Review of Palaeobotany and Palynology 297 (2022) 104562

Contents lists available at ScienceDirect

Review of Palaeobotany and Palynology

journal homepage: www.elsevier.com/locate/revpalbo

Plant use and vegetation trends in Algeria from Late Glacial to Middle Holocene: Charcoal and seeds from Gueldaman GLD 1 cave (Babors d'Akbou)

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ARTICLE INFO

Article history:
Received 7 July 2021
Received in revised form 2 November 2021
Accepted 3 November 2021
Available online 12 November 2021

Keywords:
Northern Algeria
Pleistocene–Holocene transition
Neolithic
Plant macroremains
Plant use
Taphonomy

ABSTRACT

Vegetation dynamics during the Pleistocene–Holocene transition and the beginning of farming are major topics for palaeoenvironmental sciences, especially interesting in ecologically sensitive areas, such as in North Africa. However, there are still important geographic and chronological gaps of environmental information in this region. Archaeobotanical record from Gueldaman GLD 1 deals with these issues, as it presents the longest archaeobotanical sequence available nowadays for Algeria, which includes these moments of major changes in landscapes. This topic has been approached from an interdisciplinary point of view, focused on the analysis of various types of plant remains that result in the reconstruction of both environment and use of plant resources. Results reveal the existence of a postglacial phase of plant colonization with Cupressaceae formations, which are gradually integrating some elements of sclerophyllous vegetation, such as several species of *Pistacia*, well documented both in charcoal and seed records. Neolithic levels show a shift in vegetation composition, as *Olea europaea* dominates the spectra, accompanied by strawberry tree and evergreen *Quercus*, among others. The presence of *Olea* in earlier chronologies has resulted from intrusions from the Neolithic levels: a set of radiocarbon dates has made it possible to evidence this process and detect the extent of the intrusions, which are inherent to cave records.

1. Introduction

Throughout the history of the planet, global climate changes have directly affected the spatial distribution of living beings and have forced them to develop different adaptation strategies. The last glacial cycle and, specifically, the last climatic fluctuations that occurred between the Late Glacial and Early Holocene were the changes that largely shaped our current landscape. The climatic data provided by sequences from the Alboran Sea and the Tyrrhenian Sea (Cacho et al., 2001, 2006; Combourieu Nebout et al., 2002; Moreno et al., 2005; Fletcher and Sánchez Goñi, 2008; Sanchez Goñi et al., 2008; Sánchez Goñi et al., 2013; Fletcher et al., 2010; Desprat et al., 2013) suggest that this region was incredibly sensitive to changes that took place in the North Atlantic, which led to important regional variations in vegetation: the predominance of semi-desert vegetation with Ericaceae-rich scrubland during the LGM and HE 2 and 1 gave way to rapid forestation from the Early Holocene, ending in the transition to the mid Holocene with the development of broad-leaved forests (*Quercus* being the most widely represented genus) (Fletcher and Sánchez Goñi, 2008). These events recorded at a regional or global level would also have been paralleled by the pollen sequences of the Alboran borderlands (Fletcher and Sánchez Goñi, 2008), but there are limited data on the local flora and vegetation for certain regions in these chronologies.

North Africa is one of the areas for which there is lack of data, despite attention having been paid to this region in recent decades to study climatic changes (Ruan et al., 2016) and model future scenarios. North Africa has been proposed as a possible refuge for warm-climate species during glacial periods (Carrión et al., 2010), but there is still a lack of empirical data on palaeovegetation in this region. There are few studies covering combined information provided by different types of plant remains in the Mediterranean strip of North Africa (Mercuri et al., 2011; Zapata et al., 2013; Morales et al., 2016; Ruiz-Alonso et al., 2021; Carrión Marco et al., 2021; Portillo et al., 2021), and some work has also been carried out in the South Sahara area (Mercuri et al., 2013).

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https://doi.org/10.1016/j.revpalbo.2021.104562

In comparison with the northern Mediterranean, where there is a greater tradition of studying plant macroremains (e.g., Thiébault, 2002; Aura et al., 2005; Fiorentino and Magri, 2008; Vaquer and Ruas, 2009; Badal et al., 2012; Damblon, 2013; Martínez Varea and Badal García, 2018), for North Africa there are still vast gaps in the information from a geographical and chronological point of view.

Works on first farmers in this region have made considerable progress in recent years (Garcea, 2004; Wendrich et al., 2010; Morales et al., 2013, 2016; Barich, 2014), although there is clearly a need for further studies, as the current information is still very limited if we consider the huge extent of this territory. The development of agricultural and livestock activities was a factor that, coupled with climatic changes, conditioned the transformation of the local vegetation from that moment on. It is difficult to measure the capacity of these human communities to transform the landscape. It is certainly necessary to consider factors such as population density, whether agriculture followed an intensive or extensive model, and the way in which livestock was exploited.

Plant remains from Gueldaman allow to gain a better understanding of human strategies for the exploitation of plant resources and landscape reconstruction over a long sequence covering Iberomaurusian levels, from ca. 12,500 cal. BP, and Neolithic levels dating between ca. 7160 and ca. 4230 cal. BP. The sequence presented here is interesting because of the huge resolution for the Pleistocene-Holocene transition, but it also allows us to assess the impact of the productive economy in the region by studying the Neolithic sequence.

2. Study area

The site is located near the city of Akbou, in the Adrar Gueldaman at the western end of the Babor Mountains, in the Soummam valley (Fig. 1). The karst systems of Gueldaman include several open-fronted caves on the south-eastern slopes, at an altitude of approximately 500 m. GLD 1 is a cave with an opening of approximately 6 metres facing SE, which is accessed via a 20-metre-long corridor that opens out into the main chamber, called “La Grande Salle”.

The region is currently under the effects of the Mediterranean climate, with warm dry summers and mild wet winters. The overall precipitation unit is semi-arid, with an average annual rainfall of 516 mm. Despite its low rainfall, the region has a well-developed hydrological network, with numerous tributaries that run into the river Soummam at the foot of the Gueldaman mountain (Kherbouche, 2015).

The natural vegetation in the surroundings of the cave varies according to the orography and exposure and proximity to water courses, but it could generally be described as garrigue. *Artemisia vulgaris*, *Juniperus phoenicea*, *Rosmarinus* sp., *Asparagus albus*, *Retama sphaerocarpa*, *Pistacia lentiscus* and *Pistacia terebinthus* grow on the southern slopes of Gueldaman (between 900 and 300

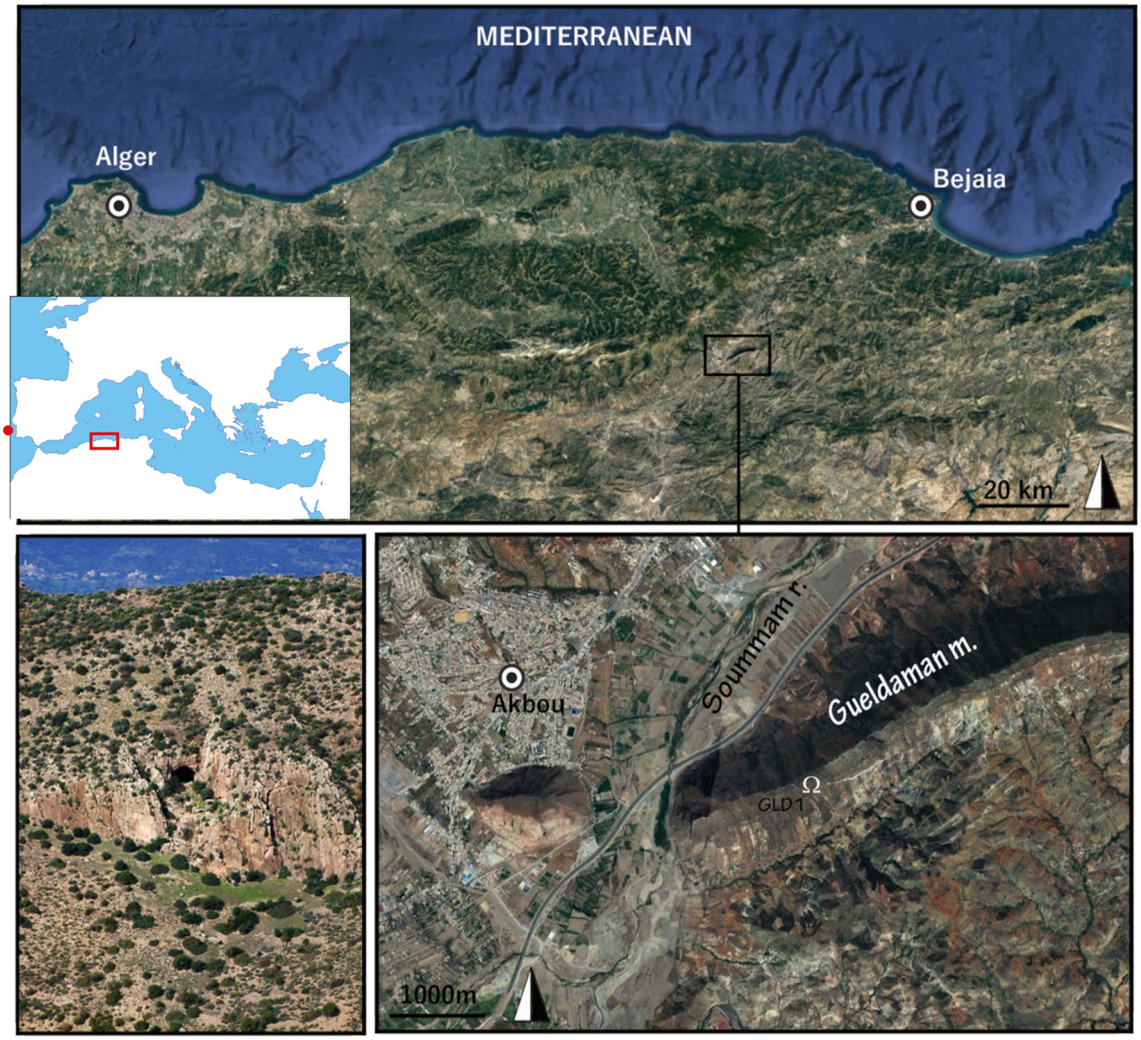

Fig. 1. Location map and view of the cave entrance. The red dot marks the MD95-2042 core location (Sanchez Goñi et al., 2008; Sánchez Goñi et al., 2013).

metres). Toward the ridges, we find more *Chamaerops humilis* and *Genista tricuspidata*, among others. *Nerium oleander* and *Typha* sp. are the most common vegetation found beside the water courses of the Soummam valley (Kherbouche, 2015).

