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Phytoliths as a seasonality indicator? The example of the Neolithic site of Pendimoun, south-eastern France

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Abstract	<p>Pendimoun rock-shelter is among the oldest Neolithic sites known on the French littoral (Impressa culture, since ca. 5700 BCE). It was discontinuously occupied from the Mesolithic to the end of the Neolithic. During the Neolithic, it was used for pastoral purposes and domestic activities as well as for pottery production. Agriculture and cereal processing are clearly attested during the Impressa occupation (grains, husk and straw macroremains, grindstones) and become more less obvious in the overlying layers. Phytolith analysis concerned 1 Mesolithic sample (Sauveterrian culture) and 16 samples covering most of the 6th millennium BCE (Impressa, Cardial, and transition to Early Square Mouthed Pottery—SMP cultures). Significant amounts of grass phytoliths and the scarcity of dicot phytoliths suggest that the livestock, whose dung constitutes an important part of the sediment, mainly fed on wild grasses. Inflorescence bract phytoliths are well represented only in the Impressa levels, confirming that cereals were partly processed in situ only during the earliest stages of the Neolithic. Amounts of BILOBATE short cells proved to be higher than expected in an area where only a few panicoid species can grow. The three candidates for BILOBATE phytolith producers (<i>Setaria</i> spp., <i>Digitaria sanguinalis</i>, <i>Echinochloa crus-galli</i>) all have a short vegetation cycle that lies entirely between the end of spring and the beginning of autumn, suggesting that the shelter was mainly used during that period. The low amount of inflorescence bract phytoliths (except during the Impressa) seems to restrict that range to the period before the ears become mature, namely the end of spring or early summer.</p>
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Keywords (separated by '-')	Phytolith - Neolithic - South-eastern France - Seasonality - Panicoideae - Pastoralism
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2 Phytoliths as a seasonality indicator? The example of the Neolithic site 3 of Pendimoun, south-eastern France

4 Claire Delhon¹ · Didier Binder¹ · Pascal Verdin¹ · Arnaud Mazuy¹

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7 Abstract

AQ1 Pendimoun rock-shelter is among the oldest Neolithic sites known on the French littoral (Impressa culture, since ca. 5700 BCE). It was discontinuously occupied from the Mesolithic to the end of the Neolithic. During the Neolithic, it was used for pastoral purposes and domestic activities as well as for pottery production. Agriculture and cereal processing are clearly attested during the Impressa occupation (grains, husk and straw macroremains, grindstones) and become more less obvious in the overlying layers. Phytolith analysis concerned 1 Mesolithic sample (Sauveterrian culture) and 16 samples covering most of the 6th millennium BCE (Impressa, Cardial, and transition to Early Square Mouthed Pottery—SMP cultures). Significant amounts of grass phytoliths and the scarcity of dicot phytoliths suggest that the livestock, whose dung constitutes an important part of the sediment, mainly fed on wild grasses. Inflorescence bract phytoliths are well represented only in the Impressa levels, confirming that cereals were partly processed in situ only during the earliest stages of the Neolithic. Amounts of BILOBATE short cells proved to be higher than expected in an area where only a few panicoid species can grow. The three candidates for BILOBATE phytolith producers (*Setaria* spp., *Digitaria sanguinalis*, *Echinochloa crus-galli*) all have a short vegetation cycle that lies entirely between the end of spring and the beginning of autumn, suggesting that the shelter was mainly used during that period. The low amount of inflorescence bract phytoliths (except during the Impressa) seems to restrict that range to the period before the ears become mature, namely the end of spring or early summer.

22 **Keywords** Phytolith · Neolithic · South-eastern France · Seasonality · Panicoideae · Pastoralism

23 Introduction

24 Pendimoun is a very important site for understanding of
25 the Neolithic transition in the northwestern Mediterranean.
26 Farming economies, which spread throughout the Near-
27 East and the Aegean, reached southern Italy shortly after
28 6000 BCE (Binder et al. 2017). The Neolithic innovations
29 were brought to the Western Mediterranean by groups of
30 pioneers belonging to the Impresso-cardial cultural complex
31 who arrived by sea from Italy. These groups settled close to
32 the littoral, while parts of the hinterlands were still occupied
33 by Late Mesolithic groups. These pioneer populations are

known thanks to a very small number of sites, scattered from
Liguria in Italy to the south-eastern Languedoc in France.
Pendimoun is one of these few key-sites documenting the
very beginning of agro-pastoral economies in south-western
Europe. With the spread of agriculture, questions arise concerning
the ways prehistoric farmers exploited the territory and managed
their resources. In particular, the mobility of the groups and
the duration of the occupations, which seem to be linked to
the kinds of activities carried out at the sites, remain difficult
to assess accurately. Due to the scarcity of archaeological sites
and to preservation hazards, plant and animal remains linked
to human activities are rare. Therefore, as many as possible
of the recovered remains need to be fully exploited and studies
must extend beyond the most obvious macroremains. Phytolith
analysis has proved to be an effective tool for obtaining reliable
quantitative information concerning plant-related activities (and
more specifically agriculture and farming), particularly in contexts
where organic remains are poorly preserved or scarce (Harvey
and Fuller 2005; Delhon et al. 2008; Cabanes et al. 2009;

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54 Lancelotti et al. 2014). In our study, phytolith analysis of
 55 Early Neolithic levels at Pendimoun shelter has been used
 56 as a means, among others (there are several ongoing studies
 57 concerning the same site which rely on a wide range of ana-
 58 lytic approaches: see Binder et al. in press), of documenting
 59 agro-pastoral activities.

60 Archaeological background

61 Pendimoun is a rock-shelter located in south-eastern France,
 62 near the Italian border, just above the City of Menton
 63 (Fig. 1). Due to the steep topography, this can be considered
 64 to be both a coastal site (at less than 4 km from the sea as the
 65 crow flies) as well as a low mountain site (at an elevation of
 66 nearly 700 m). The site is currently on the ecotone between
 67 Meso- and Supramediterranean Vegetation Belts and the
 68 surrounding landscape is strongly characterized by pasto-
 69 ral exploitation. The site was first explored in the 1950s,

and more recent excavations carried out by Didier Binder
 between 1985 and 2006 have revealed a discontinuous occupa-
 tion from the Mesolithic to the end of the Neolithic. The
 southern and northern sectors of the site are separated by
 a trench inherited from the old excavation, which unfortu-
 nately hinders any strict correlation between the two stratig-
 raphies (Binder et al. 1993).

