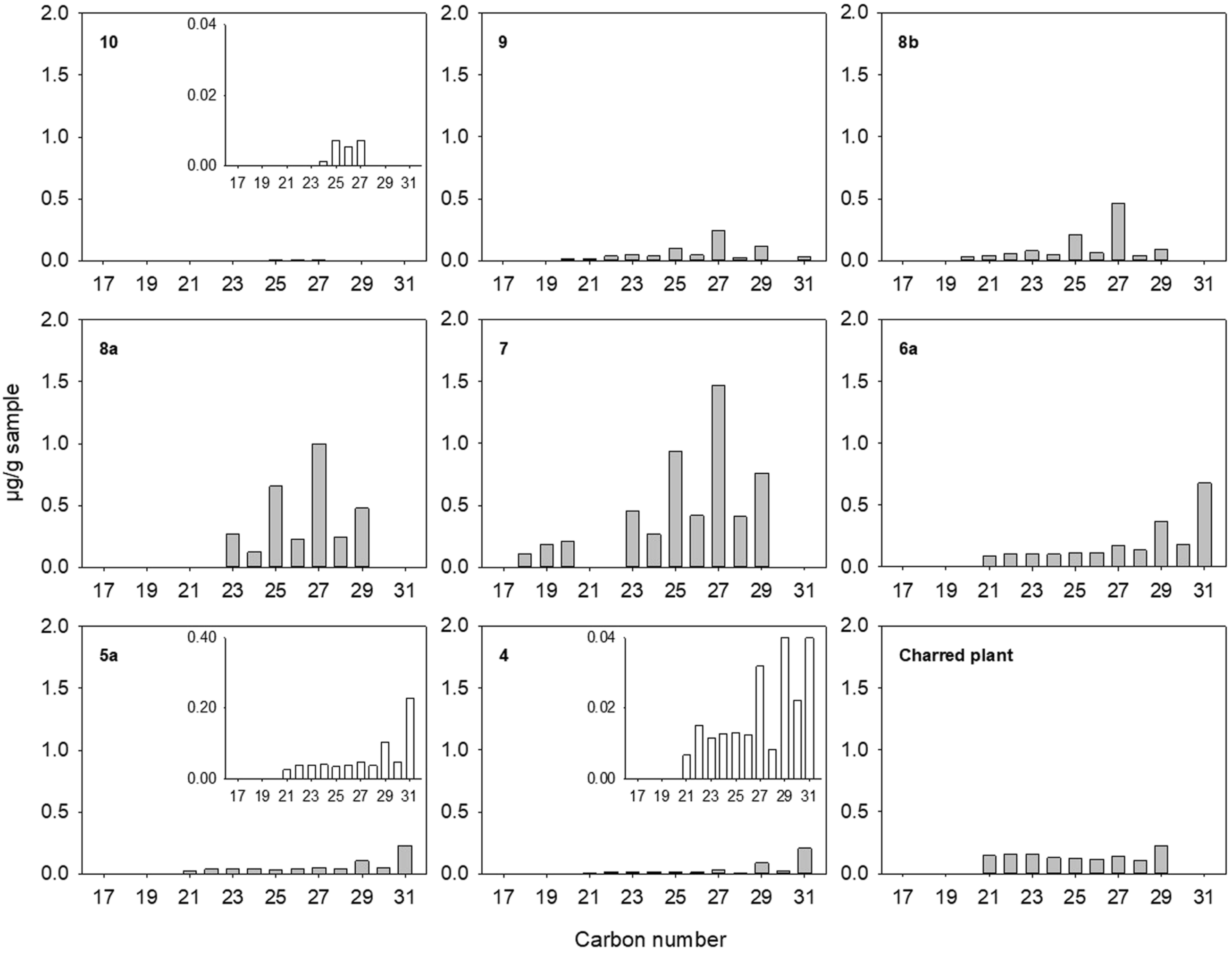


Fig. 8 Sedimentary *n*-alkane histograms

during one of the occupation events. It was also possible to identify plant residues representative of the natural habitat associated with the human occupations, preserved in the lower geogenic pyroclastic deposits (MFT 1, 2). We have also identified periods of geogenic sedimentation between human occupation layers, probably formed during abandonment periods (MFT 4, 5, 10). In the following paragraphs, we discuss the associated relevant information, their possible interpretation and their implications.

