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1 **Fossil mega- and micro-flora from Bernasso (early Pleistocene, southern France): a**  
2 **multimethod comparative approach for palaeoclimatic reconstruction**

3

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19 **Abstract**

20 Bernasso is an early Pleistocene locality that has a well-dated floral fossil content including both  
21 pollen grains and megaremaines. Pollen record shows vegetation changes corresponding to two  
22 glacial and one interglacial periods. The megafloral fossil assemblage was interpreted as an  
23 association of present-day Mediterranean and Caucasian taxa that developed during a late  
24 interglacial stage of the beginning of the Pleistocene. In the present study, climatic reconstruction  
25 using the Climate Leaf Analysis Multivariate Program (CLAMP) and the Leaf Margin Analysis  
26 (LMA) methods based on the megaflora on one hand and using the Climatic Amplitude Method  
27 (CAM) based on the pollen flora on the other hand have been used to check the qualitative climatic  
28 estimates based on the comparison between palaeovegetation data and similar modern ecosystems.  
29 CLAMP and LMA analyses show that the Bernasso climate was colder than the present-day climate  
30 of Southern France and of the Hyrcanian and Euxinian regions. On contrary, CAM shows mean  
31 annual temperatures higher than the modern Bernasso temperature and equivalent to the  
32 temperature of the Hyrcanian and Euxinian regions. Mean annual precipitation and relative  
33 humidity reconstructed by CLAMP and CAM are in agreement and indicate that the climate was  
34 wetter than today at Bernasso. The differences between the three methods highlight important  
35 methodological biases that could be solved by including additional calibration sites in Europe and in  
36 the Mediterranean region.

37

38 **Key-words:** CLAMP analyses; Leaf Margin Analysis; Climatic Amplitude Method

## 39 **1. Introduction**

40 Many methods for palaeoclimatic reconstruction exist such as Climate Leaf Analysis  
41 Multivariate Program (CLAMP; Wolfe, 1993), Leaf Margin Analysis (LMA; Wilf, 1997),  
42 Coexistence Approach (Mosbrugger and Utescher, 1997) that are generally applied on leaves  
43 assemblages, the Modern Analog Technique (MAT; Guiot, 1990) used on the recent Quaternary  
44 period for which modern analogues of pollen data may be found, isotopic analysis (Covey and  
45 Haagenson, 1984), Climatic Amplitude Method (CAM; Fauquette et al., 1998a and b) especially  
46 developed for periods without modern pollen assemblages analogues, “Climate Reconstruction  
47 Analysis using Coexistence Likelihood Estimation” (CRACLE; Harbert and Nixon, 2015). Despite  
48 this plethora, it appears that they cannot be used in all cases and they all present different biases that  
49 affect the reliability of climatic reconstruction (*e.g.* Uhl et al., 2007a; Blonder et al., 2012; St.  
50 Jacques et al., 2015). Climate reconstruction techniques based on leaf physiognomy (such as  
51 CLAMP and LMA) tend to underestimate palaeotemperature (Kowalski and Dilcher 2003). Such  
52 differences have been interpreted as a consequence of the fact that fossil floras are mostly  
53 composed by species from wet environments (Kowalski and Dilcher 2003). Uhl et al. (2007a)  
54 compared the results given by different leaf physiognomic techniques (CLAMP, LMA, CA and  
55 ELPA - European Leaf Physiognomic Approach) applied on diverse Cenozoic palaeofloras. Uhl et  
56 al. (2007a) highlighted that the differences between the different methods mostly depend on the age  
57 of the fossil localities: differences are more marked for Neogene floras than for Palaeogene ones.  
58 The same authors also showed that, in general for the Neogene, CLAMP provides lower estimation  
59 of temperature than CA and ELPA. Blonder et al. (2005) also highlighted a possible bias for leaf  
60 physiognomy methods. Before fossilisation, leaves fall on the grounds where death processes  
61 happen. In particular, Blonder et al. (2005) studied shrinkage and showed that it can strongly affect  
62 leaf area (reduction of 22% of the leaf area in average on the 3401 studied leaves, with a maximum  
63 of 82% of shrinkage). Such variation can deeply affect palaeoclimatic reconstructions based on leaf  
64 physiognomy only. Concerning pollen-based climate reconstruction, St. Jacques et al. (2015)  
65 showed that human activities have more or less altered the modern vegetation and hence the pollen  
66 rain at least since the mid-19th century. Calibrations for palaeoclimate reconstructions based on

67 modern pollen assemblages or pollen distribution are thus somehow biased.

68 Bernasso (southern France) is a fossil locality of the Early Pleistocene (Ildefonse et al.,  
69 1972; Ambert et al., 1990) that yielded well-documented micro- and megafloora (Suc, 1978; Leroy  
70 and Roiron, 1996). Bernasso palaeoflora was a unique plant assemblage, mixing both  
71 Mediterranean and Caucasian taxa (Suc, 1978; Vernet, 1981; Leroy and Roiron, 1996). Whereas the  
72 Bernasso palaeoflora is well-known, its climatic significance can be improved. In particular, we do  
73 not know why a mixed vegetation developed at Bernasso at the beginning of the Pleistocene. The  
74 coexistence of Caucasian and Mediterranean taxa needs specific climatic conditions: combination  
75 of Caucasian climatic conditions and Western Mediterranean climatic conditions. So, in order to  
76 understand the development of the atypical palaeoflora of Bernasso, Leaf Margin Analysis (LMA;  
77 Wilf, 1997), Climate Leaf Analysis Multivariate Program (CLAMP; Wolfe, 1993, 1995) analysis  
78 based on the megafloora and Climatic Amplitude Method (CAM; Fauquette et al., 1998a and b)  
79 based on pollen data were applied to mega- and micro-fossil assemblages to better characterise the  
80 climatic conditions that controlled the vegetation development in the Bernasso area at the beginning  
81 of the Pleistocene. This study has provided an opportunity to compare climatic estimates obtained  
82 through three methods based on leaf material and pollen data and to make quantitative instead of  
83 qualitative reconstructions.