The oldest archaeological level is attributed to the Sau-
 veterrian Mesolithic culture of the 9th millennium BCE and
 it is notably represented by an infant burial. Around 80 cm
 above this level, the Neolithic sequence stretches over a
 thickness of ca. 200 cm and records occupations from the
 Impressa Neolithic (Early 6th millennium BCE) to the Bell
 Beaker cultural complex (Late 3rd millennium BCE). Despite
 the fact that the two sectors of the site are now disconnected,
 it appears that the Impressa deposits from the southern sec-
 tor predate those from the northern sector. The sequence
 also includes several archaeological discontinuities due to
 periods of abandonment of the site and/or to erosion. The

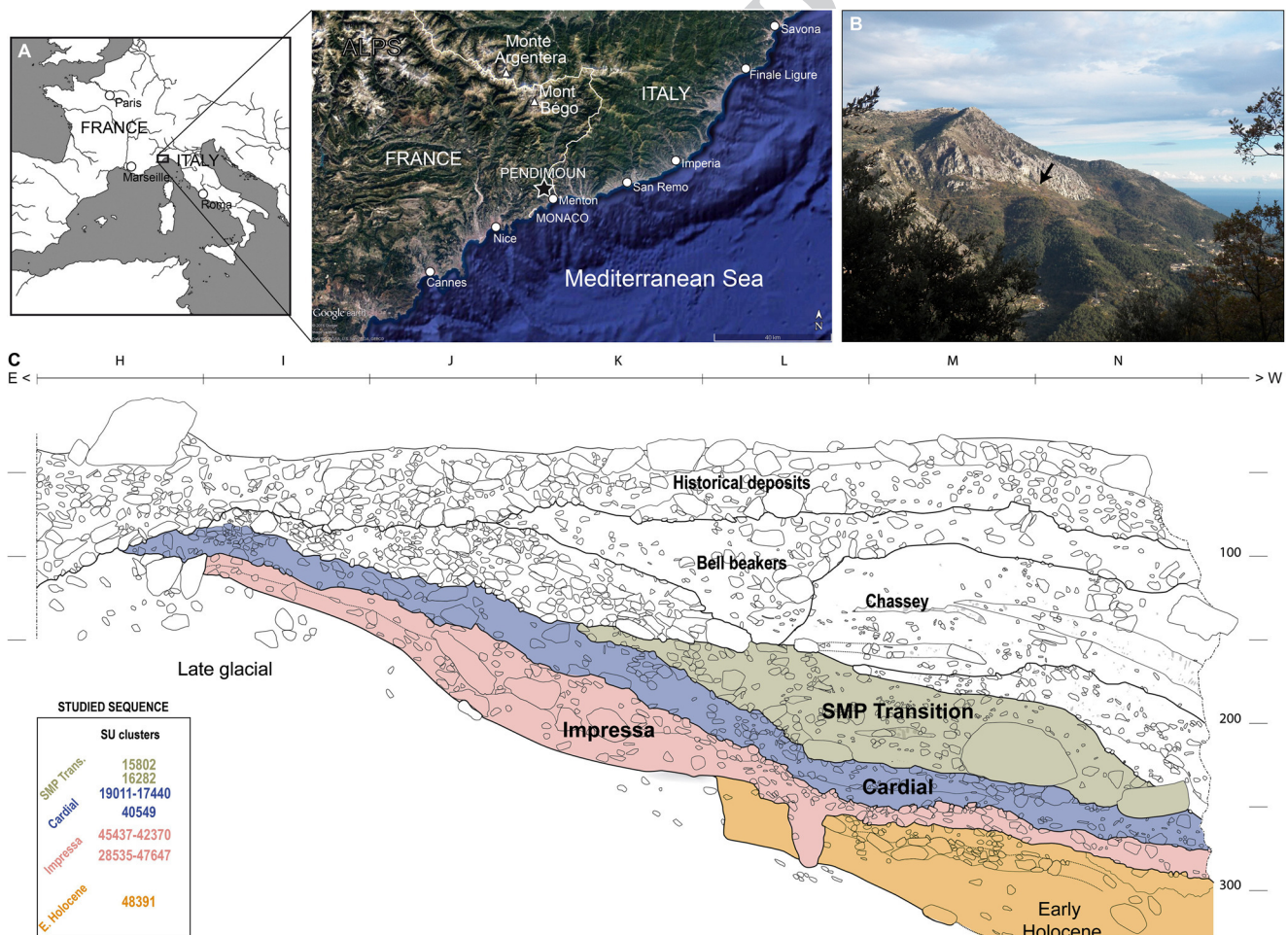


Fig. 1 Site location in south-eastern France (a), general overview of the shelter (b photograph JV Pradeau) and stratigraphic sequence of the northern sector (c east/west section)

89 identification of sheep bones and the composition of the
 90 sediment, partly made up of mineralized dung and rich in
 91 spherulites and ashes, indicate that the shelter was used
 92 for pastoral purposes since the earliest Neolithic occupa-
 93 tion, but more intensively during the Chassey Neolithic
 94 (Late fifth–Early fourth millennium) (Binder et al. 1993, in
 95 press). Charcoal analysis has shown that the impact of pas-
 96 toral practices on the vegetation remained low until the end
 97 of the fifth millennium but increased markedly during the
 98 3rd millennium BCE. It also shows the exploitation of diverse
 99 patches of a mosaic vegetation, probably linked to a staged
 100 agro–sylvo-pastoral system based on the exploitation of the
 101 resources from various altitudes (Battentier et al. 2015).
 102 Several domestic activities also took place at the site, in
 103 particular an abundant and distinctive production of ceramic
 104 wares (Basso et al. 2006; Gomart et al. 2017). Numerous
 105 hearths and waste from everyday life suggest that the shelter
 106 was used as a dwelling by shepherd-potter groups. A set of
 107 burials has also been discovered in the Cardial levels (Mid-
 108 6th millennium BCE) (Zemour et al. 2016). Agriculture is
 109 attested since the earliest Neolithic by the presence of cereal
 110 grains in the Impressa levels, which are amongst the oldest
 111 in France (Binder et al. 1993; Guilaine et al. 2007), and
 112 various tools linked with agricultural activities or with grain
 113 processing, such as sickle blades or grindstones. Seashell
 114 gathering is also attested during the 6th millennium BCE.

115 The stratigraphy is particularly detailed from the 6th to
 116 the 5th millennia BCE (235 stratigraphic units grouped in 30
 117 clusters). The present study focusses on this period, during
 118 which the shelter was used for diverse activities, sometimes
 119 successively and sometimes simultaneously. Phytolith analy-
 120 sis is part of a set of investigations implemented in order to
 121 hone our understanding of the chrono-stratigraphy and of
 122 the archaeological occupations. Despite the fact that ongo-
 123 ing studies have not as yet yielded all their results, the data
 124 currently available already provide us with a good picture
 125 not only of the activities carried out on the site but also of
 126 some aspects of the socio-economical organization through
 127 time (Binder et al. in press). Like most of these shelters and
 128 caves used during the Neolithic in such contexts, Pendimoun
 129 is considered to have been a seasonal settlement. The key
 130 challenge facing us in terms of the Neolithic in general, and
 131 this site in particular, is to understand the nature, periodicity
 132 and rhythm of the seasonal occupations, and consequently to
 133 understand the position of the site in the territory exploita-
 134 tion network. During the earliest Neolithic (Impressa), the
 135 site was inhabited by a group of farmers (Rowley-Conwy
 136 et al. 2013), who cultivated cereals and raised sheep. The
 137 activities that took place on the site were diverse and also
 138 included some hunting, gathering of plants (acorns) and
 139 of seashells as well as the manufacture of ceramics; these
 140 activities seem to have been conducted at different seasons
 141 of the year, during long-lasting occupations of the shelter.