This region, which is highly accessible from inland valleys and the sea (60 km away), would have been a very attractive location for prehistoric settlers due to the diversity of available natural resources. One such resource would have been plants, which would have had many applications as food for humans and animals, as fuel and as a building material. In this regard, the archaeobotanical analyses provide essential information to reconstruct human activities within the context of a landscape that was subjected to constant human pressure and climatic oscillations.

3. Archaeological settings

Gueldaman Cave 1 (GLD1) was discovered in 1920 by A. de Beaumais, who carried out the first excavations in the form of several trenches. The first findings were published in 1926, defining the occupation as "*Néolithique ancien*" based on the material recovered in a stratigraphy covering about 5 metres in depth (Beaumais and Royer, 1926). The interventions by A. de Beaumais led to considerable changes in the configuration of the cave, as well as certain disturbances in the archaeological levels. However, when the work was resumed between 2010 and 2014, unaltered levels *in situ* and a greater depth of archaeological levels were found, as the pioneering excavations had not reached the bedrock (Kherbouche et al., 2014). The work in 2010 began with the removal of sediment resulting from the previous work and the processing of horizontal levels from sectors 1, 2 and 3 that were preserved *in situ*.

The excavation was carried out by means of transverse and longitudinal sections (the trenches made in the pioneering excavations) at different points of the surface of the cave, excavating an area of just a few m^2, but obtaining the complete vertical sequence of the fill of the cave in different sectors. Despite the small intervention surface (Fig. 2), the archaeological materials are abundant and meaningful (Kherbouche et al., 2014), including plant remains.

A corpus of thirty radiocarbon dates on wood charcoal has been obtained for sectors 2 and 3 in order to establish the chronological framework of the occupations. Most of these dates have been published in earlier works (Kherbouche et al., 2014, 2016; Kherbouche, 2015), and some are published for the first time in this paper, with the main objective of discerning possible taphonomic problems.

The individualisation of the Archaeostratigraphic Units (A.U.), or occupation levels, was based on the stratigraphic, chronological and archaeological data. Six AUs were identified, the chronology of which is shown in Table 1. Cultural data are mainly available for the Neolithic units (A.U. 1 to A.U. 4). The historical level (A.U. 5) is present only in Sector2, the lowest area of the cave, and its thickness is less than 10 to 20 cm containing few shards of modern ceramic. All Pre-Neolithic levels tentatively together in A.U. 0, are still not excavated, only plant remains were collected in I38 column when refreshing the longitudinal stratigraphic section I/J in the area 38. In this area, excavated between 2011-2012, fieldwork was oriented towards a vertical exploration on small surfaces (100 x 100 cm in F37 and 20 x 100 cm in I38). As an example of the stratigraphy and lithological characteristics of the cave, Fig. 3 shows a stratigraphic section of square I38 (Kherbouche, 2015).

The sequence presented in this paper covers Iberomaurusian (Epipalaeolithic) and Neolithic occupations, although with certain differences in the anthracological and carpological records (Table 1).

4. Materials and methods

4.1. Sampling

The archaeobotanical material presented here was recovered during the excavation campaigns from 2011 to 2014, in sectors 2 and 3 (Fig. 2).

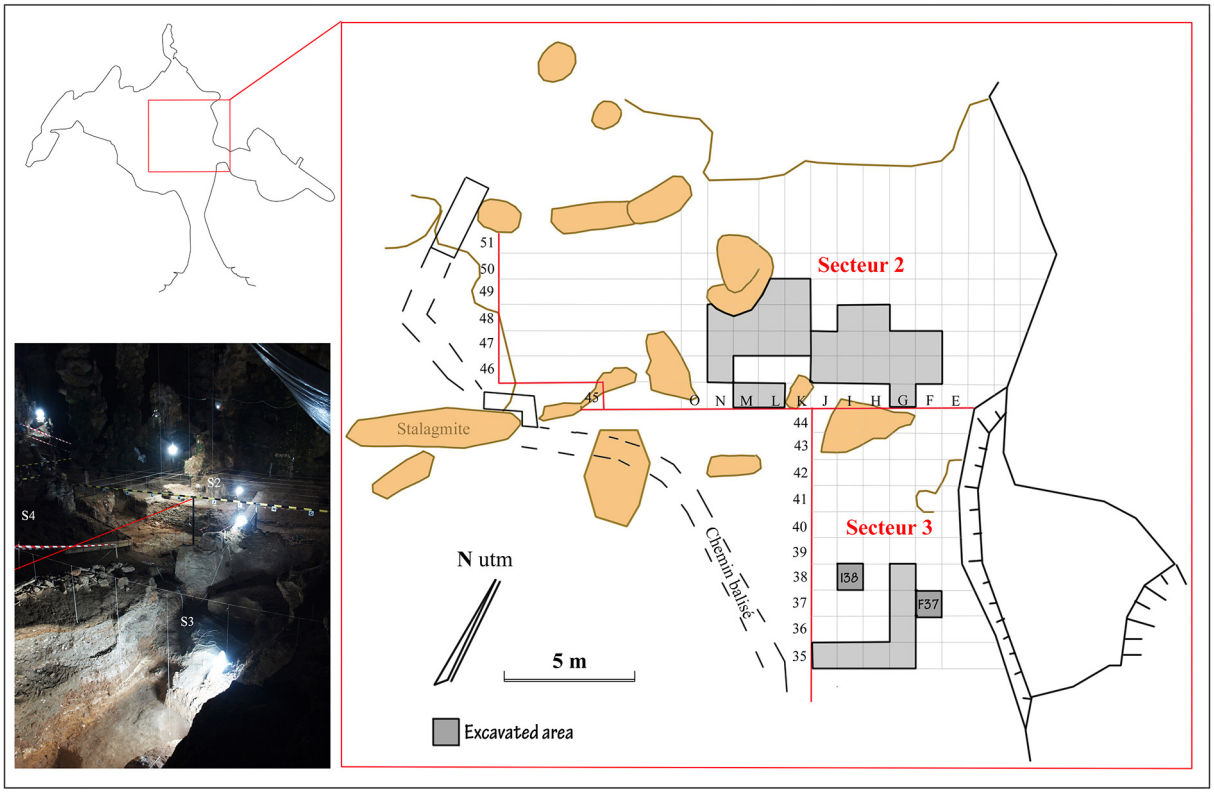

Fig. 2. Plan of Gueldaman GLD 1 cave showing the excavated sectors.

Table 1
Chronology of the Archaeostratigraphic Units, and origin of the charcoal and carpological remains studied.

Archaeo-Stratigraphic Units (A.U.)	Chronological range cal yr. BP 2σ	Squares with charcoal studied	Squares with seeds and fruits studied
A.U. 5	1552-1411		K49, L45, L49, M47, M48, N48
A.U. 4	4569-4230		N48
A.U. 3	5032-4615		F37, N47, N48
A.U. 2	6641-5909	F37, I38	F37, N47
A.U. 1	7160-6739	I38	F37, G35, G36, G46, G47, H47, I46, I48
A.U. 0	12516-8725	I38	M45, I38, G37

During fieldwork, sediment samples were systematically recovered in each split for flotation sieving. This system made it possible to recover small, fragile archaeobotanical remains, especially wood charcoal, seeds and fruits. The sediments were floated manually, and the floating material was collected with a 0.5 mm mesh. The sediment that did not float was washed in a 1 mm sieve.

In the laboratory, the organic remains were then sorted and each type of plant remain was stored individually. The preservation of plant remains in Gueldaman is exceptional, in terms of both quantity and state of preservation, which has led to a representative assemblage of macroremains for analysis.

4.2. Charcoal analysis

Charcoal was well preserved and samples have offered many fragments larger than 2 mm. Given the enormous amount of material, we have also selected a column corresponding to both I38 and F37 squares from Sector 3 (Fig. 2). 48 samples (41 from square F37 and 7 from square I38) corresponding to 22 spits have been analyzed. The charcoal sequence corresponds to the final Iberomaurusian and part of the Neolithic levels (Archaeostratigraphic Units 0 to 3).

Charcoal analysis was based on the botanical identification of the carbonized wood. Each fragment was observed under a reflected light optical microscope with bright field-dark field, with different lenses ranging from 50x to 1000x magnification. The anatomical features of the wood were compared with a reference collection of current charred wood samples in the Laboratory of Prehistory and Archaeology of the University of Valencia, which also includes some plant samples from North Africa and specialised literature on plant anatomy (Greguss, 1955, 1959; Jacquiot, 1955; Jacquiot et al., 1973; Schweingruber, 1990; Neumann et al., 2001, among others). For the standard analysis, the charcoal was broken manually and no chemical treatment was needed, so these samples could be used later for radiocarbon dating (Vernet et al., 1979).