Fuel sources

Our lipid and micromorphological information has shed some light on the possible fuel sources of the Roques de Garcia combustion structures. Fuel, understood here as combustible matter that is introduced into a fire and generates an identifiable residue, which may have resulted from a circumstantial human action or from a tradition.

MFU 8 (MFT3) is a trample (Rentzel et al. 2017) from a combustion zone, containing a significant amount of microscopic combustion residues. According to our lipid data, the predominant alkane in a sample of loose sediment from this trample is $n\mathrm{C}_{31}$ with an odd over even predominance. However, a series of cm-sized charred woody fragments from this layer that were sampled separately showed $n\mathrm{C}_{29}$ as the predominant alkane with a smooth *n*-alkane pattern. Both the sedimentary and the woody fragment samples showed conifer wood pyromarkers, specifically retene and other compounds derived from abietic acid (see supplementary material) (Mackenzie et al. 1982; Oros and Simoneit 2001a, b). These data point toward a conifer plant fuel source. Our reference plant collection includes two conifer species: *Juniperus turbinata* (sabina) and *Juniperus cedrus spp. canariensis* (Canarian cedar). Both of these showed $n\mathrm{C}_{29}$ alkane predominance and produced retene when burnt at 350 °C, as expected (Oros and Simoneit 2001a). However, we have