142 Afterwards, during the Cardial Neolithic, the shelter seems
 143 to be used during briefer but repeated periods, although the
 144 spectrum of activities remains globally the same (livestock
 145 keeping, pottery production), with the noticeable exception
 146 of the use of the shelter to bury the dead. The importance
 147 of hunting in the economy is not clear, partly because of
 148 difficulties in the identification of *Suidae* (wild boar vs.
 149 domestic pig). During the transition phase to the Square
 150 Mouthed Pottery (SMP) culture, the shelter was used for
 151 the penning of herds, but also for various other domestic and
 152 craft activities, which suggest long-lasting occupations. A
 153 hiatus of several centuries isolates the first SMP settlement
 154 from the rest of the Neolithic sequence, which exhibits an
 155 increasing specialization of the site towards pastoral activi-
 156 ties: during the Middle Neolithic, the occupation is typical
 157 of the *grottes-bergeries* (sheepfold caves) known elsewhere
 158 in the Alps and the northwestern Mediterranean area dur-
 159 ing that period (Delhon et al. 2008; Angelucci et al. 2009;
 160 Martin et al. 2011 and references therein); afterwards, dur-
 161 ing the Bell Beaker period, the pastoral economy switches
 162 to rearing cattle rather than small ruminants (Binder et al.
 163 1993). Because Pendimoun is a reference site for the first
 164 stage of the Neolithic in the area and because the following
 165 levels (from mid-fifth to the end of 3rd millennia BCE) pro-
 166 vided less artefacts and ecofacts, this paper focuses on the
 167 earliest Neolithic sequence, i.e. the Impressa first Neolithic,
 168 the Cardial Neolithic and the transition towards the SMP.

169 Materials and method

170 Phytoliths are microscopic opal silica particles produced in
 171 and between plant cells during the life of the plant. Due to
 172 their chemical composition, they are usually well preserved
 173 in various contexts, even when the organic plant remains are
 174 decomposed (Kibblewhite et al. 2015). Because of the high
 175 phytolith content of grasses (including cereals) and the spec-
 176 ificity of the forms produced by the Poaceae, these biore-
 177 mains are appropriate for reconstructing agricultural prac-
 178 tices, cereal processing and the diet of herbivores (including
 179 domesticated species). Seventeen stratigraphic units were
 180 sampled for phytolith analysis, in order to give clues to the
 181 relationships between the human groups that frequented the
 182 shelter during Prehistory and the surrounding vegetation.
 183 In particular, we aimed to gain a better understanding of the
 184 share of agriculture in the economy of the Early Neolithic
 185 societies by tracking cereal remains, and of the management
 186 of herds through the phytolith record of their diet. Focusing
 187 on the most promising archaeological levels, phytolith analy-
 188 sis was carried out on 1 sample from a Mesolithic burial
 189 and 16 samples covering most of the 6th millennium BCE
 190 (Impressa, Cardial, Early SMP). Our analysis targets chrono-
 191 cultural complexes for which sharply focused documentation

concerning the exploitation of vegetal resources is lacking, in particular the pioneer stages of the Neolithic (Impressa), but also the earliest stages of the establishment up of Middle Neolithic cultural complexes (SMP).

All of the samples come from sheltered zones of the site, where the sedimentary sequence was shown to have been protected from major erosion. Most of the samples come from the northern sector of the site and were analysed by C.D.; two samples recovered from the southern sector and previously analysed by P.V. are also included into the present study. A small number of samples originate from the fill of identified structures, while most are from the sedimentary matrix of the archaeological levels (Table 1).

Around 2 g of sediment from each sample were processed by A.M. at the CEPAM-CNRS Laboratory, following the laboratory's routine protocol for phytolith extraction. The sediment is sieved (200 µm) after soaking (12 h) in demineralized water for deflocculation of clays. The fine fraction is then treated first with concentrated hydrochloric acid and then with potassium hydroxide in an ultrasonic hot bath. After several rinses, phytoliths are concentrated by heavy liquid separation using a Thoulet solution ($d=2.35$). Once dried, the phytoliths are dispersed on a slide in a drop of immersion oil and protected by a cover-glass sealed with resin. Phytolith identification is carried out through a transmitted light microscope, at a magnification of $\times 1,000$. Where needed, polarizer/analyser devices are used to differentiate amorphous silica opal from potentially birefringent particles. The protocol used provides a very clean phytolith extract, but it does not allow the observation of spherulites. These are identified in the sediment through other analytic means (Brochier in Binder et al. 1993) and do not fall in the scope of the present study. Phytolith identification is based on a morphotypic classification prior to a taxonomic one, due to the multiplicity (a single species may produce various different morphotypes) and the redundancy (the same morphotype may be produced by various different species) of phytolith production (Rovner 1971; Brown 1984). As regards the terminology used for the description of the morphotypes, we endeavour to follow the latest recommendations of the International Committee for Phytolith Nomenclature (ICPN 2.0, ICPT in press). In order to guarantee the statistical reliability of the results, we ensured that more than 200 classified phytoliths were counted for each studied sample.

Results

All of the samples provided abundant and well preserved phytoliths (Table 1). It was not difficult to observe satisfactory quantities of significant forms on the slides, as phytoliths proved to be abundant and well preserved in