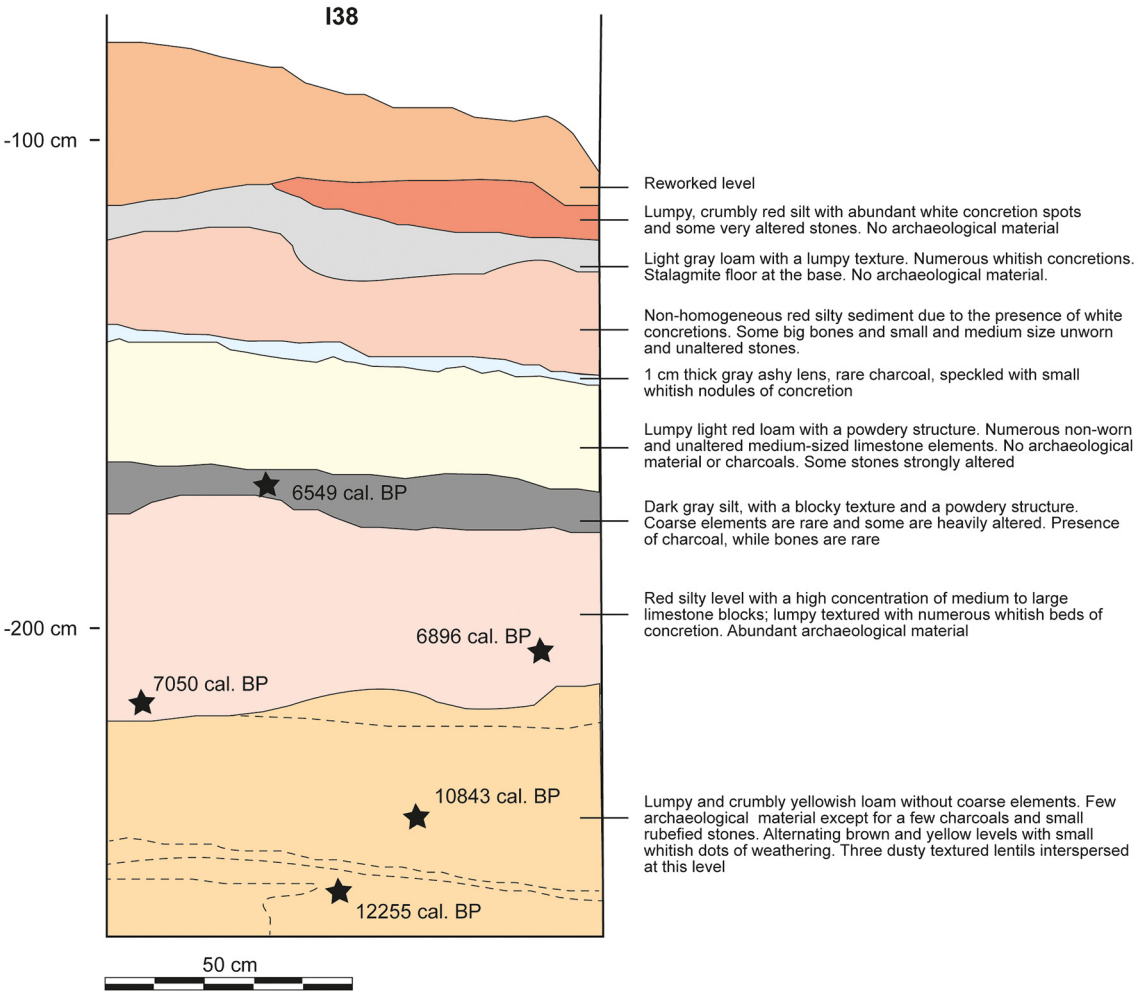

Fig. 3. Stratigraphy and lithology of I38, after Kherbouche, 2015, 54, modified.

When a higher depth of field or magnification were needed (e.g., for observation of specific anatomical features), a Hitachi S-4100 scanning electron microscope (SEM) from the Experimental Research Central Support Service (SCSIE) of the University of Valencia was used. For observation under this equipment, the material was fixed to the holder with carbon tape and coated with gold to provide conductivity, so materials treated in this way cannot undergo radiocarbon dating.

The frequency of taxa identified was measured as a percentage of fragment counts when the sample contained a statistically meaningful number of charcoal fragments, at least 100 to 200 (at Gueldaman, only one sample was below this amount). These results reflect the woody species exploited for different uses, mainly for fuel, and thus present among the local flora (Chabal, 1997), so charcoal analysis is reliable as a tool for the reconstruction of palaeovegetation.

The range of identification is not always the same. Depending on the anatomical similarities between groups of species, charcoal can be identified within the range of species, genus, family or larger groups (e.g., Conifer/Angiosperm). A specific issue that should be discussed is the case of the genera *Juniperus* and *Tetraclinis*. These are anatomically very close. The basic difference between them is the presence of wedge-shaped cell walls around the bordered pits in *Tetraclinis articulata* (Schweingruber, 1990), a feature that is absent in junipers. Many fragments from Gueldaman were prepared for SEM observation and a comparative morphometric study of prehistoric and current specimens of both *Juniperus* and *Tetraclinis articulata* was carried out. No significant differences were found in relation to the individual from the reference collection, even at high magnifications (Plate I). It is possible that the anatomical features proposed for differentiation (Schweingruber, 1990) disappear with carbonisation, the state in which most of the archaeological samples are preserved. For this reason, we have labelled the taxon *Juniperus/Tetraclinis*, without ruling out the possibility that both genera may have been present in the surroundings of Gueldaman, as they are both currently very common in the Maghreb (Fennane, 1989; Charco, 1999). Nevertheless, only *Juniperus* was present among the carpological remains, and not *Tetraclinis articulata*.

4.3. Seed analysis

The material from all the sections excavated in sectors 2 and 3 was systematically analysed (Fig. 2), which included more samples (111) than those processed for the anthracological analysis, and the complete sequence from Archaeostratigraphic Units 0 to 4.

The plant remains were preserved by charring and they were identified using a binocular microscope (8-80x magnification). Their identification was carried out by comparison with modern specimens from the seed reference collection of the Archaeobiology Lab of the Spanish National Research Council in Madrid, and by consulting specialised literature on plant anatomy. The botanical nomenclature for crops follows

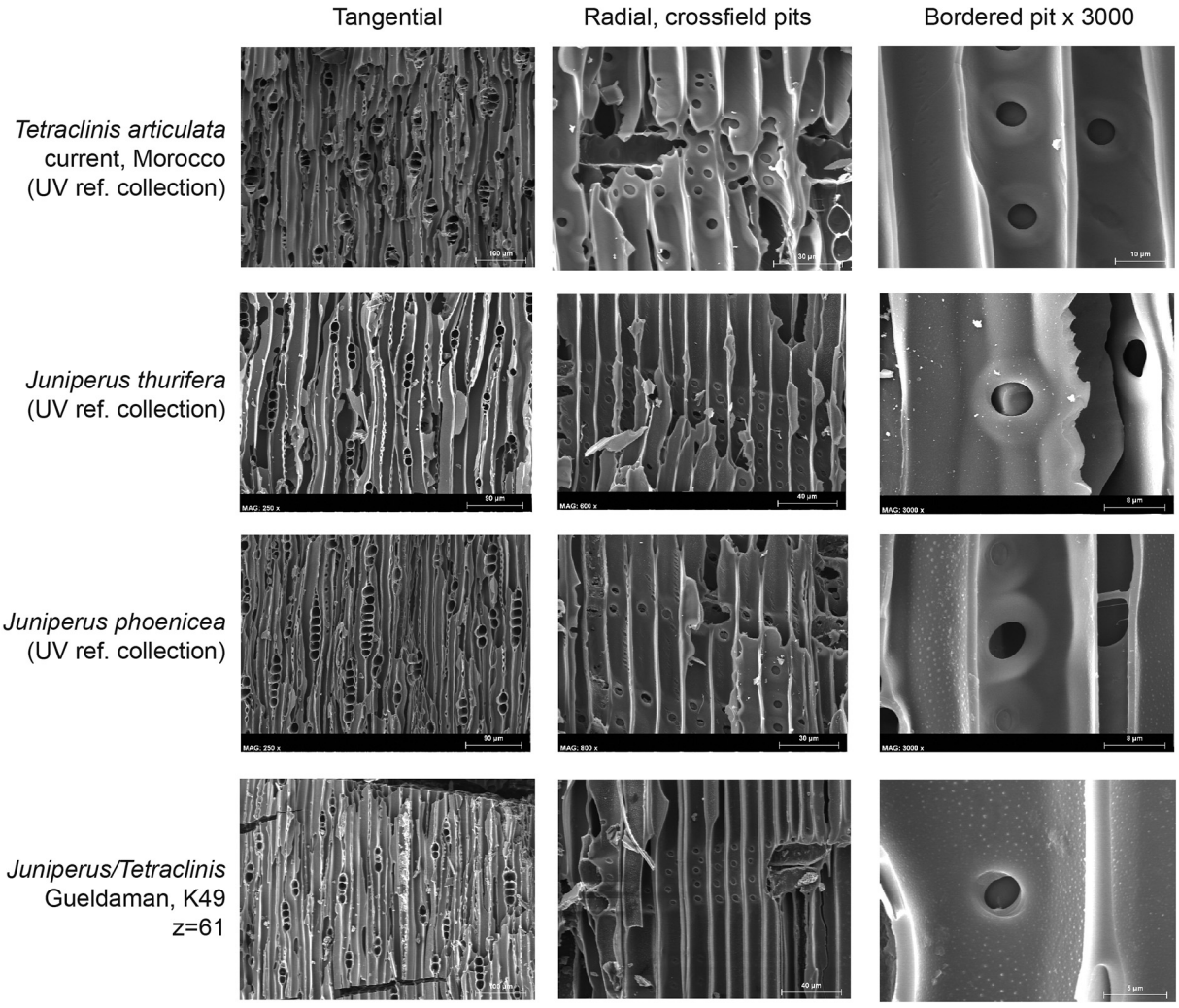

Plate I. Comparative anatomy of two species of *Juniperus* and *Tetraclinis articulata* from the reference collection of the University of Valencia (UV) with the archaeological wood remains from Gueldaman GLD 1 cave.

the traditional binomial classification (Zohary et al., 2012). The material was quantified based on the number of remains from each of the phases and the ubiquity of each taxon.