84

## 85 **2. Material and methods**

### 86 *2.1. Site of Bernasso*

87 The fossil locality of Bernasso (43°43'34"N, 3°15'25"E) is located in the northwestern part  
88 of the Hérault Department (southern France), at an altitude of 512 m asl (Fig. 1). Today, at Lunas  
89 (altitude of 371 m asl), the nearest small town at ~5 km from Bernasso (Fig. 1), the climatic  
90 parameters are the following: a mean annual temperature of 12.8°C, a mean temperature of the  
91 coldest month of 4.8°C, a mean temperature of the warmest month of 21.3°C, a mean annual  
92 precipitation around 720 mm (source: <https://fr.climate-data.org>).

93 The site of Bernasso represents lacustrine deposits (diatomites and clays) that formed in the  
94 volcanic context of the Escandorgue Massif that was active at the end of the Pliocene and beginning

95 of the Pleistocene. As a consequence of this volcanic activity, a basalt flow completely blocked a  
96 palaeovalley, which resulted in the formation of the lake of Bernasso in which pollen grains and  
97 fossil leaves were preserved. For more details about the geological and sedimentological contexts,  
98 see following references: Ildefonse, 1970; Ildefonse et al., 1972, 1976; Suc, 1978; Ambert et al.,  
99 1990; Leroy, 1990; Leroy and Seret, 1992; Roiron, 1992; Leroy and Roiron, 1996.

100

101 Ambert et al. (1990) and Løvlie et al. (1992) showed that the entire succession belongs to a reverse  
102 palaeomagnetic time-interval between the end of the Matuyama period (top of normal Chron  
103 C2an.1n at 2.581 Ma; Hilgen et al., 2012) and beginning of the normal Olduvai episode (base at  
104 1.945 Ma; Hilgen et al., 2012), dates confirmed by K-Ar dating. Considering this chronological  
105 frame, Leroy and Roiron (1996) placed the Bernasso floral succession within the oxygen isotope  
106 stratigraphic interval MIS 81 to 73. Suc and Popescu (2005) refined the correlation with the oxygen  
107 isotope stratigraphy with respect to the feature and amplitude of climatic changes suggested by the  
108 pollen record: the Bernasso floral succession spanned MIS 82 to MIS 78, i.e. from about 2.2 to 2.1  
109 Ma. On the basis of pollen record (Suc, 1978), three successive pollen zones have been defined  
110 illustrating different vegetation types: the oldest (pollen zone I) and the youngest (pollen zone III)  
111 are dominated by a steppe assemblage and correspond to dry and/or cold periods, the intermediate  
112 zone (pollen zone II) indicates a vegetation that developed under a wetter and warmer climate (Fig.  
113 2). By comparison to regional pollen diagrams and to other glacial-interglacial cycles, pollen zone  
114 II has been attributed to the last part of an interglacial when the climate was already cooling down,  
115 but with still relatively high precipitation (Leroy, 1990, 2007). Outcrop collapse did not allow  
116 sampling the transition from pollen zone I to pollen zone II; hence a hiatus is recognised despite the  
117 attempt to fill it in by making a borehole (core BNI). Pollen zones I and III provided only pollen,  
118 while in one horizon of pollen zone II an abundant megafloreal assemblage including leaves and  
119 fruits has been found (Ildefonse et al., 1976) (Fig. 2).

120

## 121 2.2. *The fossil megaflorea*

122 More than 800 fossil leaves, attributed to 23 different taxa (for details, see Leroy and

123 Roiron, 1996), were collected at Bernasso. These leaves are now preserved in the Collection of the  
124 Institut des Sciences de l'Evolution of Montpellier (ISEM) (contact:  
125 vincent.girard@umontpellier.fr) and form part of the palaeontological Collection of the University  
126 of Montpellier (<https://collections.umontpellier.fr/>; contact: suzanne.jiquel@umontpellier.fr). When  
127 the present study was conducted, the collection was split into two sub-collections, one housed in the  
128 ISEM, one housed in the former Centre de Bioarchéologie et d'Ecologie of Montpellier. The  
129 present study was conducted on this second sub-collection that represents only 590 leaves. No  
130 particular selection was done to partition the collection and the subset used in this study contains all  
131 the species and morphological variants found at Bernasso.

132 The most abundant megaremaines correspond to the species *Carpinus orientalis* Mill.,  
133 *Parrotia persica* (DC) C.A. Mey., and the genera *Acer* L. and *Carya* Nutt. The other leaves are  
134 mostly angiosperms (15 taxa) and only few correspond to ferns (1 taxa) and gymnosperms (only 2  
135 needles). For more details about this fossil assemblage, see Leroy and Roiron (1996) and the  
136 Appendix.