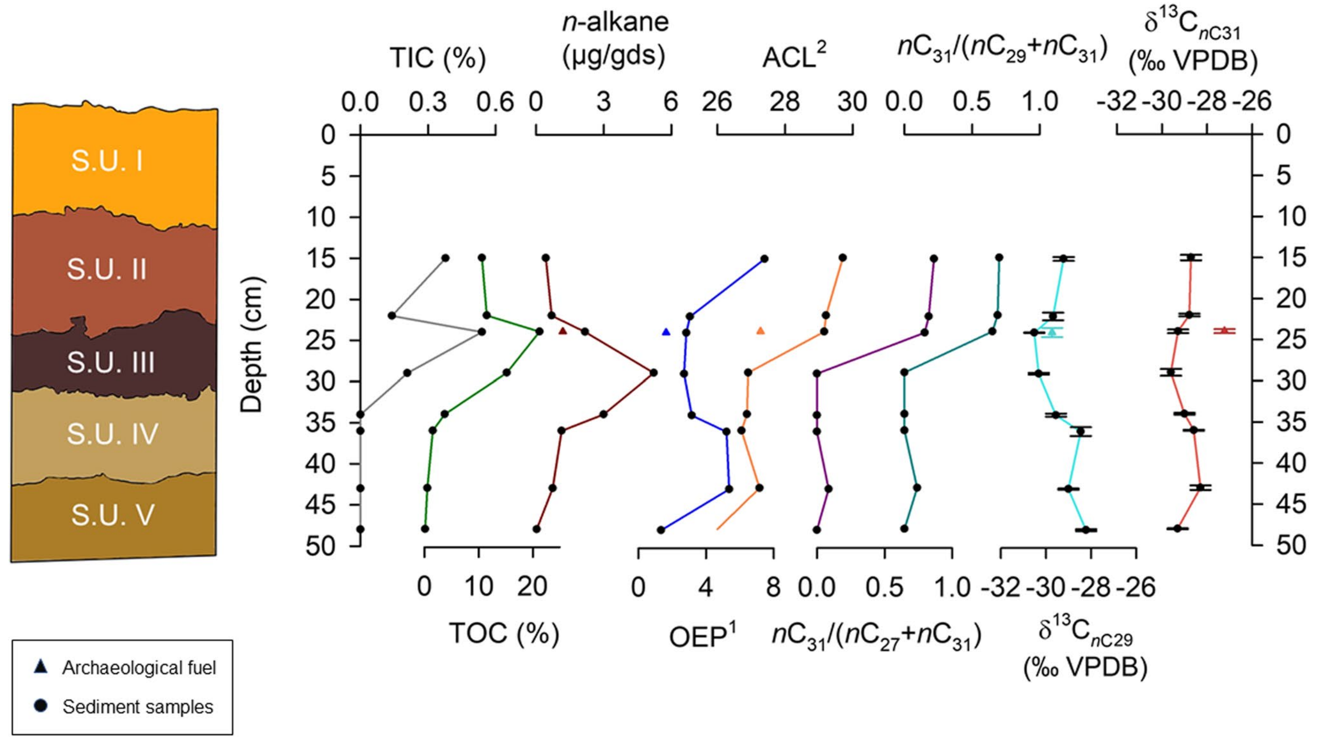


Fig. 9 Archaeological samples and their TIC, TOC, total *n*-alkane concentration, OEP[1], ACL[2], $nC_{31}/(nC_{27}+nC_{31})$, $nC_{31}/(nC_{29}+nC_{31})$, $\delta^{13}C$ of nC_{29} and nC_{31} *n*-alkanes values. OEP[1] $27\text{–}31=(nC_{27}+nC_{29}+nC_{31})\,/\,(nC_{26}+nC_{28}+nC_{30})$; ACL.[2] $25\text{–}31=(Ci^{*}[Ci])\,/\,\sum[Ci]$; Ci is the concentration of each *n*-alkane with i carbon atoms, $25<i<33$

identified differences between the two species regarding the abundance and concentration of *Cupressaceae* specific terpenoids (Otto and Simoneit 2001). While *Juniperus cedrus spp. canariensis*' (Canarian cedar) predominant compound is ferruginol (before and after burning), our *Juniperus turbinata* (sabina) samples showed abietane-type acids as the more abundant, characteristic terpenoids. However, and considering the nC_{31} *n*-alkane predominance in the sediment in which these twigs were found, we cannot absolutely rule out the presence of *Pinus canariensis* (Canarian pine) *input*, even though pine-related features (e.g., pine needles) were not identified micromorphologically.

In addition, $\delta^{13}C$ $C_{16:0}$ and $C_{18:0}$ values from archaeological charred woody fragments (Fig. 10) plot in a different area in 95% confidence ellipses than fresh and burnt (350 °C) branches of modern *Pinus canariensis* (Canarian pine) (Jambrina-Enríquez et al. 2019). In fact, our modern references, fresh and burnt-350 °C *Juniperus cedrus spp. canariensis* (Canarian cedar) and *Juniperus turbinata* (sabina), plot in a different area than the ellipses for C3 wood that were built with modern *Pinus canariensis* (Canarian pine). Moreover, when our reference *Juniperus turbinata* (sabina) fatty acids values were plotted against the archaeological charred wood, we observed significant similarities between them. More interestingly, we found probable indication that wood was collected during the summer season, or at least during a season with environmental conditions similar to the present-day Las Cañadas summer (Fig. 11). This result is promising and prompts further investigation as it could be used as an indicator of aboriginal fuel and/or wood management and subsistence practices (Machado and Galván 1998; Vidal-Matutano et al. 2019, 2021).

Thus, we propose that the predominance of nC_{29} alkane, the dominance of abietic-type compounds and the carbon isotopic signature of palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) acids in the MFU 8 charred woody fragment suggest that *Juniperus turbinata* (sabina) wood was one of the fuel sources used by the Guanches occupying the site. The use of sabina wood by the aboriginal people of Tenerife has been previously documented for the manufacturing of artifacts, such as vessels and sticks (García Morales and Sánchez-Pinto 1993; Rosario Adrián et al. 1993). At present, this thermophilic species is not found near the site but at much lower altitudes, in the midlands of Tenerife (Jiménez et al. 2017). If this was the case in Guanche times, procuring this fuel required planning and transport strategies. However, the possibility of *Juniperus turbinata* (sabina) populations growing at higher altitudes in the past cannot be ruled out, as paleoecological studies have shown for the related species