every sample. As a result, identifiable phytoliths counts vary between 167 and 409. Weathering and surface alteration (Fredlund and Tieszen 1997) were rarely observed. The phytoliths were nearly always represented by single-cell particles: connected silicified cells, also known as silica skeletons, were only rarely encountered in five different samples, mainly from the sedimentary matrix (Impressa, Cardial, SMP transitions levels) but also from one Impressa combustion structure. They account for 0.3 to 1.2% of the assemblages in which they have been observed, i.e. 1 to 4 individuals per sample. These multicelled phytoliths are mainly made up of grass epidermal cells, apart from one example of contiguous silicified grass bulliform cells. The observed morphotypes (Fig. 2) mainly relate to the Poaceae (grass) family. Phytoliths attributed to dicots are rare over all, but reach noticeable values in the southern area. They are represented by globular morphotypes (SPHEROID ORNATE) and by probable epidermal cells (tabular polygonal morphotype). Concerning grass phytoliths, the morphotypes produced in the vegetative parts of the plants (culm, leaves) are abundant. Among them, ELONGATE ENTIRE, ELONGATE SINUATE, ACUTE BULBOSUS are very common and cannot be taxonomically identified further. The silicified bulliform cells have also been allocated to the general grass family due to a lack of published descriptions and of modern comparison reference material for the area. They were represented by the BULLIFORM FLABELLATE and BLOCKY morphotypes. Although BLOCKY forms are not unequivocal (ICPT in press), the overall composition of the phytolith spectra, dominated by grass phytoliths, points to silicified bulliform cells. A silica skeleton made of articulated BLOCKY phytoliths, likely silicified bulliform cells, was observed. BULLIFORM FLABELLATE and BLOCKY morphotypes are subsumed into the BULLIFORM category in Table 1 and Fig. 3. On the other hand, short cells allow us to distinguish between several Poaceae sub-families (Twiss et al. 1969; Twiss 1992). CRENATE morphologies characterize the Pooideae subfamily, while RONDEL is more widespread, but, in a temperate context, can be interpreted as mainly originating from the Pooideae family too. BILOBATE morphotype, also previously known as "dumbbells", is mainly produced by the Panicoideae subfamily. SADDLE, only present in low amounts in Pendimoun sediment, is frequently used as a diagnostic the Chloridoideae, despite that it can be found in other related subfamilies (ICPT in press). Nearly all of the species of wild grasses from temperate Europe are Pooideae, as are the first cereals domesticated in the Middle East and then introduced into Europe (*Triticum* spp., *Hordeum* spp.). Panicoideae are only represented by a small number of genera in middle latitudes of Western Europe, particularly *Setaria* (wild millets), *Digitaria* and *Echinochloa*. Domesticated millets also belong to the Panicoideae subfamily.

Table 1 Results of the phytolith analysis of the Mesolithic and Early Neolithic levels of Pendimoun shelter (analyses C. Delhon)

Chronocultural attribution	Sauveterrien		Impressa (base)		Cardial (base)		Cardial (mid.)		Cardial (top)		Cardial (top2)		SMP trans. (base)		SMP trans. (mid.)	
	48,391	28,535	28,936 ^a	29,000 ^a	45,437	42,370	40,549	19,011	41,859	40,048	18,489	17,440	16,282	16,518	15,802	
Sample	48,413	28,936 ^a	29,000 ^a	47,884	45,596	43,662	42,110	40,317	41,859	40,048	19,879	18,489	16,863	16,518	15,539	
Zone	North	South	South	North	North	North	North	North	North	North	North	North	North	North	North	
Square	N22C	O13C	N15C	M22B	L21A	L21B	L21D	L23A	L22A	L20A	K21D	K20D	L22C	M23C	M22	
Stratigraphic unit	48,391	28,890	28,889	47,803	47,647	43,661	42,108	19,909	19,000	19,908	19,011	17,440	16,581	16,283	14,999	
Structure	Burial			Combustion		Posthole	Burial (sec. fill)									
Silica skeleton	69	118	42	3	1	81	96	77	115	80	51	89	86	92	4	
ELONGATE ENTIRE			86			82										
ELONGATE SINUATE			2			4	2	2	3				3	4		
ELONGATE DENDRITIC	2	6	32	43	35	6	4	17	8	7	2	7	6	11		
BULLIFORM	28	2		28	12	13	4	22	10	15	5	7	6	17	16	
Articulated BLOCKY								3								
ACUTE BULBOSUS	9	16	40	14	16	9	17	22	17	14	8	13	30	21	11	
RONDEL	149	60	162	168	117	145	123	149	132	176	94	129	146	155	158	
CRENATE	2	12	2	4	10	2	5	6	6	7	1	1	3	8	2	
BILOBATE	4	18	26	8	5	5	1	8	1	8	5	7	10	15	13	
SADDLE	2			1	2				1							
PAPILLATE				1		1										
SPHEROID ORNATE	18			6	3		4	5	3	3	1	1		2		
Tabular polygonal	1	44	94													
Total no. classified phytoliths	284	276	400	396	287	333	264	305	409	313	167	254	290	329	270	

The samples are chronologically sorted and grouped in relevant stratigraphic unit clusters (SU cluster) based on field observation and Bayesian processing of the ¹⁴C dates (Binder, ongoing work)