137

### 138 2.3. *The fossil microflora*

139 On the basis of pollen record (Suc, 1978), three successive pollen zones have been defined  
140 illustrating different vegetation types: the oldest (pollen zone I) and the youngest (pollen zone III)  
141 are dominated by a steppe assemblage and correspond to dry and/or cold periods, the intermediate  
142 zone (pollen zone II) indicates a vegetation that developed under a wetter and warmer climate (Fig.  
143 2). Unfortunately, a hiatus has been identified between pollen zones I and II. By comparison to  
144 regional pollen diagrams and to other glacial-interglacial cycles, pollen zone II has been attributed  
145 to the last part of an interglacial when the climate was already cooling down, but with still relatively  
146 high precipitation (Leroy, 1990, 2007). Pollen zones I and III provided only pollen, while the  
147 abundant megafloral assemblage including leaves and fruits has been found in pollen zone II  
148 (Ildefonse et al., 1976) (Fig. 2).

149 In the present study, we focus on the three pollen records covering pollen zone II: 1) the  
150 megaflora layer itself (Leroy and Roiron, 1996), 2) the outcrop studied by Suc (1978) and 3) the

151 borehole BN I (Leroy and Roiron, 1996) (Fig. 2). The taxa recorded are given Table S2. In pollen  
152 zone II, pollen data point to an environment dominated by a vegetation rich in arboreal taxa such as  
153 *Carya*, *Pterocarya*, *Celtis*, *Ulmus-Zelkova*, *Carpinus orientalis*, *Acer*, *Parrotia persica*, *Alnus*, etc.  
154 Gymnosperms like *Tsuga*, *Abies*, *Picea* are also present in the pollen data (Suc, 1978). Pollen zone  
155 II has been related to a warm and wet climatic phase, but already belonging to the end of an  
156 interglacial (Suc, 1978; Leroy, 1990; Leroy and Roiron, 1996; Leroy, 2007).

157         Based on these pollen data, palaeoclimate has been reconstructed using the Climatic  
158 Amplitude Method (CAM) in which the climatic requirements of modern taxa are transposed to  
159 fossil data (Fauquette et al., 1998a, b). This approach relies on the relationship between the relative  
160 pollen abundance of each individual taxon and climate. It takes into account not only  
161 presence/absence criterion as in the Coexistence Approach (Utescher and Mosbrugger, 1997) but  
162 also pollen percentages to provide more reliable reconstructions.

163         The most probable climate for a fossil pollen assemblage is estimated as the climatic interval  
164 in which the highest number of taxa can exist and a “Most Likely Value” (MLV) corresponding to a  
165 weighted mean according to the size of the climatic intervals of all taxa. As the precision of the  
166 information obtained from a taxon’s climatic interval is inversely related to the width of this  
167 interval, the weights are greater for taxa with smaller intervals (for more details, see Fauquette et  
168 al., 1998a).

169         *Pinus* pollen grains are excluded from the pollen sum as they are generally over-represented  
170 due to a prolific production and over-abundance due to long-distance transport. Moreover, at the  
171 genus taxonomic level, the various species of *Pinus* develop under a large variety of climates and  
172 *Pinus* is thus not really informative. High latitude/altitude taxa are also excluded from the  
173 reconstruction process to avoid a cold bias linked to pollen transport from higher elevations  
174 (Fauquette et al., 1998a). The excluded taxa are defined on the basis of their occurrence in modern  
175 vegetation zones (Fauquette et al., 2018): vegetation types described for the Neogene and lower  
176 Pleistocene are found today in the Southeastern China (Wang, 1961; Hou, 1983). There, the vertical  
177 distribution of vegetation is characterized from the base to the top of the mountains by evergreen  
178 broad-leaved forest, mixed evergreen and deciduous broad-leaved forest, *Picea/Tsuga* forest, *Abies*



179 forest and high mountain meadows (Wang, 1961; Hou, 1983). In our study, this altitudinal  
180 stratification and the absence of high altitude taxa in the megaflores are the base for excluding the  
181 modern high altitude taxa from the climatic reconstruction in order to infer the low to middle-low  
182 altitude climate (Fauquette et al., 1998a). Comparison with other diatomite palaeofloras justifies  
183 also this choice. Indeed at Murat (Roiron, 1991), the high percentages of *Abies* pollen grains in the  
184 diatomites are associated with *Abies* megafossils (leaves and reproductive structures), which is not  
185 the case at Bernasso.

186

#### 187 *2.4. Methods used for palaeoclimatic quantification*

188 The Leaf Margin Analysis (LMA) is used to provide mean annual temperature estimates. It  
189 was applied on the leaves of Bernasso with the different equations derived by Wolfe (1979), Wilf  
190 (1997), Gregory-Wodzicki (2000), Greenwood et al. (2004), Traiser et al. (2005) and Miller et al.  
191 (2006) for the different regions of the globe. The only one available for Europe (Traiser et al., 2005)  
192 is compared to other equations of the Northern Hemisphere, as it is the equation with the weakest  
193 correlation between the mean annual temperature and proportion of entire margined leaves (Traiser  
194 et al., 2005).