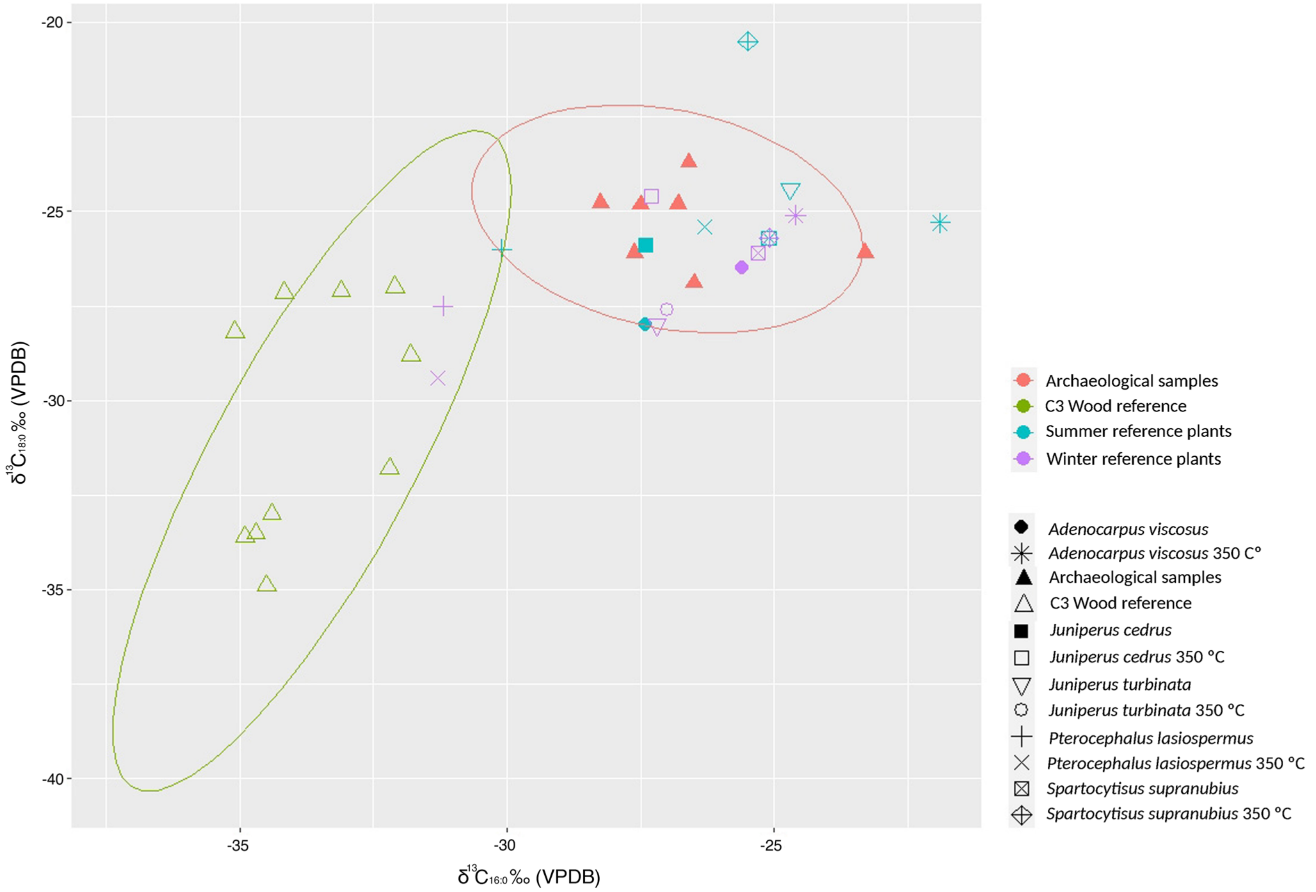


Fig. 10 Scatter plot of $\delta^{13}C_{16:0}/\delta^{13}C_{18:0}$ ratios comparison with 95% confidence ellipses plotted using the archaeological sediment samples, reference published data on isotopic ratios for C3 wood (*Celtis australis* and *Pinus canariensis* from Jambrina-Enríquez et al. 2019), and the modern plants collected for this study (summer and winter season). Note that modern samples from *Juniperus turbinata* (sabina) fall into the archaeological samples ellipse

Juniperus cedrus (Canarian cedar) in Tenerife (Rumeu and Nogales 2021; Sangüesa-Barreda et al. 2022).