^aAnalyses: P. Verdin

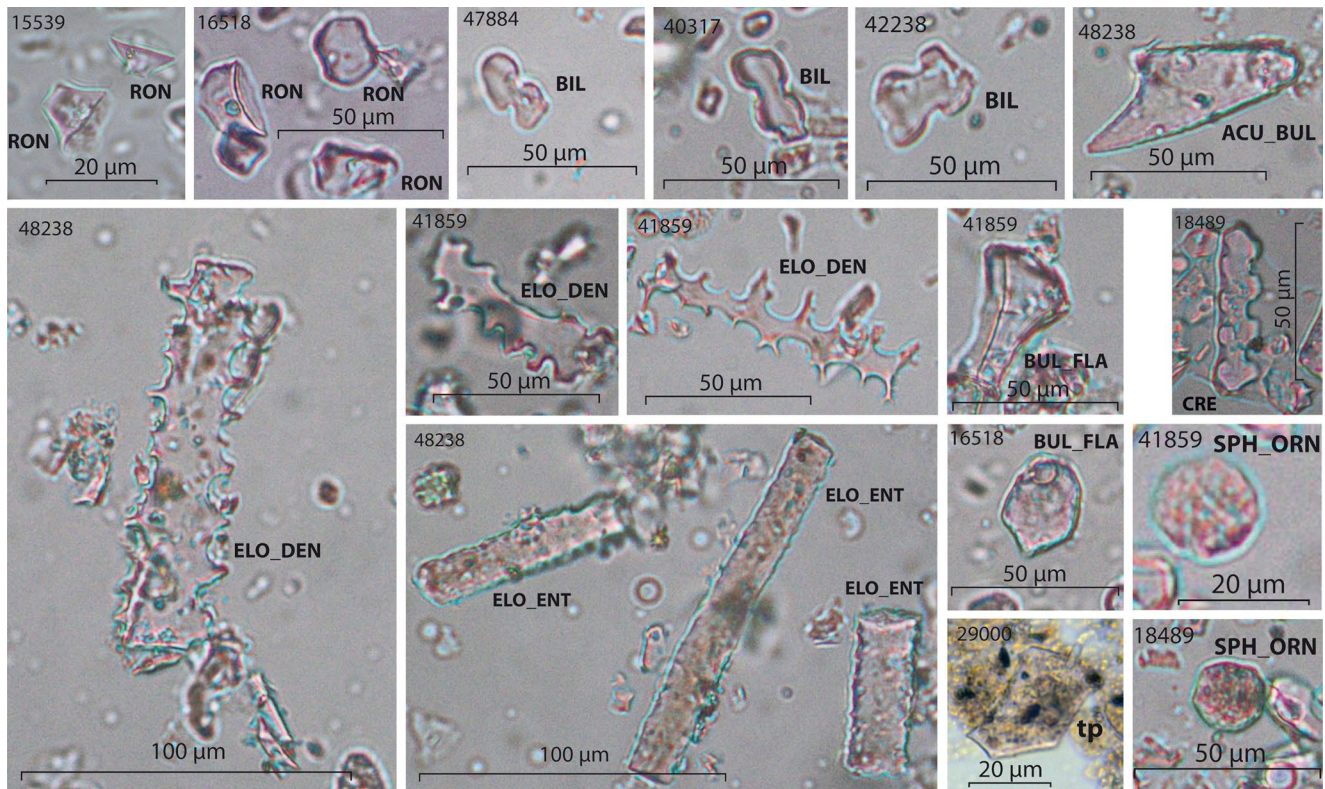


Fig. 2 Photographs of the main phytolith morphotypes found at Pendimoun: RONDEL (RON), BILOBATE (BIL), CRENATE (CRE), ELONGATE DENDRITIC (ELO_DEN), ELONGATE ENTIRE (ELO_ENT), BULLIFORM

FLABELLATE (BUL_FL), ACUTE BULBOSUS (ACU_BUL), SPHEROID ORNATE (SPH_ORN), tabular polygonal (tp). The number in the left corner refers to the phytolith sample

295 Finally, the Chloridoideae subfamily is mainly distributed
296 in intertropical areas, but it is nevertheless represented in
297 southern France by *Cynodon dactylon* (Bermuda grass).
298 The common reed, *Phragmites australis*, which belongs
299 to the Arundinoideae subfamily, also produces saddle-
300 shaped short cells (Ollendorf et al. 1988), but this spe-
301 cies is restricted to wetlands, especially in Mediterranean
302 areas. Morphotypes from grass inflorescence bracts have
303 also been observed, in the form of ELONGATE DENDRITIC and
304 scarce PAPILLATE (Parry and Smithson 1966; Rosen 1992).

305 Most of the spectra show a strong dominance of grass
306 phytoliths (Fig. 3). In the Neolithic samples from the
307 northern sector, dicot morphotypes show a discontinuous
308 curve and only account for nil to 1.6% of the total. The
309 pattern is completely different for the samples from the
310 southern area, in which dicots phytoliths, in the form of
311 tabular polygonal particles interpreted as leaf epidermal
312 cells (tp in Fig. 2) have high values: 16.1 and 23.5%. The
313 variability of the phytolith spectra might be linked to a
314 spatial distribution of the activities inside the shelter, but
315 more samples from the southern zone would have been
316 necessary to assess the extent of the phenomenon and to
317 propose further interpretations. The Sauveterrian burial,
318 in the northern area, also exceeds the Neolithic levels in

this sector in terms of dicots, which represent 6.7% of its
319 phytolith content. 320

321 Discussion

322 Livestock diet

323 In pastoral sites like Pendimoun, phytolith accumulation
324 is thought to be mainly due to shepherds bringing vegeta-
325 tion into the cave as bedding or fodder for the livestock,
326 and also, depending on the frequency and the duration of
327 their presence in the shelter, to the transportation of plant
328 material within the digestive systems of the animals. Nev-
329 ertheless, it remains difficult to determine whether these
330 microremains mainly stem from livestock alimentation or
331 if they could also partly result from the use of plants for
332 other purposes. Based on ethnoarchaeological observations,
333 a significant presence of multi-cell phytoliths (also called
334 silica-skeleton) is sometimes considered as a marker of
335 dung accumulation (Portillo et al. 2014) or of the presence
336 of bedding (Cabanes et al. 2009). Yet, these forms are rather
337 rare in Pendimoun. Nevertheless, in some cases, like in La
338 Grande Rivoire, the abundance of spherulites indicates that

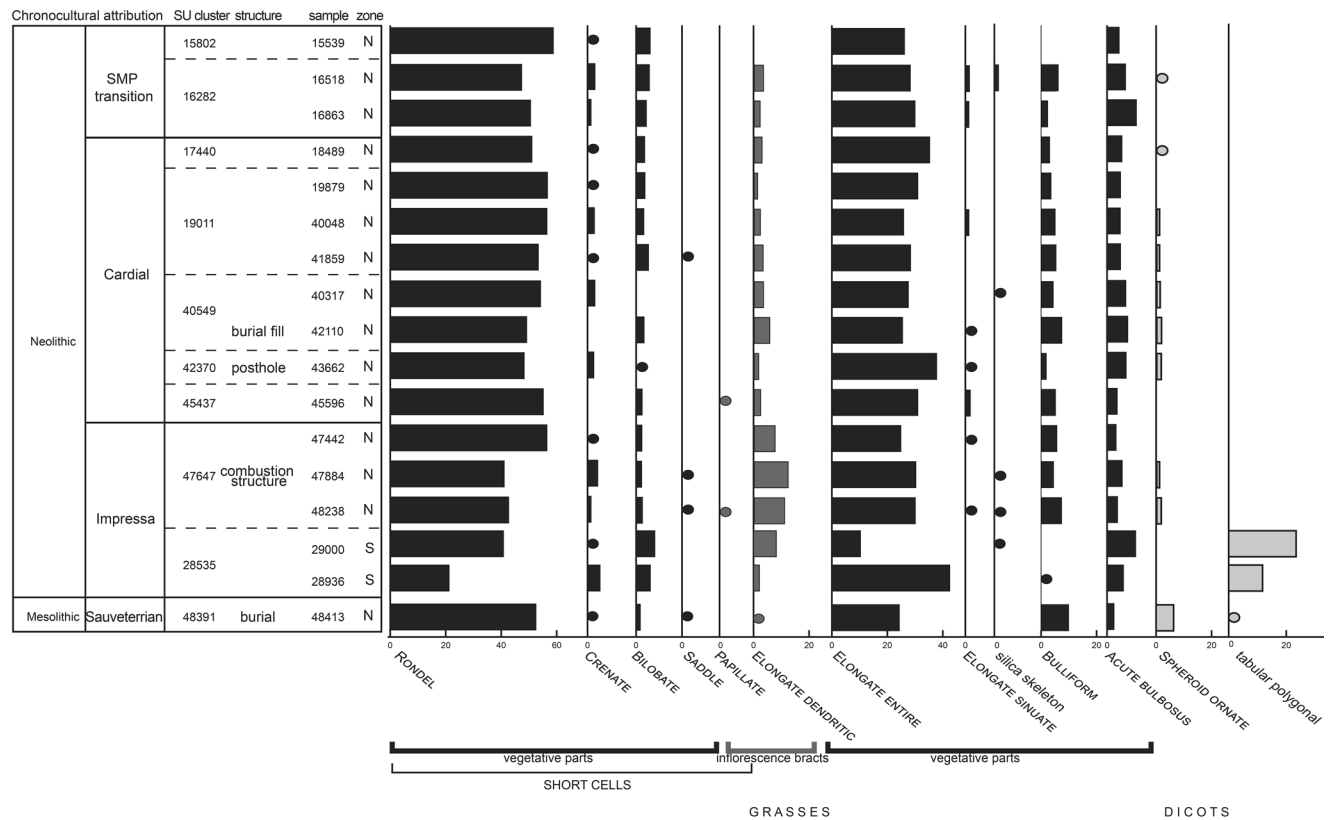


Fig. 3 Results of the phytolith analysis of the Mesolithic and Early Neolithic levels of the Pendimoun shelter