195 The Climate Leaf Analysis Multivariate Program (CLAMP) was also applied to the fossil  
196 leaves of Bernasso. The online CLAMP application was used for this purpose (Wolfe, 1993, 1995;  
197 <http://clamp.ibcas.ac.cn/>). Since its initial introduction, CLAMP has undergone continuing  
198 development (Kovach and Spicer, 1995; Wolfe and Spicer, 1999; Spicer, 2007, 2008; Spicer et al.,  
199 2004, 2009) including an online version (Yang et al., 2015) and now encompasses 32  
200 morphological characters of leaves concerning the shape and size of the leaf, its margin (presence or  
201 absence of teeth), the shape of the leaf apex, base and surface. For each morphological character, a  
202 value between 0 and 1 was attributed according to standard CLAMP protocols. All the data were  
203 summarized in a matrix (Table S1). This was then analysed with the CLAMP online canonical  
204 correspondence analysis (CCA). We tested the different CLAMP calibrations that concern the  
205 Northern and Southern hemispheres to provide ranges of values for different environmental  
206 parameters from Bernasso. Two plant species from Bernasso were not taken into account (*Aspidium*

207 *meyeri*, Filicophyta and *Ceratophyllum demersum*, Ceratophyllaceae, aquatic angiosperm) because  
208 they do not correspond to woody dicotyledon angiosperms. CLAMP does not provide directly mean  
209 annual precipitation data but precipitation during the three wettest and driest months, which allow  
210 estimating the mean annual precipitation. It can be estimated as an interval comprised between a  
211 low value of precipitation (LMP) and a high value (HMP). The low value can be calculated as  
212 follows:

$$213 \text{ LMP} = 3 \times 3\text{DRY} + 3\text{WET} \quad (1)$$

214 where 3DRY corresponds to the precipitation during the three driest months and 3WET to the  
215 precipitation during the three wettest months. The high value can be calculated as follows:

$$216 \text{ HMP} = 3\text{DRY} + 3 \times 3\text{WET} \quad (2).$$

217 LMP and HMP provide an interval of precipitation between a very low value (nine “dry” months  
218 and three “wet” months) and a very high value of precipitation (three “dry” months and nine “wet”  
219 months), the real mean annual precipitation being between these two extreme values.

220 Using pollen data, palaeoclimate is reconstructed with the Climatic Amplitude Method  
221 (CAM) in which the climatic requirements of modern taxa are transposed to fossil data (Fauquette  
222 et al., 1998a, b). This approach relies on the relationship between the relative pollen abundance of  
223 each individual taxon and climate. It takes into account not only presence/absence criterion as in the  
224 Coexistence Approach (Mosbrugger and Utescher, 1997) but also pollen percentages to provide  
225 more reliable reconstructions.

226 The most probable climate for a fossil pollen assemblage is estimated as the climatic interval  
227 in which the highest number of taxa can exist and a “Most Likely Value” (MLV) corresponding to a  
228 weighted mean according to the size of the climatic intervals of all taxa. As the precision of the  
229 information obtained from a taxon’s climatic interval is inversely related to the width of this  
230 interval, the weights are greater for taxa with smaller intervals (for more details, see Fauquette et  
231 al., 1998a).

232 *Pinus* pollen grains are excluded from the pollen sum as they are generally over-represented  
233 due to a prolific production and over-abundance due to long-distance transport. Moreover, at the  
234 genus taxonomic level, the various species of *Pinus* develop under a large variety of climates and

235 *Pinus* is thus not really informative. High latitude/altitude taxa are also excluded from the  
236 reconstruction process to avoid a cold bias linked to pollen transport from higher elevations  
237 (Fauquette et al., 1998a). The excluded taxa are defined on the basis of their occurrence in modern  
238 vegetation zones (Fauquette et al., 2018): vegetation types described for the Neogene and Early  
239 Pleistocene are found today in the Southeastern China (Wang, 1961; Hou, 1983). There, the vertical  
240 distribution of vegetation is characterized from the base to the top of the mountains by evergreen  
241 broad-leaved forest, mixed evergreen and deciduous broad-leaved forest, *Picea/Tsuga* forest, *Abies*  
242 forest and high mountain meadows (Wang, 1961; Hou, 1983). In our study, this altitudinal  
243 stratification and the absence of high altitude taxa in the megaflores are the base for excluding the  
244 modern high altitude taxa from the climatic reconstruction in order to infer the low to middle-low  
245 altitude climate (Fauquette et al., 1998a). Comparison with other diatomite palaeofloras justifies  
246 also this choice. Indeed at Murat (Roiron, 1991), the high percentages of *Abies* pollen grains in the  
247 diatomites are associated with *Abies* megafossils (leaves and reproductive structures), which is not  
248 the case at Bernasso.

249

### 250 **3. Results**

251 The results obtained with the three methods (LMA, CLAMP, CAM) are summarized in  
252 Figures 3 (temperatures) and 4 (precipitation) and are detailed in Tables S3 (LMA results), S4  
253 (CLAMP results) and S5 (CAM results) of the Supplementary material. Figure S1 shows CLAMP  
254 CCA plots of physiognomic space obtained with the global CLAMP calibration.