The anthropogenic context

Regarding the predominance of nC_{31} in the anthropogenic microfacies (MFUs 8, 13–16 / MFT 3, a trample from a combustion zone, and MFT 6–7, human occupation deposits mixed with reworked ash and anthropogenic components) we propose two possible sources: 1) grasses and/or 2) conifers (Schwark et al. 2002).

In the upper layers (MFUs 13–16), the nC_{31} alkane *input* is microstratigraphically associated with sheep/goat dung scatters reworked into the human occupation deposits, as identified micromorphologically by the presence of spherulite-rich pellets mixed with reworked combustion residues. This evidence suggests that the lipid signature could derive from sheep/goat dung derived from consumption of herbaceous fodder (Cranwell 1973; Égüez et al. 2018). Alternatively, or in addition to the possible fodder signature, the presence of dehydroabietic acid in the sample from these mixed, reworked combustion units could link the nC_{31} alkane input with conifer fuel residues (Otto and Wilde 2001).

The conifer source is more evident in the lower anthropogenic microfacies (MFU 8), which showed presence of varied terpenoids (Otto and Wilde 2001) (see supplementary material). Micromorphologically, dung was not observed in this microfacies, and we interpret it as a combustion zone trample in which other plant specimens could have been burnt in different events.

The natural vegetation

Micromorphological analysis elucidates a distinction between combustion-rich anthropogenic surfaces (MFT 3, 6, 7, 8, 9) and natural, non-anthropogenic deposits with geogenic, pyroclastic sandy-clayey components and