4.4. Radiocarbon material selection

Among the existing tools to detect taphonomic processes, radiocarbon dating is the one that ultimately confirms the chronological assignment of the material and if the result is consistent with the context of origin. However, a previous protocol of material selection, including the taxonomic identification of the remains to date, allows an assessment of the result in context, to know the history of the species, and to avoid dates inconsistent with the archaeological contents, if some samples are discarded for dating when, *a priori*, present evidence of being intrusive. *This protocol has been largely proved to be* workable for taphonomic processes detection (e.g., Badal, 2006; Carrión et al., 2010; Carrión Marco et al., 2018).

In addition to the set of radiocarbon dates already available for Gueldaman, in this study, material for new dating has been selected through the above protocol. Macro-remains of *Olea europaea* (an ecological marker of warm conditions) have been selected in pre-Holocene contexts, in order to reveal whether the presence of this species is the result of intrusions, or it confirms its permanence in the region since at least the end of the Pleistocene.

All dates presented are in calendar years BP and have been calibrated to 2 sigma using the CalPal-2007 program (Weninger et al., 2009) and the CalPal-2007-Hulu calibration data set (Weninger and Jöris, 2008).

5. Results of the analyses

5.1. Charcoal remains

A total of 3443 charcoal fragments were analysed and 28 woody taxa were identified, corresponding to at least 22 species (Plates II and III). Only one conifer was identified, *Juniperus/Tetraclinis*, and the difficulty of distinguishing between these two genera is discussed above. The other taxa correspond to angiosperms, for which a great variety of trees and shrubs have been recorded: *Arbutus unedo* (strawberry tree), *Ceratonia siliqua* (carob tree), Cistaceae (rockrose family), Compositae (sunflower family), *Ephedra* sp. (jointfir), *Erica* sp. (heather), *Ficus carica* (fig tree), *Fraxinus* sp. (ash), Labiatae (mint family), Leguminosae (legume family), Monocotyledon, *Olea europaea* (olive tree), *Pistacia* tp. *lentiscus* (mastic), *Pistacia terebinthus* (terebinth), *Pistacia* sp., deciduous *Quercus* sp., evergreen *Quercus* sp. (evergreen oak), *Quercus* sp., *Rhamnus-Phillyrea* (buckthorn and/or green olive tree), Rosaceae (rose family), Rosaceae Maloideae (whitebeam family), *Salix-Populus* (willow and/or poplar) and *Tamarix* sp. (tamarisk). Some fragments have also remained undetermined, generally due to preservation problems, although the percentage is very small (generally $<1\%$), and it has only been possible to identify others within the range of angiosperms.

In general, the assemblage offers a variety of species, mostly shrubs and scrub, typical of dry to semi-arid Mediterranean environments, as well as some riparian species.

In terms of percentages, few taxa show significant values throughout all or most of the sequence. Those which are better represented are *Juniperus/Tetraclinis* and *Pistacia* (at the base of the sequence) and *Olea europaea*, especially in the Neolithic sequence (Fig. 4). Labiatae, Compositae, *Ephedra*, *Rhamnus-Phillyrea* and the riparian taxa (*Salix-Populus* and *Fraxinus*) present much lower percentages than the former and are limited almost exclusively to the lower half of the sequence. *Arbutus unedo*, on the other hand, only appears in the Neolithic levels. Evergreen *Quercus* sp. is present throughout the entire diagram, with percentages just over 10%.

The remaining taxa are scattered throughout the sequence (some offering only one or a few fragments). These must be species that were exploited sporadically, perhaps because they were not common in the surroundings of the cave, and the presence or absence of them in the different phases of the sequence may be due to chance.

With regard to the genus *Pistacia*, wood has been identified from at least two species: *P.* tp. *lentiscus* and *P. terebinthus*. The first of these taxa could include other species characteristic of the area (e.g., *P. atlantica*), the anatomical features of which are very similar and cannot be individually distinguished. In many cases, it has not been possible to identify them at species level, but only at genus level (*Pistacia* sp.); for this reason, the taxon *Pistacia* is shown in the diagram grouping together all the taxa belonging to this genus, so that its relative importance is not distorted by problems of identification. In any case, they may have shared an ecological niche resulting in scrubland rich in species of this genus (Babali et al., 2013).

The case of the genera *Rhamnus* and *Phillyrea* is special, as they belong to two different families (Rhamnaceae and Oleaceae) whose anatomical features are very similar to each other and cannot be distinguished from one another (Schweingruber, 1990). The genus *Phillyrea* is typical of the Mediterranean environment, in holm oak and kermes oak groves and scrubland that grows in spaces cleared due to degradation; it can be found from sea level up to an altitude of 900 or 1000 metres, preferably in warm, dry atmospheres. *Rhamnus* has a greater ecological range, as it can be found from thermo-Mediterranean to supra- or even oro-Mediterranean bioclimatic zones, depending on the species. Despite this wide range, in the case of Gueldaman, the taxon *Rhamnus-Phillyrea* appears to be associated with the dynamics of *Pistacia*, since it only occurred at the time when the latter was dominant in the spectra (Fig. 4).

Likewise, the taxa Labiatae and Compositae, which include species from very diverse environments, only appear in the Iberomaurusian sequence and, in the case of Labiatae, they are associated with the dynamics of *Juniperus/Tetraclinis*, so this may have been a species (or several species) that shared the same environment.

The dating (Table 1; Kherbouche et al., 2014, 2016) indicates that between the Iberomaurusian levels (A.U. 0) and Neolithic levels (A.U. 1 onwards), at least for I38 square, there is a hiatus of nearly 2000 years. In other areas of the cavity, Iberomaurusian levels have not still been reached. The end of the Pleistocene and beginning of the Preboreal coincides with the maximum values of *Juniperus/Tetraclinis* (as much as 70%), Labiatae and *Ephedra*. We also find Compositae, *Pistacia* and some riparian taxa, among others, as well as intermittent examples of *Olea europaea*, whose presence in this phase will be discussed below. The level corresponding to the base of the sequence, dated to $12{,}316 \pm 179$ cal. BP, has not provided a sufficient amount of charcoal for the results to be quantitatively relevant, which is probably why the frequencies of the main taxa are distorted.

There was a visible change in these dynamics after $10{,}878 \pm 151$ cal. BP, i.e. probably coinciding with the Preboreal-Boreal transition: *Juniperus/Tetraclinis* started to decline, whereas *Pistacia* increased to values of 40% (in this phase, at least two species of this genus were always present, as mentioned above). Parallel to this, the continuous curve of evergreen *Quercus* sp. began.

In the Neolithic sequence, the beginning of which is dated to 7046 ± 84 cal. BP, there was a considerable change in the vegetation represented in the charcoal from the cave, with the absolute dominance of *Olea europaea* in values of almost 90%. Evergreen *Quercus* is documented more or less constantly (generally in values between 7 and 10%), as is *Arbutus unedo*, although to a more modest extent ($>3\%$). The percentages of *Juniperus/Tetraclinis* and *Pistacia* are very small and they even disappear at the top of the sequence. Riparian taxa were also occasionally present, but not continuously and in very low percentages.

5.2. Seed and fruit remains

A total of 363 seeds and fruits were recovered, most of them charred (336), although there is also a small collection of mineralised material