255

256 In what concerns CLAMP, we only retain in the discussion the results obtained with the  
257 calibrations from the Northern Hemisphere. Indeed, Calib 5 to Calib 7 correspond to calibrations for  
258 Asian vegetation that suffer strong monsoonal climate (Calib5 and Calib6) and for 378 sites from  
259 all continents (Calib7). Due to their specificity, these last three calibrations were not analyzed in our  
260 study, but the complete CLAMP calibrations are however given Supplementary Table S4.

261 Regarding CAM, the climatic conditions reconstructed from pollen data of the leaf level and  
262 of pollen zone II data (borehole BN I and outcrop) are summarized in the Supplementary Table S5.

263 Concerning Bernasso mean annual temperatures, CLAMP and LMA show similar ranges  
264 but are lower than that reconstructed by CAM. In the same way, CLAMP indicates once again  
265 largely lower values for mean temperature of the coldest and warmest months than CAM (Fig. 3).  
266 However, mean annual precipitation and relative humidity are in agreement between both methods  
267 (Fig. 4 and Supplementary Table S4 and S5), even if precipitation is slightly higher with CLAMP  
268 than with CAM.

269

#### 270 4. Discussion

271 Comparison to modern floras highlighted similarities between the Bernasso palaeoflora and  
272 the modern flora of the Hyrcanian (South of the Caspian Sea) and the Euxinian (East of the Black  
273 Sea) regions (Ambert et al., 1995; Leroy and Roiron, 1996). The climate under which Bernasso  
274 palaeovegetation grew was thus interpreted by these authors, by comparison with modern climatic  
275 data from diverse stations of the Caucasian region (Table S6; see also Table 4 in Leroy and Roiron,  
276 1996 ), as similar to that of both regions, i.e. characterised by a mean annual temperature of 14-  
277 17°C, temperature of the coldest month of 5-6.5°C and of the warmest month of 24-26.5°C and  
278 high precipitation (more than 800 mm per year). The Bernasso palaeoflora was estimated to have  
279 thus developed under a warmer (+ 2 to 5°C) and wetter (at least + 300 to 500 mm per year) climate  
280 than today. However, the presence of taxa such as *Carpinus orientalis*, *Acer monspessulanum* L.,  
281 *Celtis australis* L., *Fraxinus ornus* L. in the megafloa (Leroy and Roiron, 1996) and *Olea*,  
282 *Phillyrea*, *Phlomis* cf. *fruticosa* and *Quercus ilex*-type in the pollen flora (Suc, 1978), suggests that  
283 the Bernasso palaeoflora was exposed to climatic conditions that made the occurrence of typical  
284 Mediterranean sclerophyllous elements possible in the underneath vegetation belt (Suc, 1978).

285 Leroy and Roiron (1996) could have thus misjudged the Bernasso palaeoclimate.

286

##### 287 4.1. Comparison of the results obtained with the three methods

288 CLAMP and LMA indicate mean annual temperatures largely lower than the modern  
289 temperatures observed in the Caucasian region and Lunas near Bernasso (Fig. 3). The CAM values  
290 are furthermore in agreement with the temperatures deduced by Leroy and Roiron (1996) and are

291 close to the modern Hyrcanian values. Compared to the Hyrcanian region (that Leroy and Roiron  
292 (1996) supposed to be a modern analogue to the fossil flora of Bernasso), all the methods provide  
293 very low temperature values of the coldest month (Fig. 3 and Table S6). Concerning this parameter,  
294 the very low temperature values with CLAMP (-3.79 to -6.33° C) seem to be incompatible with the  
295 presence of mesothermic Mediterranean sclerophyllous taxa (Leroy and Roiron, 1996) that do not  
296 support such negative temperatures (Quézel and Médail, 2003) (Fig. 3 and Table S6). Concerning  
297 the temperature of the warmest month, CLAMP values (17.18 to 19.19°C) are also very low  
298 compared to those of the supposed analogue of the Hyrcanian region. On the contrary, CAM values  
299 for this parameter of more coherent with those of the supposed analogue of the Hyrcanian region  
300 (Fig. 3 and Table S6).

301         Precipitation results are included in the precipitation range of the Hyrcanian region that has  
302 precipitation varying at low altitude from 500-600 mm to the East to 2000-2200 mm to the West  
303 (Fig. 4 and Table S6; Molavi-Arabshahi et al., 2016; Iran Meteorological Organization (IRIMO),  
304 <http://www.irimo.ir/eng/>). Leroy and Roiron (1996) suggested that the Bernasso palaeoflora grew  
305 under a humid (perhaps very humid) climate and our results tend to support their hypothesis.  
306 However, Suc (1978) and Leroy and Roiron (1996), on the basis of pollen data, interpreted the  
307 climate of the pollen phase II (during which megaremaines were deposited) as warm and wet with  
308 only a weak hydric seasonality (weak decrease in summer precipitation). CLAMP results do not  
309 completely confirm this last conclusion and show that the hydric seasonality could have been well-  
310 marked, with a ratio between wettest and driest months according to some CLAMP calibrations  
311 varying from ca. 1.4:1 to 5.7:1. The question of a possible seasonal drought is still unsolved,  
312 especially as the CLAMP global calibration places Bernasso between East Asian (excluding  
313 Southeastern), North American and Russian localities (Supplementary Figure S1). It could have  
314 been the case as it is today in the Mediterranean region, but no reconstruction, whatever the method  
315 used, allows to confirm it and no leaf specimen from Bernasso displays obvious functional  
316 adaptation to drought.