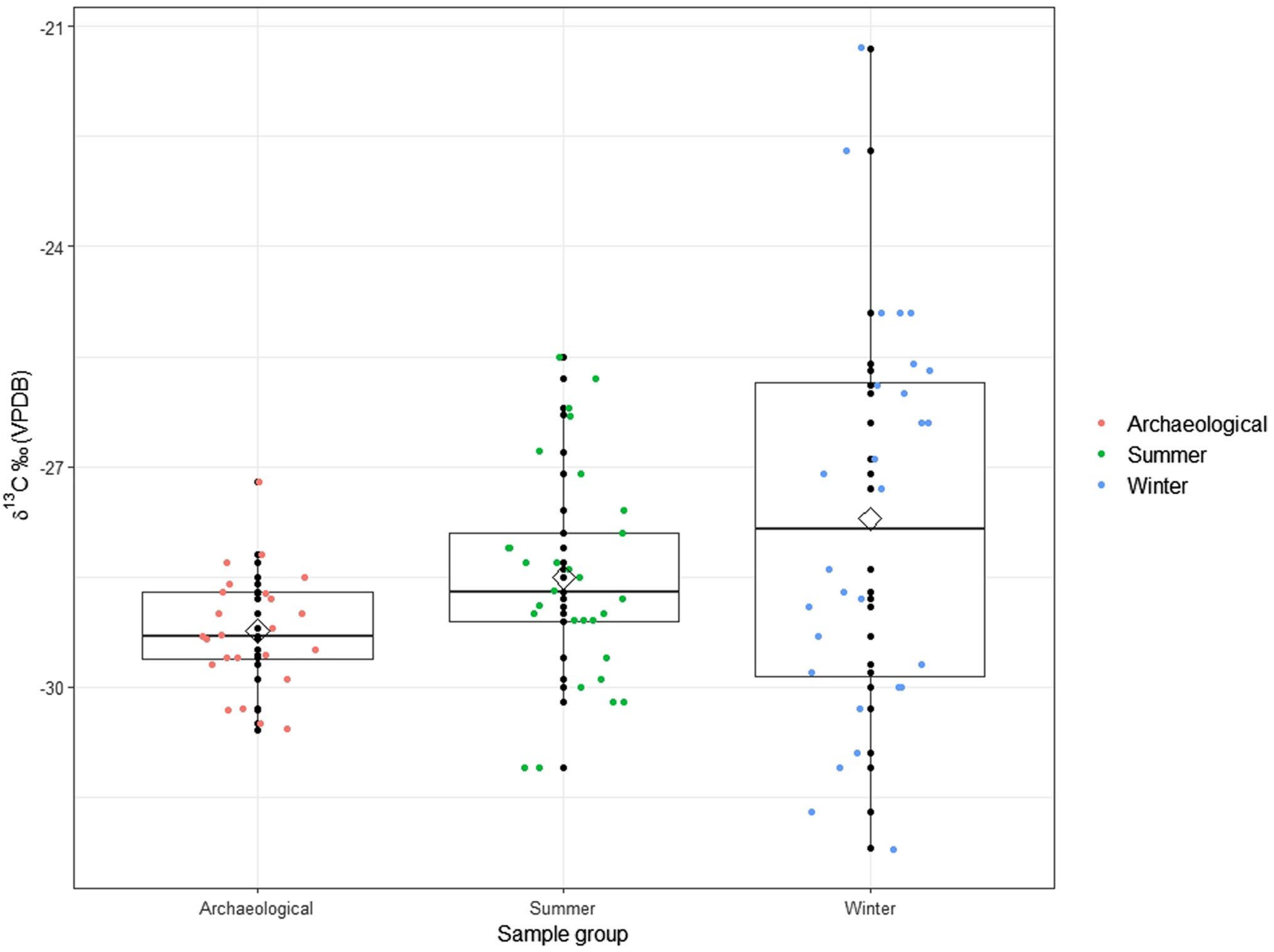


Fig. 11 Boxplot showing the *n*-alkane carbon isotope values for the three analyzed group samples: archaeological, summer and winter. The isotopic composition for all samples falls into the range of C3 plants. Note that the largest isotopic range is from modern plants sampled during the winter season

abundant silt-sized plant fragments (MFT 1–2, horizontally layered geogenic pyroclastic deposits). This distinction has also been observed in the organic matter *input* and preservation shift documented in the middle of the sequence (between 30 and 25 cm depth) (Fig. 9). The non-anthropogenic layers showed *n*-alkane patterns with predominant nC_{27} and absence of terpenoids. Among the different shrubs we analyzed, as part of our reference plant collection from the site surroundings, *Adenocarpus viscosus* (codeso de cumbre), S*partocytisus supranubius* (retama) and *Pterocephalus lasiospermus* (rosalillo de cumbre) were the only species with a significant nC_{27} content. Thus, we propose these taxa as likely candidates for the nC_{27} alkane predominance observed in the non-anthropogenic facies. A similar disparity between the fuel type and the plants that were naturally present around the site has been previously observed (Leierer et al. 2019).

General remarks and future perspectives

As discussed above, we have differentiated between different kinds of plant input at the site: 1) fuel (sabina), 2) sheep/goat dung and/or conifer *input*, and 3) bushy vegetation from the natural surroundings (codeso de cumbre, retama, rosalillo de cumbre). These data may shed some light on the group mobility and subsistence strategies of the Guanches occupying Las Cañadas. The presence of charred conifer wood associated with combustion features and occupation surfaces implies that the inhabitants of the rockshelter preselected and transported their fuel from lower altitudes. In fact, the exploitation of plant resources from different areas of the island in Las Cañadas, such as barley and *Visnea mocarena*, has been previously documented (Morales et al. 2021). On the other hand, the presence of sheep/goat excrements in close association with the human occupation surfaces suggests that highland herding activities played a role in the use of the rockshelter. This is in agreement with previous hypotheses on Guanche highland subsistence strategies (Arnay de la Rosa et al. 2011; Arnay de la Rosa and González Reimers 2006).