339 sediment mainly derives from dung, despite the fact that
 340 the abundance of grass multi-cell phytoliths remains low
 341 (from 0 to 6%, Delhon 2014). Taphonomical processes may
 342 enhance the breakage of these forms into single-cell partic-
 343 les. Moreover, depending on environmental factors and on
 344 the age of the vegetal tissues, multicelled phytoliths may
 345 not be present in the browsed grasses. Thus, the absence or
 346 scarcity of silica skeletons at Pendimoun is not sufficient to
 347 rule out the possibility that the phytolith assemblages derive
 348 from dung accumulation. Focusing on the northern zone, it
 349 thus seems that the livestock mainly fed on grasses, either
 350 brought into the shelter by the shepherds or grazed from the
 351 surrounding vegetation. Even though phytolith production is
 352 far more important in grass than in dicots (Delhon 2010), the
 353 presence of dicot phytoliths suggests that such plants were
 354 introduced into the shelter, albeit in smaller quantities com-
 355 pared to grasses. In dicots from temperate areas, phytolith
 356 production seems to be mainly concentrated in leaves (epi-
 357 dermal cells) and wood (globular morphotypes), although it
 358 remains very low in the latter (Scurfield et al. 1974; Kondo
 359 et al. 1994; Alexandre et al. 1997; Albert and Weiner 2001;
 360 Delhon 2010). Wood was used on the site, at least for fuel,
 361 as documented by the presence of scattered charcoal in all
 362 of the levels. Nevertheless, the scarcity of dicot phytoliths

indicates that branches and leaves were probably not used
 as bedding or for feeding animals.

These results are similar to those reported from two
 Ligurian sites (Italy). In the phytolith analysis of Riparo
 di Pian del Ciliegio shelter (transition to and early SMP:
 5000–4800 to 4600–4300 BCE), only grass morphotypes are
 reported (Arobba and Caramiello 2009), while at the Arene
 Candide Cave there is a “sharp prevalence” of grass origin
 (Nisbet 1997). In contrast, the use of tree branches bear-
 ing leaves and/or flowers has been demonstrated on various
 other Neolithic shelters in southern France (*grottes-berger-
 ies*) (Thiébaud 2005). At La Grande Rivoire (Isère, Vercors
 massif, Alps), the use of tree fodder is clearly indicated by
 very high proportions of dicot phytoliths (most of the time
 between 30 and 50%) throughout the Neolithic (Delhon et al.
 2008). At Pendimoun, it seems that the livestock mainly fed
 on grasses, either freely browsed or brought for this pur-
 pose into the shelter by the shepherds. This is consistent
 with the data from charcoal analysis, which failed to identify
 any evidence of leaf-fodder either in the taxonomic spectra
 (Battentier et al. 2015) or in the diameter of the branches
 (absence of charcoal fragments characteristic of twig mor-
 phology) (Battentier 2018). Perhaps a climatic gradient
 might explain the need to gather tree fodder only at certain

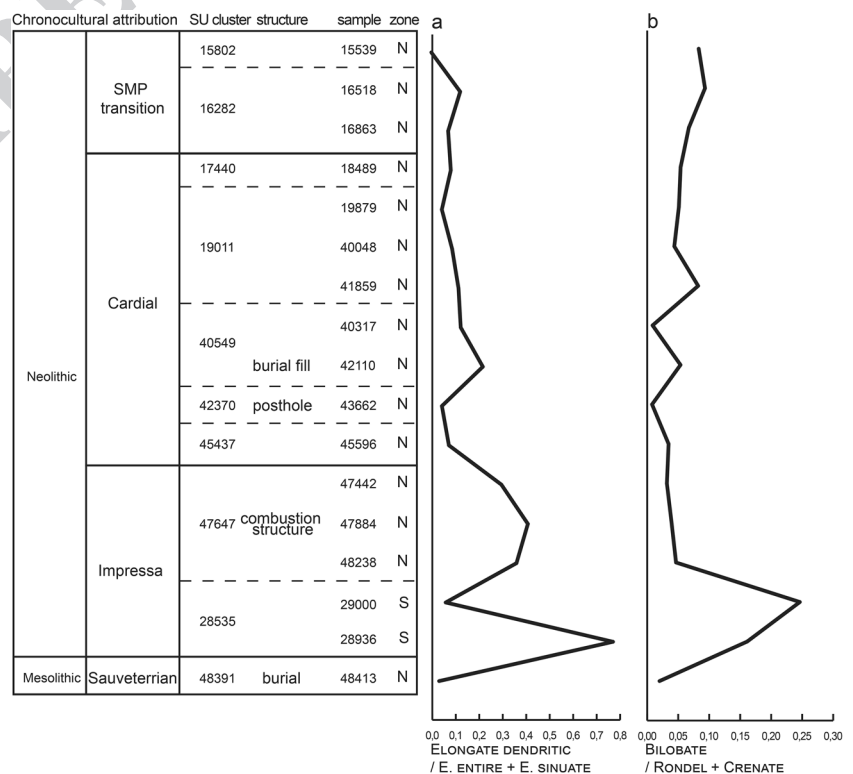
altitudes or latitudes (for example at La Grande Rivoire and not at Pendimoun) where it would have compensated for a lack of vegetation. However husbandry practices could also be involved, such as the duration of the period when the animals were stabled, the season during which the shelter was used as a sheepfold or the type of animals being kept (sheep and/or goats) and their proportions. Concerning the northern sector of Pendimoun, it is noteworthy that the only structure which is not linked with pastoral activity is also the one that provides the best evidence for the potential use of dicots: the phytolith spectra for the Sauveterrian (Mesolithic) burial contain 6.7% dicot phytoliths, including a fragment of silicified epidermis. Although we are dealing with a single sample, it is tempting to think that this result could be linked to Sauveterrian funerary practices.