317

318         In the CAM, high latitude-altitude taxa are excluded from the reconstruction process to

319 avoid a cold bias linked to pollen transport from higher vegetation belts. The Bernasso valley was a  
320 long, narrow and steep-sided valley (Ildefonse et al., 1972), as today, and the palaeoforest was  
321 growing from the lake level to the plateau at the top of the canyon. Suc (1978) and Leroy and  
322 Roiron (1996) suggested that an altitudinal zonation of the palaeoflora existed. They advocated that  
323 the mid-altitudinal mixed forest on the slopes of the Bernasso palaeocanyon was composed of  
324 *Carpinus orientalis*, *Parrotia persica* and several species of *Acer*. *Carya* and *Zelkova* should have  
325 grown only in sheltered areas of the palaeocanyon. Gymnosperms like *Tsuga*, *Abies*, *Picea* are  
326 present in the pollen flora (Suc, 1978), but they were certainly not growing close to the lake  
327 shoreline as no leaf or cone specimens have been found in the megaf flora (Leroy and Roiron, 1996).  
328 These pollen grains certainly came from a conifer forest growing at higher altitude. Such an  
329 altitudinal zonation may be found today in the Southern Caspian Sea region (Rmezani et al., 2013)  
330 even if it is incomplete as *Abies*, *Picea* and *Tsuga* are absent there. It may be also found in China, in  
331 the subtropical evergreen broad-leaved forest region (Hou, 1983).

332 However, taking into account the high percentages of *Tsuga* in the pollen data (Suc, 1978;  
333 Leroy and Roiron, 1996), although this taxon is considered as a middle to high altitude-latitude  
334 taxon and is not present in the megaf flora (Leroy and Roiron, 1996), we could hypothesize that  
335 *Tsuga* was developing relatively close to the lake, as it was in the case of a nearby maar lake in  
336 Nogaret (1.9 Ma; Brugal et al., 1990; Leroy and Seret, 1992). We thus made a climate  
337 reconstruction with the CAM including the climatic requirements of this taxon. The obtained  
338 temperatures are lower than the temperatures estimated excluding *Tsuga*: mean annual temperatures  
339 are between 11 and 15°C (most likely value ~13°C), mean temperature of the coldest month  
340 between -2 and 5°C (most likely value ~1.3°C), mean temperature of the warmest month between  
341 23 and 27°C (most likely value ~24.8°C). Remarkably, mean annual precipitation and relative  
342 humidity are equivalent to values without *Tsuga*. In any case the temperatures are never as low as  
343 the CLAMP and LMA temperatures.

344 Adroit et al. (2016) supported the fact that the Bernasso flora should have existed under a  
345 high mean annual precipitation on the basis of the low diversity and high quantity of galling found  
346 on the fossil leaves of Bernasso. However, the analysis of plant insect interactions on modern and

347 fossil leaves of *Parrotia persica* made a likely correlation between mean annual precipitation and  
348 proportions of insect damages on leaves unclear (Adroit et al., 2018). More in-depth analyses are in  
349 development to improve our understanding of the links between plant-insect interactions and  
350 climatic parameters. These future results will possibly help clarifying Bernasso palaeoclimate.

351

#### 352 4.2. Potential and limits of the methods

353 The three methods used in the present study have the advantage to give quantitative instead  
354 of qualitative reconstruction of the climate that allows direct comparisons. However, each  
355 quantitative methodology proposing climatic reconstructions based on biological palaeoproxies has  
356 its own characteristics influencing the results. For the CAM, we decided to exclude the high  
357 altitude/latitude taxa based on their absence in the megaflores and on their modern altitudinal  
358 distribution. However, reconstructions based on leaf physiognomy (LMA, CLAMP) methods give  
359 generally lower temperature values when applied to European palaeobotanical records (e.g.  
360 Utescher et al., 2000; Uhl et al., 2003, 2006, 2007a, b; Peppe et al., 2011; Thiel et al., 2012). In fact  
361 the modern datasets used to calibrate the relationships does not originate from modern floras  
362 distributed evenly worldwide (Yang et al., 2015). For CLAMP, the available modern data sets do  
363 not include data from southern Europe (only five sites in the United Kingdom and some sites in  
364 western FSU; Yang et al., 2015), nor from the Middle East (<http://clamp.ibcas.ac.cn>). This may be  
365 problematic as many authors have shown that temperate floras of different continents may have  
366 different leaf-climate relationships (e.g. Gregory-Wodzicki, 2000; Greenwood et al., 2004) that led  
367 to significant differences in temperature estimates up to 5°C or more (Jordan, 2011). The case of the  
368 Bernasso megaflores falls into this gap as it is composed of a mixture of taxa living today in the  
369 Mediterranean region and in the SW Asia (including the Hyrcanian region). However Yang et al.  
370 (2015) showed that, in general, CLAMP results seem to be more influenced by climate than  
371 biogeography, corroborating CLAMP results. Also CLAMP calibrations have been validated  
372 against isotopic methods and found to give reliable results, in any case for the Early Eocene and  
373 Miocene periods in the Southern Tibet (Xu et al., 2017 and references therein).