Further research is needed to provide more detailed information about fuel sources, seasonality, mobility patterns and functionality of the Roques de Garcia rockshelter. Our unburnt and burnt lipid reference collection of Las Cañadas endemic plants should be expanded to include plant species from outer, adjacent areas, including *Pinus canariensis* (Canarian pine). Characterizing plant sources from different altitudes could allow us to identify other possible fuel and fodder sources. Data collection should include 1) obtaining δ^2H data for each reference species to help us identify burning temperatures (Connolly et al. 2021), 2) experimental burning of different anatomical plant parts, which might show significantly different lipid profiles (Connolly et al. 2021; Jambrina-Enríquez et al. 2018) and 3) including reference plant samples in different states of degradation (e.g., fresh *vs* dry). Charring experiments with mixed anatomical parts should also be performed and compared against archaeological data (Jambrina-Enríquez et al. 2019). Finally, further micromorphological and biomarker samples should be collected from different areas of the rockshelter to corroborate the interpretations made by this study.

The joint application of the geoarchaeological high-resolution techniques of micromorphology and lipid biomarker analysis to this case study has provided us with an accurate interpretation of the deposit of Roques de García Rockshelter. Our results and their implications corroborate the high potential of the microcontextual, multi-technique approach in geoarchaeology and contribute to advance our knowledge on the aboriginal Canary Island societies, as well as our understanding of highland pastoralist societies. We have also been able to build significant interpretations about fire use and fuel sources by studying the sedimentary record of archaeological combustion features.

Conclusion

In this geoarchaeological study of the Roques de García Rockshelter site, we have identified different combustion events and we have proposed *Juniperus turbinata* (sabina) as a likely fuel source used in one of them. Our data has also allowed us to differentiate between periods of non-anthropogenic natural sedimentation and anthropogenic occupation events associated with combustion activity and sheep/goat excrement input. These results corroborate the potential of geoarchaeological high-resolution techniques applied to highland archaeological contexts. These interpretations provide proof for some of the main hypotheses about the economic activities carried out by the Guanches at Las Cañadas del Teide, mainly sheep/goat herding. Furthermore, our data shows that the inhabitants of the site preselected and transported their fuel from other parts of the island. Further research is needed to corroborate the preliminary hypotheses presented in this paper, as well as to provide answers to the new questions that resulted from this study.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12520-022-01661-9.

Acknowledgements We would like to thank the Teide National Park institution for supporting this research and providing permits. We thank Enrique Fernández-Palacios and the members of the AMBILAB, PRORED Soc. Coop. and the Roques de García Rockshelter excavation team for their field and lab work. We also thank Caterina Rodríguez de Vera and Thomas Beckmann for thin section manufacture and the lab personnel at IPE-CSIC for the Total Organic and Inorganic Carbon analysis. We are thankful to Santiago Sossa Ríos, Jonay Neris Tomé and Sara Rueda Saiz for their help in the artwork. We thank Cristo Hernández Gómez for his comments and suggestions in the writing of the manuscript.

Author contributions All authors have made substantial contributions to this study. Laura Tomé: molecular and isotopic analysis, soil micromorphology, research design, artwork design and writing. Margarita Jambrina-Enríquez: molecular and isotopic analysis, research design, artwork design, writing review. Natalia Égüez: molecular and isotopic analysis, artwork design, writing review. Antonio V. Herrera-Herrera: molecular and isotopic analysis supervision, writing review. Javier Davara: molecular analysis, artwork design, writing review. Efraín Marrero Salas: field data, artwork design, writing review). Matilde Arnay de la Rosa: field data, funding acquisition, project administration, writing review. Carolina Mallol: soil micromorphology, manuscript development, artwork design, research design and writing.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. This research was funded by the Spanish Ministry of Science and Innovation (Project HAR2015-68323-P;MINECO-FEDER), the "Fundación Obra Social Caja Canarias" (Project 2018PATRI19) and a Gobierno de Canarias (ACIISI – Agencia Canaria de Investigación Innovación y Sociedad de la Información / Fondo Europeo de Desarrollo Regional "*Canarias Avanza con Europa*") predoctoral contract to LT (TESIS2021010119).

Declarations

Competing Interests The authors have no competing interests to declare that are relevant to the content of this article.

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