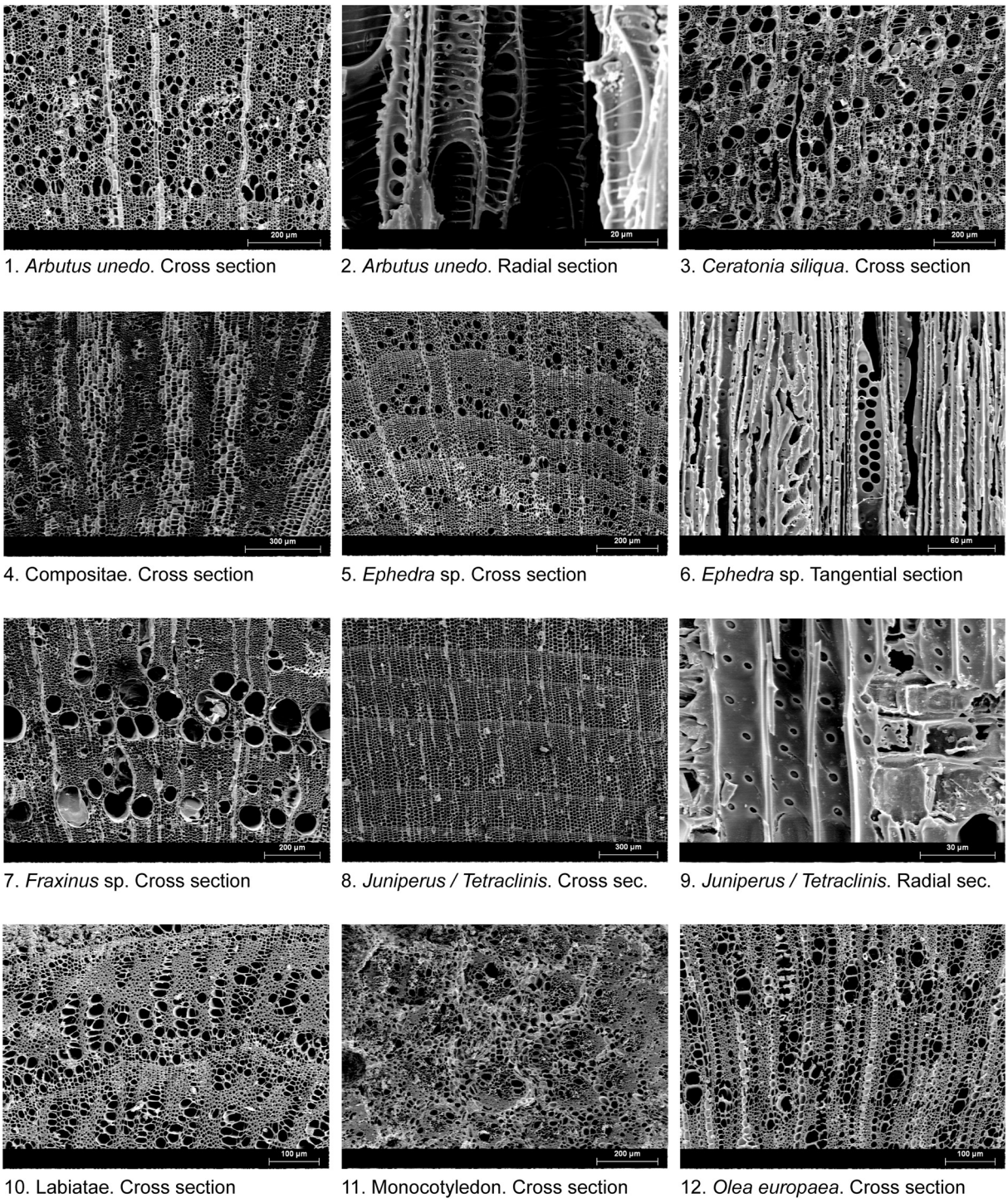

Plate II. SEM photographies of some taxa identified in charcoal assemblages from Gueldaman GLD 1 cave.

(27) which include just one legume, fruits and wild plants (Plate IV). The most abundant are *Lithospermum* sp. nucules, which mainly appear in the two oldest units. The only legume is carob (*Ceratonia siliqua*), and the fruits are *Cotoneaster* sp. and grape (*Vitis vinifera*).

The record of charred material is much richer, with 23 identified taxa. The cultivated species include cereals, for which it is only possible to confirm the presence of naked wheats (*Triticum aestivum-durum*) and hulled barley (*Hordeum vulgare* subsp. *vulgare*), as well as *Triticum* sp. and *Hordeum vulgare* that are altered, so it is not possible to specify the determination. The other group of cultivated plants are Fabaceae, with individuals that could correspond to pea (*Pisum sativum*), vetch (*Vicia sativa*) and grass pea (*Lathyrus sativus/cicera*), in addition to the possible case of carob.

The remainder of the materials have been divided into two groups. The first covers fruits and cones that may have been gathered as food or accidentally collected together with firewood. The taxa identified are grape (*Vitis vinifera*), Mediterranean fan palm (*Chamaerops humilis*), juniper (*Juniperus oxycedrus/communis*), olive (*Olea europaea*), stone pine (*Pinus pinea*), mastic (*Pistacia lentiscus*), acorn (*Quercus* sp.) and possibly yew (*Taxus baccata*). The second group includes other wild taxa. In some cases, it has only been possible to identify them at family level (Apiaceae, Fabaceae and Poaceae), others at genus level (*Erodium*

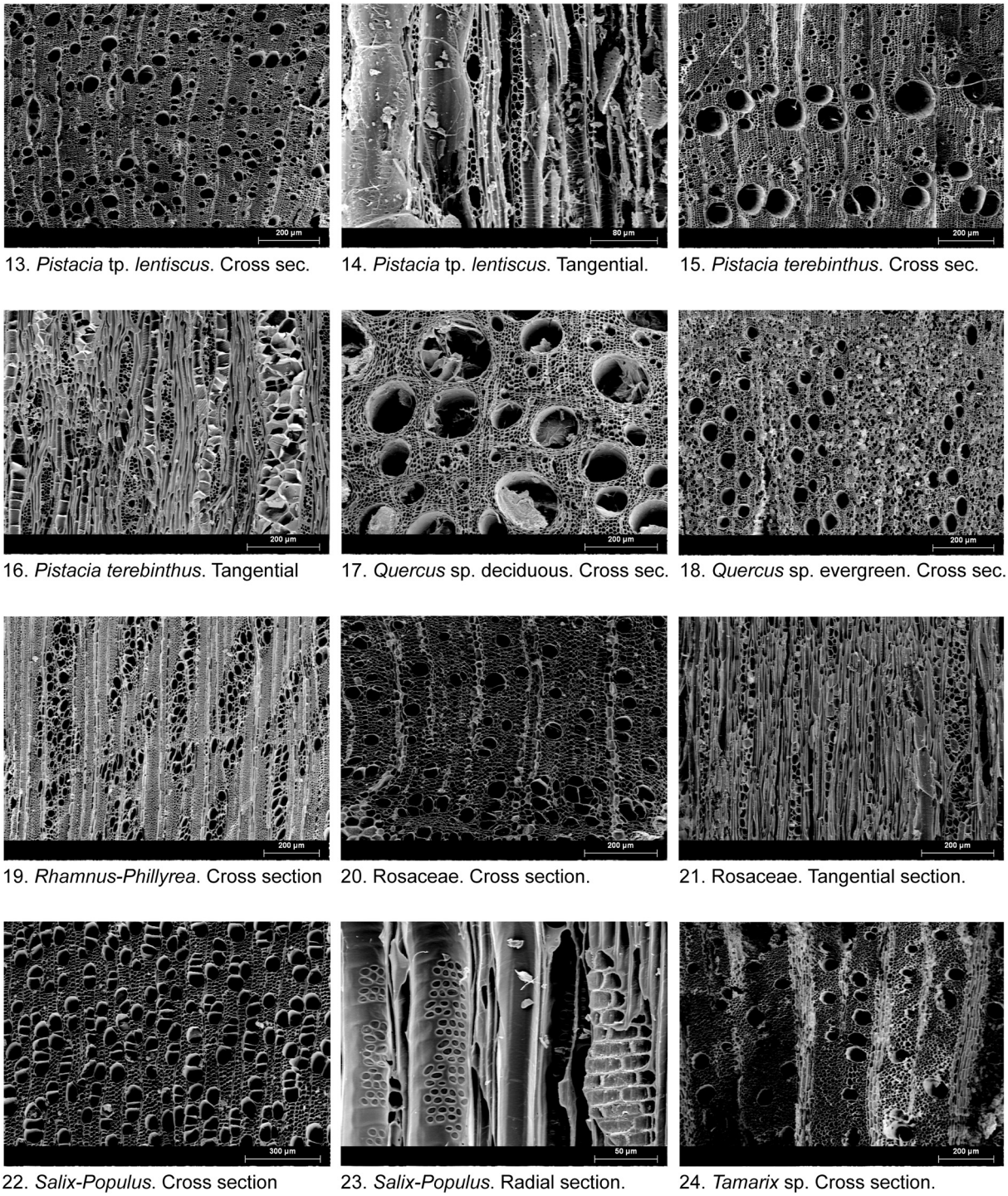

Plate III. SEM photographies of some taxa identified in charcoal assemblages from Gueldaman GLD 1 cave (continuation).

sp., *Medicago* sp. and *Polygonatum*/*Asparagus* sp.) and in other cases it has been possible to define the species (*Scorpiurus muricatus*, *Rosmarinus officinalis* and *Chenopodium* tp. *murale*).

The sequence of seeds and fruits remains has been divided into 5 phases based on the chronology of the samples (Fig. 5). The record from the Pleistocene levels (A.U. 0) is limited and includes fruits and cones such as juniper, mastic and possibly yew, in addition to other indeterminate remains and a more or less constant presence of mineralised *Lithospermum* nucules. The presence of this taxon is problematic, as it is easily mineralised (Van Zeist and Buitenhuis, 1983) and tends to be collected by different insects. Its presence in prehistoric sites has sometimes been linked to its medicinal properties (Baczyńska and Lityńska-Zając, 2005; Badal and Martínez-Varea, 2018), but in this case there are no elements that confirm its age or verify that its presence is related to human occupation of this cave. The presence of *Olea europaea* stones found in base levels is intrusive, as evidenced by the dating of these materials.

After the hiatus in occupation, it is not possible to confirm the presence of cultivated plants at the beginning of the Neolithic sequence (A.U. 1). There are no cereals and only some legumes, which may have been cultivated (*Vicia*/*Lathyrus* and *Lathyrus* cf. *sativus*/*cicera*). The rest of the record shows that the cave was used as a livestock