402 Cereal processing on the site

Morphotypes from inflorescence bracts (ELONGATE DENDRITIC and PAPILLATE) are very rare among Pendimoun grass phytoliths (Fig. 4a), except in the Impressa levels where they reach 12% of the identified phytoliths. In the other levels, the only instance in which they attain frequencies higher than 3.3% is the sample from the Cardial burial (42,110), where they could originate from the Impressa levels. In fact, the funerary pit may have been filled using the surrounding sediment, including the layers deposited during the preceding Impressa period. In archaeological contexts, an

accumulation of inflorescence bract phytoliths is generally considered as a sign of an important contribution of cereals to the phytolith record. In cereals, fertile parts (ears) usually represent a greater part of the total biomass than is the case for most European wild grasses, and the increase of seed mass that characterizes domestic grasses could have led to an increase of glume silicification (Novello and Barboni 2015), both phenomena leading to higher amounts of inflorescence bract phytoliths than in wild species. Moreover, even when the archaeological record results from the accumulation of culm and leaves, cereals are most likely to have been harvested when ears were mature, which is not necessarily the case for wild grasses; this leads to the systematic occurrence of significant amounts of inflorescence bract phytoliths. The very Early Neolithic levels at Pendimoun also yielded preserved cereal grains (emmer wheat, einkorn and barley) and grindstones (Binder et al. 1993, in press). In the southern part of the site, one of the research team (P.V.) has identified two different types of ELONGATE DENDRITIC phytoliths (Fig. 5). Nevertheless, the range of intraspecific variation of ELONGATE DENDRITIC is considerable (Ball et al. 2017) and makes it hazardous to connect these forms to the cereal taxa identified through macro-remains analysis. Inflorescence bract phytoliths clearly do not occur in the same quantities as on later sites where cereal-related activities have been proved with certainty. For example, in the Bronze Age layers of El Mirador cave (Sierra de Atapuerca, Spain), inflorescence bract phytoliths reach 30% in an assemblage (*facies*

Fig. 4 Phytolith ratios. **a** Ratio of the proportions of ELONGATE DENDRITIC phytoliths (from inflorescence bracts) versus ELONGATE ENTIRE and E. SINUATE (from culms and leaves). **b** Ratio of BILOBATE short cells versus RONDEL and CRENATE short cells



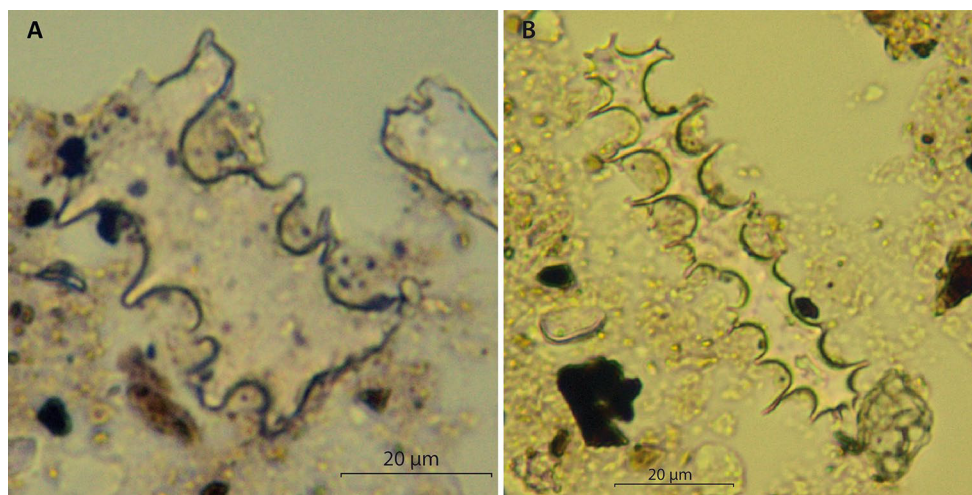


Fig. 5 Main types of ELONGATE DENDRITIC (a and b) distinguished by P.V. in Pendimoun phytolith assemblages

441 f) considered to be made up of crop-processing (threshing/
442 winnowing or milling/pounding) residues and also rich in
443 cereal pollen (Cabanès et al. 2009). Nevertheless, our opin-
444 ion is that the amount of inflorescence bract phytoliths found
445 in the Impressa levels, which is not only high per se but is
446 also significantly higher than what is observed in all of the
447 other levels of the sequence, is evidence of an input of grass
448 inflorescences in the shelter which could be linked to in situ
449 processing of cereals during the earliest Neolithic.

450 With the exception of the Impressa levels, the very low
451 presence of inflorescence bract phytoliths seems to indicate
452 that no crop processing occurred at the site in other periods
453 of occupation. Cereal macroremains were identified in the
454 Cardial levels and in very low quantities in the SMP transi-
455 tion levels (Binder et al. in press). These cereals, presum-
456 ably consumed by the shelter's inhabitants, seem to have
457 been introduced onto the site in a dehusked form. At Els
458 Trocs (Early and Middle Neolithic, Pyrenees, Spain, 1,564 m
459 a.s.l., end of the sixth/beginning of the third millennia: Rojo
460 Guerra et al. 2013), very low amounts of inflorescence bract
461 phytoliths have been interpreted not only as suggesting an
462 absence of cereal processing but also as a sign of a very low
463 input of grass inflorescences, either domesticated or wild,
464 at the site (Lancelotti et al. 2014). The authors suggest that
465 the site was occupied before the complete formation and
466 silicification of the inflorescence bracts, which is achieved
467 at the end of the summer at the altitude which the site is
468 located. Concerning the Cardial and SMP occupations of
469 Pendimoun, the low but variable amount of inflorescence
470 bract phytoliths could also be evidence for the grazing of
471 young grasses, before they bear mature inflorescences, i.e. at
472 an early stage of their life-cycle. Nevertheless, it is more dif-
473 ficult to connect it to a specific season of occupation because
474 of the location of the site at a lower altitude (ca. 700 m a.s.l.)

in a Mediterranean context in which the favourable season 475
for seed production may be longer. 476

Seasonality of pastoral activities as recorded by phytolith assemblages 477 478

479 Grass short cells are very abundant and mainly belong to
the RONDEL and CRENATE types, which is not surprising 480
given the importance of Pooideae in the area. Nevertheless, 481
BILOBATE is regularly encountered and in certain instances 482
is quite abundant (around 5% of the total) (Fig. 4b). As a 483
comparison, the forms mainly attributed to Panicoideae are 484
not reported at Pian del Ciliegio (Arobba and Caramiello 485
2009), are nearly absent at La Grande Rivoire (Delhon et al. 486
2008) and seem to show very variable amounts at Arene 487
Candide (Nisbet 1997). In the area of Pendimoun, during the 488
Neolithic, only three different grasses may have contributed 489
to the production of BILOBATE: *Setaria* sp. (mainly *Setaria* 490
viridis), *Digitaria sanguinalis* and *Echinochloa crus-galli*. 491
Such plants were thus present near the shelter and/or used 492
by the dwellers during the Neolithic. All of these grasses 493
exhibit a C₄-metabolism and display a ruderal behaviour. 494
Echinochloa seems to be the least likely of the three as it 495