374 Moreover, the modern dataset incorporates many types of sites including dry land sites  
375 although fossil megafloras are predominantly deposited in wet land sites, which also leads to  
376 discrepancies. Due to this bias, Kowalski and Dilcher (2003) indicated that physiognomic methods  
377 lead to an underestimation of temperatures between 2.5 and 10°C. With the results obtained by  
378 CLAMP and LMA methods in this study, one can note that the low temperatures estimated for  
379 Bernasso are found today in southern Norway, at Kristiansand (58°09'N, at sea level, source:  
380 <https://fr.climate-data.org>) (Fig. 3; Table S6). Applying the range of underestimation of the mean  
381 annual temperature given by Kowalski and Dilcher (2003), we obtain a corrected mean annual  
382 temperature for Bernasso comprised between 7°C and 17°C, a range of mean annual temperature  
383 more consistent with the results given by the CAM, even if it is still slightly lower.

384 Peppe et al. (2011) made reconstructions using “digital leaf physiognomy” calibrated on  
385 modern data corresponding to 92 sites sampled in biomes where fossil leaves are generally  
386 preserved. The correlations between the chosen leaf characters and climate parameters show that  
387 these physiognomic variables are linked to climate. When applying this calibration to fossil floras,  
388 the authors obtained a warmer and wetter climate, similar to that estimated by other independent  
389 palaeo-proxies (Peppe et al., 2011). However, it is noteworthy that improvements can be made,  
390 particularly in adding more modern sites to have a larger training set of data in calibrating the  
391 model with additional sites that are still absent from this database (for instance from Europe and  
392 Africa, Peppe et al., 2011).

393 All these evidences indicate that the CLAMP method seems not optimal to reconstruct the  
394 climate of the early Pleistocene in Europe because of the lack of modern data to calibrate the  
395 method on European ecosystems (Uhl et al., 2007a). These results are thus opposite to those of Xia  
396 et al. (2009) and Bondarenko et al. (2013) in which CLAMP analyses provided coherent results  
397 with other palaeoclimate reconstruction methods. CLAMP results from Bernasso probably reflect  
398 the absence of modern analogues from Mediterranean climate in CLAMP. At Bernasso,  
399 palaeotemperatures estimated by CLAMP and LMA are lower than those given by CAM. Also, as  
400 the quantification by CLAMP and LMA made on Bernasso remains unique, it is difficult to see if  
401 the Bernasso results are similar to other regional results or different from them. The values obtained



402 with CAM are in agreement with the climate reconstructed at Garraf in Northern Spain for the same  
403 period (Fauquette et al., 1998a). It thus appears that, at a regional scale, CAM provides coherent  
404 results and may be used to reconstruct the climate at the beginning of the Pleistocene, at least in the  
405 South European region.

406

## 407 **5. Conclusions**

408 The fossil site of Bernasso is remarkable, recording both leaves and pollen grains that allows  
409 applying different climatic reconstruction methods and thus comparing results. Climatic  
410 reconstruction using CLAMP and LMA methods based on megafloora on one hand and using the  
411 Climatic Amplitude Method (CAM) based on pollen flora on the other hand have been made to  
412 check the values given in an earlier study based on the comparison between palaeovegetation data  
413 and similar modern ecosystems. In the latter study, the climate at Bernasso was compared to the  
414 modern climate of the Hyrcanian and Euxinian regions.

415 The comparisons of the three methods used in this study highlight their complementarity as  
416 LMA and CLAMP are based on leaf physiognomy and do not take into account the taxonomy of the  
417 plants, whereas CAM is based on the modern climatic requirements of the taxa present in the pollen  
418 flora from the same sediment level. CLAMP provides supplementary data about precipitation  
419 pattern (*e.g.* precipitation during the three wettest and driest months) that can be partly compared to  
420 the CAM results (*i.e.* mean annual precipitation).

421 However, despite this possible complementarity, the results of this study highlight important  
422 differences between the three methods. CLAMP and LMA analyses show that late-interglacial  
423 Bernasso climate was colder than the present-day climate in Southern France and in the Hyrcanian  
424 region. Against all expectations, the obtained values are found today in southern Norway (58°09'N  
425 at sea level; Fig. 3; Table S6). CAM shows mean annual temperatures higher than the modern  
426 Bernasso mean annual temperature and equivalent to the temperature of the Hyrcanian region. For  
427 what concerns mean temperature of the coldest and warmest months, CLAMP indicates again lower  
428 values than the Climatic Amplitude Method. The only parameters more or less in agreement  
429 between CLAMP and CAM are mean annual precipitation and relative humidity: the climate was

430 wetter than today at Bernasso with the existence of a weak precipitation seasonality highlighted in  
431 the CLAMP results.

432 The two physiognomic methods lead to an underestimation of temperatures from 2.5 to  
433 10°C may be due to problems of calibration. Absence of calibration sites in Europe and in the  
434 Mediterranean region are a critical problem in the underestimation by CLAMP. Calibrations are  
435 also still needed for the Climatic Amplitude Method in order to have a better precision on the  
436 presence of some taxa in the local flora deduced from pollen data and to get more accurate climatic  
437 reconstruction.

438

439

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447

448

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614 **Figure captions**

615 **Figure 1** – Location map of Bernasso situated in the Northwestern part of the Hérault Department  
616 (Southern France).

617 **Figure 2** – Lithology, synthesized pollen diagrams of the three pollen records and position of the  
618 megafloora layer. Pollen diagrams of the exposed section refer to Suc (1978), those of the Borehole  
619 BNI and Leaf outcrop refer to Leroy (1990) and Leroy and Roiron (1996).