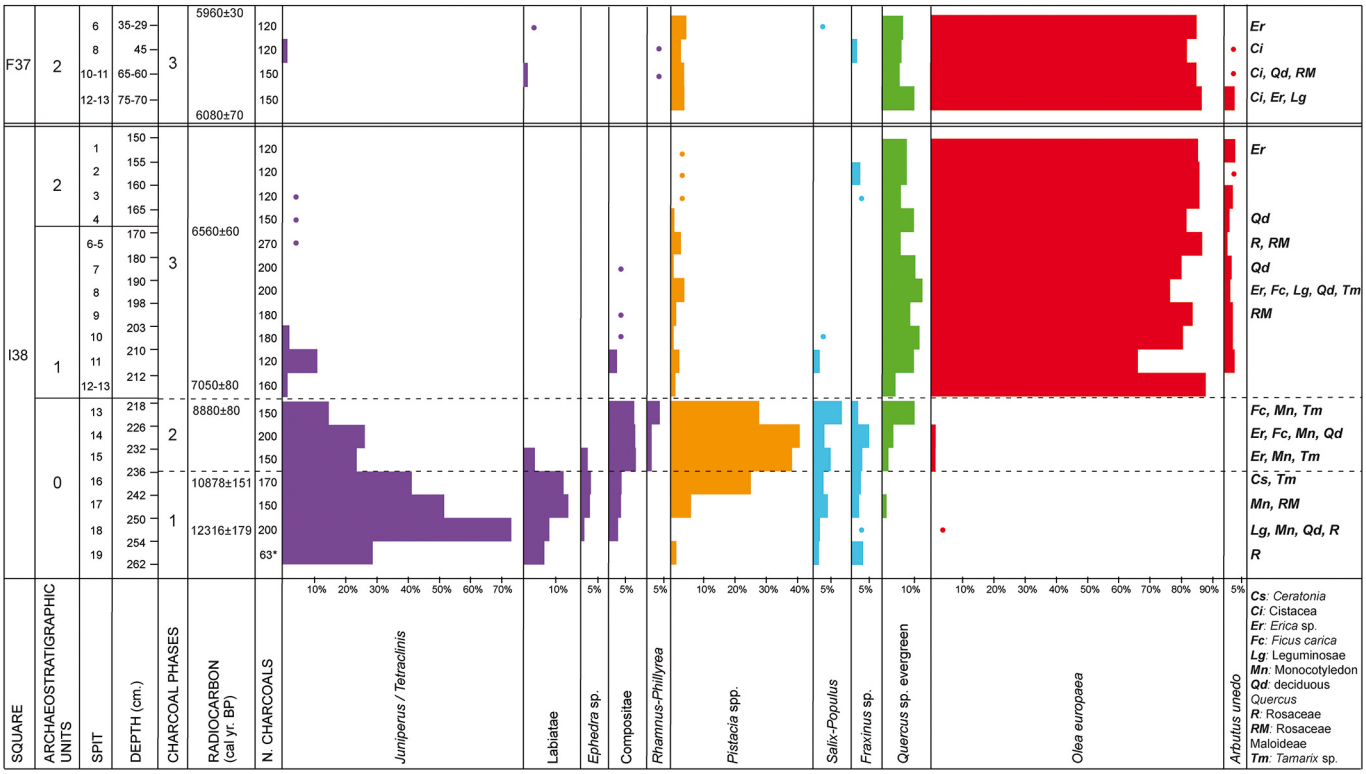

Fig. 4. Charcoal diagram of Gueldaman GLD 1. Dashed lines indicate the Charcoal Phases (**Olea europaea* has been removed from levels where it has been dated and given inconsistent results, see Table 2).

enclosure. In addition to abundant ovicaprid coprolites, we constantly find olive stones and some charred mastic nucules, as well as many mineralised grape pips. The olive and mastic fruit carbonisation processes could be linked to burning of organic accumulations in the livestock enclosure levels. Also, the flow of water within the cave may have helped in some way to mineralise the grape pips. Acorns (*Quercus* sp.) appear for the first time together with these fruits.

In A.U. 2, there are some changes that coincide with an absence of coprolites. The vine disappears and the proportion of *Olea europaea* becomes marginal; instead, the presence of *Pistacia* increases considerably in the case of both *P. lentiscus* and *P. terebinthus*. Likewise, there is an increased presence of acorns and legumes, possibly including the pea (*Pisum sativum*).

In A.U. 3 and 4, its use as a livestock enclosure can once again be inferred from the presence of coprolites. We continue to observe the same features as in the previous phase, such as the proportion of *Pistacia* and *Chamaerops*, with another increase in olive stones. The vine also makes a reappearance, once again mineralised. It is at that point when the first cereals appear, of which it is only possible to confirm the presence of barley (*Hordeum vulgare*), although poorly preserved, so it is not possible to determine whether it corresponds to the naked or hulled variety. The most prominent wild plants are Poaceae and *Scorpiurus muricatus*.

The last phase of occupation (A.U. 5), in the historic age (5th–6th centuries AD), basically sees a continuation of the previous trend. Found together with the excrements are abundant remains of olives and to a lesser extent *Pistacia lentiscus* and *Chamaerops humilis*. *Ceratonia siliqua* is mineralised in this case and bracts of *Pinus pinea* appear for the first time. It is also the point at which naked wheat (*Triticum aestivum-durum*) is first documented and the presence of hulled barley (*Hordeum vulgare* subsp. *vulgare*) can be confirmed. The only legume that could have been cultivated is the grass pea (*Lathyrus* cf. *sativus/cicera*). In terms of wild plants, it is only possible to confirm the presence of *Chenopodium* cf. *murale* and caterpillar plant (*Scorpiurus muricatus*).

5.3. Radiocarbon and taphonomy. The case of Olea europaea

The abundant identification of *Olea europaea* in the Neolithic sequence of Gueldaman points to a significant presence of this species in the landscape, as a fundamental element of the thermo-Mediterranean maquis shrubland, even though its use as fodder for the animals stabled there would have led to its over-representation in the record.

In any case, the presence of this species is a good indicator of temperature conditions, as it requires average annual temperatures of 17–18°C, with warm summers; it is currently one of the species that define the thermo-Mediterranean bioclimatic zone and it is naturally confined to coastal areas of the Mediterranean below latitudes of 41–39° (Ozenda, 1975; Rivas-Martínez, 1987). Other studies show its rapid expansion from the Middle Holocene, while it was found in very restricted enclaves during the Early Holocene and Pleistocene (Pons and Quézel, 1998; Jalut et al., 2000; Rodríguez-Ariza and Montes, 2005; Carrión et al., 2010; Mercuri et al., 2013; Langgut et al., 2019; Fernández et al., 2021). In some of these studies it has been postulated that North Africa may have been a refuge area for this species during the last glacial cycle, which would explain the aforementioned rapid colonisation during the Holocene; however, the limited amount of data available at present on palaeovegetation in North Africa means that it is not possible to corroborate this hypothesis or describe the circum-Mediterranean distribution of the species in more detail. Within this research context, the presence of *Olea europaea* macroremains prior to the Holocene is a potential matter for this line of research.

Three *Olea europaea* wood and olive stone remains, found at Gueldaman GLD 1 cave from the base of the sequence (Fig. 4) have been the object of direct dating, because *a priori* they could be considered evidence that this area was a refuge for warm-climate species, including the wild olive. Table 2 summarises the selected contexts, the type of material and the results obtained.

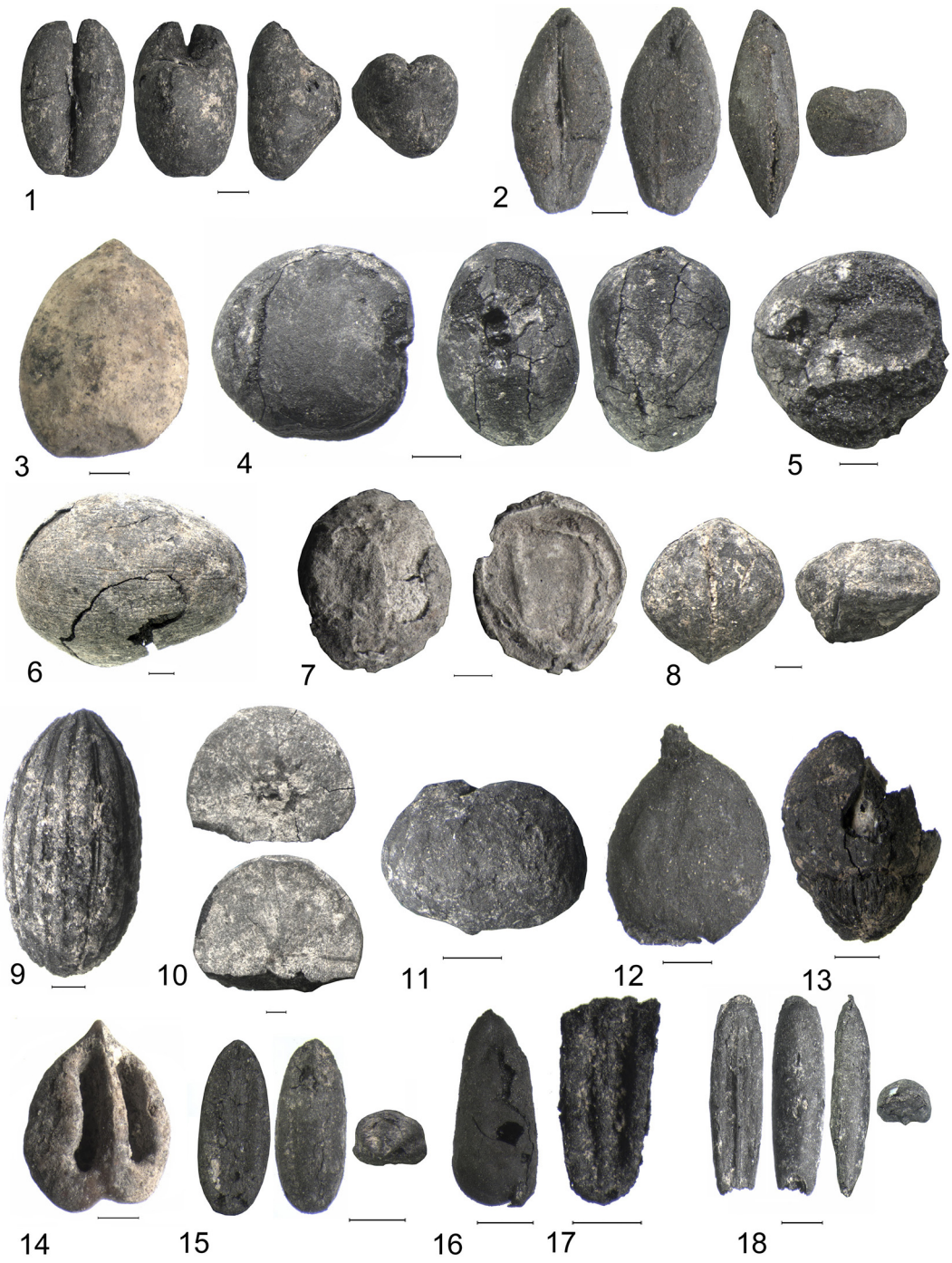

Plate IV. Seeds and fruits from Gueldaman GLD 1 cave. l. *Triticum aestivum-durum,* 2. *Hordeum vulgare* subsp. *vulgare,* 3. *Ceratonia siliqua,* 4. Cf. *Lathyrus sativus/cicera,* 5. Cf. *Pisum* sp., 6. *Chamaerops humilis,* 7. *Cotoneaster* sp., 8. *Juniperus oxycedrus/communis,* 9. *Olea europaea,* 10. *Pinus pinea,* 11. *Pistacia lentiscus,* 12. *Pistacia terebinthus,* 13. Cf. *Taxus baccata,* 14. *Vitis vinifera,* 15. Apiaceae, 16. *Erodium* sp., 17. *Rosmarinus officinalis* leaf, 18. Poaceae. Scale bar = 1 mm.