	J	F	M	A	M	J	J	A	S	O	N	D
<i>Setaria</i> sp.												
<i>Digitaria sanguinalis</i>												
<i>Echinochloa crus-galli</i>												

Fig. 6 Life calendar (dark grey) of the panicoid grasses which could have grown near Pendimoun shelter during the Neolithic, from sprouting (light grey) to seed maturity (black) (data from Institut Technique de l'Agriculture Biologique 2012)

needs humid contexts, but its presence cannot be excluded. All of these plants are annual, with short so-called “summer” lifecycles (for example no more than 8 weeks for *S. viridis*) (Fig. 6). According to modern data for weeds from organic crops (Institut Technique de l’Agriculture Biologique 2012), germination occurs from the end of spring to the middle of autumn (June/September for *S. viridis*, May/October for *E. crus-galli*, June/October for *D. sanguinalis*) and seed maturity, followed by plant decay, is reached at the end of summer or during autumn (August/October for *S. viridis* and *E. crus-galli*, September/October for *D. sanguinalis*). Because they contain significant amount of BILOBATE short cells, most of the studied levels should therefore record plant collection or grazing during summer (broadly speaking: from the end of spring to the beginning of autumn). Combining this evidence with the absence or scarcity of inflorescence bracts phytolith (in most of the SMP and Cardial levels) allow us to narrow down the season of pastoral use of the shelter to the end of spring and early summer, before the complete silicification of inflorescence bracts cells. The levels where BILOBATE are lacking (43662, 40317) might record winter/early spring frequentation of the site, unless a heterogeneous use of plants through time and space led to their absence in the posthole (43,662) and when the site was used for burial (40,317). Nevertheless, a survey of the actual life-cycles of these plants in the area around the Pendimoun shelter would clarify the picture of suggested seasonality of the Neolithic frequentation of the shelter for pastoral purposes. Indeed, we cannot exclude the possibility that these short-lived grasses may be able to take advantage of temporarily favourable climatic conditions so as to colonize limited areas outside of their “normal” growing season.

528 Conclusions

529 The phytolith spectra from the Pendimoun shelter indicate
530 an important use of grasses, mainly wild Poaceae. Because
531 mineralized dung is a major component of the sediment,
532 we assume that these plants microremains mainly originate
533 from digested animal food. However, the phytolith spectra
534 also partly originate from a mixture of plant used for vari-
535 ous purposes. It can be easily argued that cereals, which
536 were probably processed inside the shelter during the earli-
537 est Neolithic, were intended to feed the human inhabitants
538 rather than their flocks.

539 In the most probable case, i.e. that phytoliths mainly
540 result from the plant parts eaten by the animals, the low
541 level of morphotypes attributed to dicots indicates that live-
542 stock management during the Early/Middle Neolithic did not
543 require any additional food supply in the form of leaf fod-
544 der. Thus, the available vegetation in the pasturelands was
545 probably sufficient to address the needs of the farmers. The

546 reasons why livestock fodder was supplemented with leafy
547 or flowering branches in some pastoral Neolithic sites (for
548 instance at La Grande Rivoire) and not in others (for instance
549 at Pendimoun) requires further investigation. The recourse to
550 additional food supply may have been necessary in certain
551 areas due to the duration of the bad season, or because of
552 pastoral practices resulting in the presence of livestock in
553 some areas (mountains) before or after the period when pas-
554 turelands were accessible or productive (before the melt-
555 ing of snow or the greening of the vegetation, after the first
556 snowfalls or the senescence of grasses, in cases of severe
557 drought...); the species of animal being raised (goat, sheep,
558 cow...) may also have an influence. Woody leafy branches
559 are easy to dry and stock over few months, and are thus con-
560 venient for filling a seasonal shortage of fresh vegetation.
561 Tree fodder may also have been used simply to facilitate the
562 housing of flocks (Battentier et al. 2016) and would have
563 allowed the spacing of the browsing periods. It is broadly
564 acknowledged that mobility was a component of the Neo-
565 lithic farming systems in the south of France, as shown by
566 the existence of various types of sites, some of them exhib-
567 iting an organization typical of long-term settlements asso-
568 ciated with crop production, others being more occupied
569 for shorter periods of time and dedicated to hunting activi-
570 ties, and others, like Pendimoun, which provide evidence
571 for probable seasonal pastoral occupation. These different
572 patterns illustrate the increasing complexity of the territory
573 exploitation system, in the form of a network of more or
574 less specialized sites used during certain periods of the year
575 and by different elements of the social groups (Binder 1991;
576 Rowley-Conwy 1991; Beeching et al. 2000; Bréhard et al.
577 2010; Martin 2014). Nevertheless, the season(s) when the
578 pastoral shelters (*grottes-bergeries*) were occupied, the dura-
579 tion of the occupation and its frequency (once a year, several
580 times a year, repeatedly in a given period of the year) are
581 difficult to specify, and could differ from one site to another.

582 In the area concerned, where the winters are mild, the
583 observation that leaf fodder was not used gives no informa-
584 tion on the season, but the data from Pendimoun offer other
585 clues concerning that issue: the grasses were consumed
586 before the development of the inflorescences, which seems
587 to exclude a period from mid-summer to the beginning of
588 autumn, and the presence of panicoid grasses restricts the
589 window to a period focused on summer (broadly speaking).
590 Finally, phytolith data make it probable that pastoral activi-
591 ties in Pendimoun during the Early/Middle Neolithic prin-
592 cipally took place from the end of spring to the beginning
593 of the summer.

594 Of course, this initial hypothesis concerning seasonality
595 now has to be verified by means of other kinds of data. Other
596 phenomena could explain part of the observed spectra, for
597 example the use of grass fodder (harvested during spring
598 and stocked to be used later), which is still not evidenced
599

599 for the Early Neolithic period, or intense browsing which
600 would prevent the plants from flowering. Moreover, it must
601 be kept in mind that, thanks to their very short lifecycle, the
602 panicoids may have been able to sprout and grow locally
603 outside of the usual season, thanks to temporarily favour-
604 able climatic conditions. Besides, the seasonality of pastoral
605 activities may have changed over time. During the Impresa
606 period, pastoralism is combined with agriculture and the
607 shelter seems to be almost continuously occupied, while dur-
608 ing the Cardial/SMP periods shepherds may have used the
609 shelter at certain period of the year only, in a system where
610 pastoralism alternated with other activities.

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