The results reveal that all the *Olea europaea* remains that appear in the Iberomaurusian levels and have been dated are intrusions that actually belong to Neolithic chronologies. This shows that there is a certain movement of materials between the layers, probably due to: 1) the fact that the underlying levels were altered by Neolithic groups, and/or 2) other subsequent taphonomic processes, such as the action of microfauna or alterations caused by the excavations carried out at the beginning of the 20th century. Anyway, this dynamic is inherent to all caves, and the rest of the taxa present a high ecological coherence, supported by the consistent result of the rest of radiocarbon dates.

The incoherent dating of *Olea europaea* sheds reasonable doubt on all the remains of this species that appear in levels prior to the Neolithic at Gueldaman, even those that have not been directly dated. Therefore, we can even assess the percentage of contamination, which should roughly correspond to the percentage of *Olea europaea* in Iberomaurusian levels.

6. Discussion

6.1. Vegetation dynamics in the Pleistocene–Holocene transition

The analyses of macroremains (charcoal and seeds) from Gueldaman provide information about the natural local vegetation exploited by the occupants of the cave and enable us to reconstruct

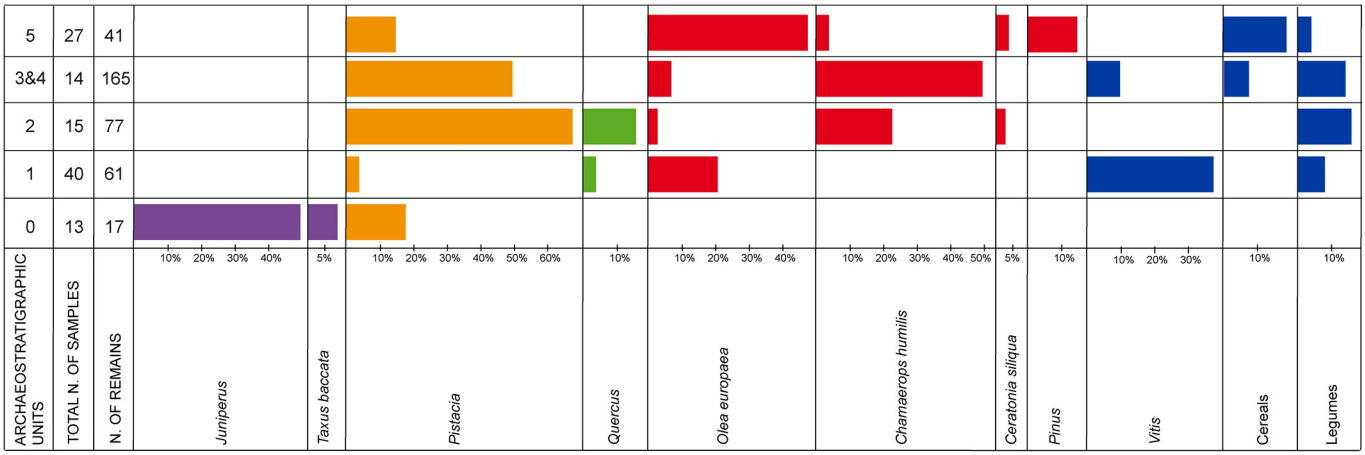

Fig. 5. Ubiquity of carpological remains of Gueldaman GLD 1 cave. Fruit remains of *Olea* from Pleistocene levels are not represented in this figure because are considered intrusive.

the environment at a key time of significant climatic changes. The dating carried out for the base of the studied sequence places it just within chronologies prior to the Holocene, at a time before 12,316 ± 179 cal. BP (SacA36980/Gif-13079), whereas the Iberomaurusian sequence lasts until 8880 ± 80 cal. BP (Beta–425424).

During the Pleistocene-Holocene transition, *Juniperus/Tetraclinis* plays a fundamental role in the first post-glacial formations (fig. 4). It is accompanied by Labiatae and Compositae, in addition to some xerophytic taxa, although these are not very frequent (*Ephedra* and *Tamarix*). Riparian vegetation such as *Salix-Populus* and ash is present in steady but modest percentages throughout the phase; this could indicate the persistence of stable riparian formations during this period, although in percentage terms their exploitation and/or presence in the landscape are not very significant. *Pistacia* starts to appear at this point and undergoes a rapid growth; at least two species of this genus are present from the start of the sequence, both as charcoal and as seeds. From all the taxa found it can be inferred that the conditions would have been mild and the climate dry to semi-arid in terms of precipitation; the plant formations would mostly have been open, and the main species would have been those that best adapted to the impoverished soil of the Late Glacial period.

There are few reference sequences for the region under study, but the dynamics observed at Gueldaman appear to follow a trend that was common to both north and south of the central-western Mediterranean. The existence of a Late Glacial phase with junipers is also documented in the north-western Mediterranean (Vernet, 1980a, 1980b; Uzquiano, 1990; Aura et al., 2005; Carrión Marco, 2006), which could be mean that this genus adapted perfectly to the impoverished soil. The marine pollen sequence of core MD04-2797CQ (located in the Siculo-Tunisian Strait –Desprat et al., 2013) shows vegetation dominated by Asteraceae-Poaceae, which the authors interpret as a persistence of arid conditions even as the temperature started to rise, which lasted until at least 10,100 cal. BP. The important pine pollen curve in this sequence shows the regional presence of this genus. Its absence in the anthracological record at Gueldaman may denote a somewhat more pronounced aridity in the surroundings of this cave. Lowland pines are occasionally present in other enclaves of the Maghreb (Neumann, 1992; Wengler and Vernet, 1992). However, pollen sequences of the mountains near Gueldaman indicate a persistence of *Quercus* and pine forest formations in these elevations, with occasional presence of *Cedrus* (Salamani, 1991; Benslama et al., 2010), thus showing the sub-humid character of important parts of the region. The absence of the main taxa identified in the pollen sequences of the region (i.e., *Quercus*, *Erica*), evidences the heterogeneity of the Algerian flora at a local scale.

In the second part of the sequence (Charcoal Phase 2, fig. 4) from the Boreal, the top of which is dated at 8880 ± 80 cal. BP, there is a visible increase in certain thermo- and meso-Mediterranean sclerophyllous species, mainly *Pistacia*, accompanied by *Rhamnus-Phillyrea* and Compositae. Evergreen *Quercus* sp. also underwent an increase, which is very clear in the level dated to 8880 cal. BP. In contrast, there was a drastic decline in *Juniperus/Tetraclinis*, *Ephedra* and Labiatae. This was probably the initial phase of colonisation by Mediterranean vegetation associated with an increase in temperature and precipitation, which coincides with the increase in pollen from Mediterranean species in marine sequences (Naughton et al., 2007, 2016; Sanchez Goñi et al., 2008; Sánchez Goñi et al., 2013, among others – Fig. 6). Although there are only isolated elements, *Ficus carica*, *Erica* sp. and *Tamarix* sp., among others, appear in this phase of the charcoal record of Gueldaman. In general, in the Mediterranean environment these chronologies show a transition from open formations, dominated by conifers in almost all regions during the Preboreal, to consolidated formations of mesothermophilic or clearly warm-climate species in some Mediterranean regions (Fig. 6). In marine sequences, the presence of thermophilic species starts to increase between 10.1 and 6.6 ka, although the expansion of typically Mediterranean plants becomes more evident after 6.6 ka (Desprat et al., 2013).

The presence of *Pistacia* formations, accompanied by other species characteristic of semi-arid steppe environments, is also recorded in the pollen sequences from central Tunisia up to the Middle to Late Holocene transition, when they were replaced by *Olea europaea* formations, prior to 5000 cal BP (Lebreton et al., 2015) or in other Mediterranean areas and the Central Sahara ca 6000 cal BP (Mercuri, 2008).

The fact that it has not been possible to identify *Olea europaea* with any certainty during the Iberomaurusian levels of Gueldaman (in the

Table 2
AMS dating performed on *Olea europaea* macroremains.

Material	Context of origin	Square	Level	Depth (cm)	Lab. reference	AMS BP	Years cal. BP
Olea europaea charcoal	Pre-Neolithic	I38	19	250-262	Beta - 411100	6170 ± 30	7165-6975
Olea europaea charcoal	Pre-Neolithic	I38	17	242-245	Beta - 411099	4300 ± 30	4875-4835
Olea europaea charcoal	Pre-Neolithic	I38	13	217-222	Beta - 411097	6130 ± 30	7160-6940

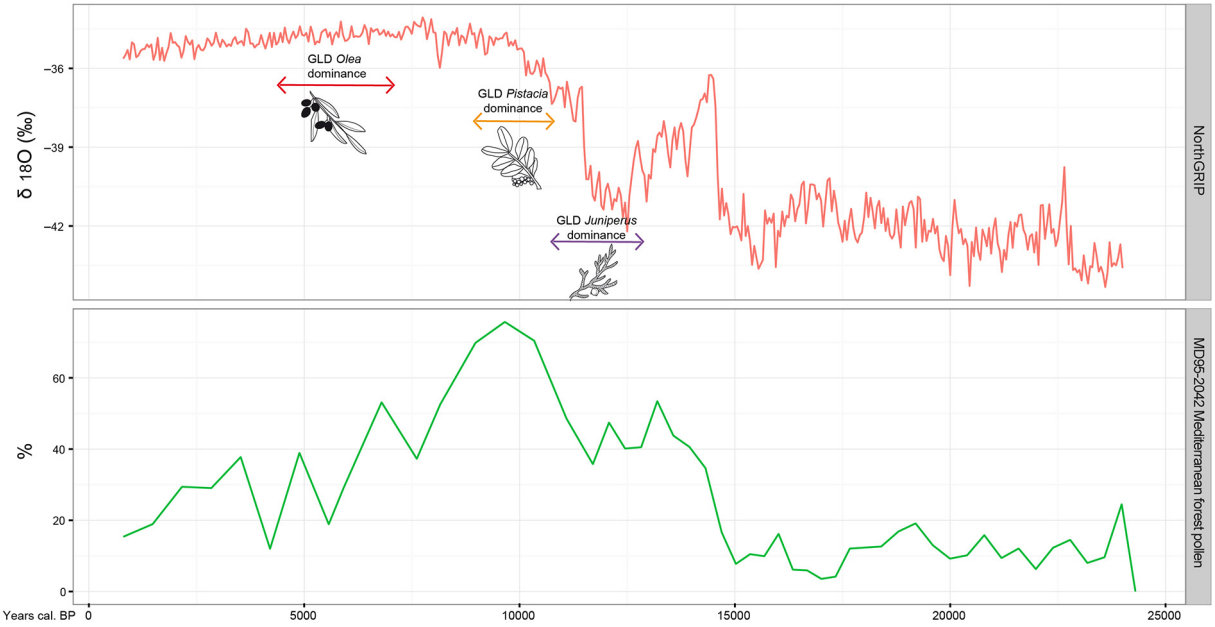

Fig. 6. Correlation between $\delta^{18}O$ from NGRIP ice-core (Andersen et al., 2004; Rasmussen et al., 2006, 2014), Mediterranean forest pollen from Cores SU81-18 & MD95-2042 in SW Iberian margin (Sanchez Goñi et al., 2008; Sánchez Goñi et al., 2013) and dominant woody taxa at Gueldaman GLD 1 cave.

absence of relevant dating to confirm its presence) leaves the question of the distribution of this species in the Pleistocene period open. It is essential to locate the presence (properly dated) of *Olea europaea* in Pleistocene contexts if we are to describe the post-glacial expansion of thermophilic flora and the establishment of sclerophyllous formations in any detail. In the Gueldaman sequence, the moment when this substitution of vegetation took place is not represented due to the existence of a sedimentary hiatus of almost 2000 years. However, *Olea europaea* formations would have been located in an enclave more or less close to Gueldaman, which would explain its rapid expansion in the Middle Holocene, as will be discussed in the following sections.

Unlike Mediterranean forest pollen in MD95-2042, which reaches its peak towards 10,000 cal. BP before declining again (Fig. 6), Mediterranean species remain highly and constantly represented in the charcoal record of Gueldaman after ca. 7000 cal. BP throughout the Neolithic sequence (Fig. 4). This difference is probably seen because the pollen represents the regional situation, whereas the charcoal record of Gueldaman corresponds to the local environment, in which *Olea europaea* formations continued to dominate local formations.

6.2. Specific use of plants during the Neolithic in Gueldaman GLD 1 cave

The beginning of the Neolithic sequence at Gueldaman is dated to 7046 ± 84 cal. BP. The vegetation represented in the macroremains changes drastically with respect to the previous phase, with the absolute predominance of *Olea europaea* in percentages of around 80-90%, accompanied by other taxa related to Mediterranean sclerophyllous woodland, such as evergreen *Quercus* and *Arbutus unedo* (Charcoal Phase 3, Fig. 4). The carpological remains also include *Olea europaea* and *Vitis vinifera*, which seem to be associated with the presence of coprolites at these levels. This denotes a change in use of the cave, as a livestock enclosure, which would have been in line with the new economy.

Indeed, although hunting continued to play an important role, at least during AU 1, it coexisted with livestock practices based on rearing goats and sheep (more than 55% of the remains), but predominantly goats (Kherbouche, 2015; Kherbouche et al., 2016; Merzoug et al., 2016). This type of livestock is consistent with the mountainous environment of the Adrar Gueldaman region. However, from A.U. 2, bovids would certainly have been introduced as well, as bone morphology point to the presence of the wild species (aurochs) in early units and domestic specimens in this unit (Kherbouche et al., 2016: 58).

It therefore seems logical that some of the plant material found in these levels would have been brought to the cave as fodder for the animals stabled there, and *Olea europaea* was a species that was particularly valued for this purpose. As part of the typical Mediterranean vegetation, wild olive stems, and subsequently olive stems, were used as animal fodder in many traditional societies. Olive leaves are highly palatable for both goats and sheep, but even goats can browse the woody stems of this species as a high percentage of their diet (Badal, 1999). Therefore, the provision of whole branches so that the leaves, fruit and stems could be eaten, and the woody remains subsequently burned (a practice also observed in the area in the present day) could explain the presence of organs, xylem and stones in Neolithic levels at Gueldaman.

Pistacia and other taxa that had been important in the Iberomaurusian sequence decline or disappear from the anthracological record at that time. In the case of *Pistacia*, these are species that are ecologically consistent with *Olea europaea*, and their notable presence among the carpological remains leads us to believe that it did not really disappear from the landscape. It is necessary to question whether this presence denotes collection of the *Pistacia* nucules exclusively, either to extract their oil (Rivera Núñez and Obón de Castro, 1991; Torres-Montes, 2004; Morales et al., 2013) or for some other use as food. Firewood collection may have been highly focused on wild olive, which would mask the actual percentages of the other species. *Pistacia* is very sensitive to forestry activities, fires and the action of animals, which are the causes of its current reduction in many areas of the Maghreb (Belhadj, 2001); this, together with a strong preference for collecting *Olea europaea*, may explain its limited presence in the Neolithic records of Gueldaman. However, it would certainly have been present in the landscape, although the percentage is difficult to gauge from the archaeobotanical material. The anthracological data available for the Oujda Plain in Eastern Morocco show the importance of *Olea europaea* and *Pistacia* (*P. lentiscus* and *P. atlantica*) formations during the Middle Holocene, which would indicate a more humid atmosphere than at present (Wengler and Vernet, 1992). It is therefore postulated that *Olea europaea* formations and several species of *Pistacia* would have been much more widespread than at present, in the form of forests

that would later have been transformed into "maquis" by the effect of agriculture, pasturage, intense wood gathering and fire (Sadki, 1995).

Therefore, the data obtained indicate that thermo-Mediterranean formations with *Olea europaea* would have been taxonomically much richer than those we see in the Neolithic record of Gueldaman, where it could be argued that wild olive is clearly over-represented, making it more difficult to reconstruct the plant landscape. This over-representation is probably related to a specific use of this plant as fodder for livestock. This use had already been postulated for some Neolithic sequences with a great abundance of woody remains of this plant (Badal, 1999). The wild olive leaf makes more suitable fodder for livestock than other traditionally used species (oak, holm oak, etc.), as it has a higher fat content than other trees and even than herbaceous plants, providing a greater amount of energy, while its crude fibre values are lower, making it more digestible and palatable (Badal, 1999).

Similarly, there are several taxa whose presence is possibly explained by their use as food for human communities. There is no evidence to affirm that their presence could be linked to livestock feeding. This is the case of acorns or fan palm. Despite its astringent properties, fan palm has typically been consumed (Rivera Núñez and Obón de Castro, 1991; Torres-Montes, 2004), as has been recorded in Epipalaeolithic and Neolithic levels, for example, at Ifri Oudadane (Morocco) (Morales et al., 2013).

7. Conclusions

The archaeobotanical research carried out at the Gueldaman GLD 1 cave provides a better understanding of the use of this cave by different human communities and the landscape dynamics in an extensive sequence that runs from the Late Glacial to the Middle Neolithic, with high resolution data for the Pleistocene-Holocene transition. The application of a strict sampling protocol for the recovery of the botanical remains and their comparison with the chrono-stratigraphic data has been fundamental in obtaining this sequence. It is also supported by the dating carried out using a previous sample identification and selection protocol based on bioclimatic consistency criteria. Thus, a series of radiocarbon dating carried out on *Olea europaea* remains has shown that the presence of this species in Iberomaurusian levels has resulted from intrusions from Neolithic levels, where this taxon is dominant in plant assemblages.

Global climatic events reveal changes in the vegetation over major phases: Late Glacial, development of Mediterranean sclerophyllous formations, and landscape of the Middle Holocene, with a predominance of wild olives.

The combined analysis of woody macroremains and fruits/seeds has made it possible to assess the management of plant resources throughout this sequence and to suggest specific uses of certain plants, such as the probable use of *Olea europaea* as animal fodder.

Declaration of Competing Interest

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

Acknowledgements

The archaeobotanical analyses at Gueldaman were carried out within the framework of the PALEOPLANT project (ERC 2013 CoG 614960). YCM's work was carried out under a Ramón y Cajal research fellowship (RYC-2014-16027) funded by the Spanish *Ministerio de Economía, Industria y Competitividad* and GPJ's work was carried out under the post-doctoral contract (CIDEGENT/2019/003) funded by *Generalitat Valenciana*. The authors would like to thank Dr. Mª F. Sánchez Goñi for providing the Mediterranean Forest Pollen data for Fig. 6.

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