620 **Figure 3** – Comparison of the temperatures (in °C) estimated with the three methods, in blue the  
621 mean temperature of the coldest month, in black the mean annual temperature and in red the mean  
622 temperature of the warmest month. For LMA and CLAMP, the darker bars correspond to the  
623 estimated values and the intervals to the standard errors for LMA regression equations Reg 1, Reg  
624 2, Reg 7 and Reg 8 and CLAMP calibrations Calib 1 to Calib 4. See details for LMA and CLAMP  
625 calibrations in Tables S3 and S4. For CAM, the intervals correspond to the estimated climate and  
626 the darker bars to the Most Likely Values (weighted means), see details in Table S5. The green  
627 bands correspond to the modern annual temperature at Kristiansand in Southern Norway, Lunas in  
628 Southern France (source: <https://fr.climate-data.org>) and in the East and West Hyrcanian regions in  
629 Iran (Molavi-Arabshahi et al., 2016; source: Iran Meteorological Organization (IRIMO),  
630 <http://www.irimo.ir/eng/>), see Table S6 for more details.

631

632 **Figure 4** - Comparison of the precipitation (in mm) estimated with four different calibrations of  
633 CLAMP and with CAM. For CLAMP calibrations, the calibrations Calib1 and Calib2 correspond to  
634 Physg3brcAZ calibration (based on 144 modern vegetation sites from the Northern Hemisphere  
635 temperate regions; Calib2 was obtained thanks to a meteorological correction applied in Calib1);  
636 the calibrations Calib3 and Calib4 correspond to Physg3arcAZ calibration (based on 173 modern  
637 vegetation sites from the Northern Hemisphere including samples from areas with pronounced  
638 winter cold; Calib4 was obtained thanks to a meteorological corrections applied in Calib3). Calib5  
639 is an Asian calibration. For CAM, the intervals correspond to the estimated climate and the darker  
640 bars to the Most Likely Values. The four yellow bands correspond to the modern annual

641 precipitation at Kristiansand in Norway, Lunas in Southern France (source: <https://fr.climate->  
642 [data.org](https://fr.climate-data.org)) and in the East and West Hyrcanian regions in Iran (Molavi-Arabshahi et al.2016; source:  
643 IRIMO, <http://www.irimo.ir/eng/>), see Table S6 for more details.

644

### 645 **Supplementary material**

646 **Figure S1** - Canonical correspondence analysis (CCA) plots showing the place of Bernasso within  
647 the 378 vegetation sites available in CLAMP. A- axes 1-2 space; B- axes 1-3 space; C- axes 2-3  
648 space. Climate vectors are positioned for information. MAT- mean annual temperature; CMMT-  
649 cold month mean temperature; WMMT- warm month mean temperature; LGS- length of the  
650 growing season; GSP- growing season precipitation; MMGSP- mean monthly growing  
651 season precipitation; 3-WET- precipitation during the three wettest months; 3-DRY-  
652 precipitation during the three driest months; SH- specific humidity; RH- relative humidity;  
653 ENTHAL- enthalpy (modified from Yang et al., 2015).

654

655 **Table S1** - Data matrix input to on-line CLAMP analysis tool.

656 **Table S2** – List of the pollen taxa recorded respectively in the outcrop, leaf level and borehole.  
657 High latitude/altitude taxa that are excluded of the climatic reconstruction process are indicated in  
658 bold and taxa used to reconstruct the climate are underlined. The Mediterranean sclerophyllous taxa  
659 have been also excluded because they probably inhabited a lower vegetation belt than that of the  
660 Bernasso interglacial forest. The others correspond to taxa that do not give precise climatic  
661 information because of large climatic amplitudes or to taxa for which we do not know the climatic  
662 requirements.

663 **Table S3** – Mean Annual Temperature (MAT) obtained from the different LMA regression  
664 equations considering that Bernasso megafloora contains 25.00% untoothed leaf taxa, as shown in  
665 Table S1. Reg 1, Reg 2, Reg 7 and Reg 8 are reported on Figure 3.

666 **Table S4** – CLAMP results obtained from the Bernasso megafloora. Calib 1 to 4 are reported on  
667 Figures 3 and 4.

668 **Table S5** – Climatic estimates obtained with the Climatic Amplitude Method using pollen data of

669 the leaf level and of the pollen zone II (borehole BN I in Leroy and Roiron (1996) and outcrop in  
670 Suc (1978)). Values are reported on figures 3 and 4.

671

672 **Table S6** – Climatic parameters of the three modern analogues used in the discussion: the

673 Hyrcanian region (data obtained from Molavi-Arabshahi et al. (2016) and IRIMO

674 (<http://www.irimo.ir/eng/>), Kristiansand (Norway) and at Lunas (France) (data obtained from

675 Climate-data - <http://fr.climate-data.org>).

Species*	Dissection		Margin character States					
	Unlobed	Lobed	No Teeth	Teeth Regular	Teeth Close	Teeth Round	Teeth Acute	Teeth Compound
<i>Acer integerrimum</i>	0	1	1	0	0	0	0	0
<i>Acer opulifolium</i>	0	1	0.5	0.5	0.5	0.25	0.25	0
<i>Acer protojaponicum</i>	0	1	0	1	1	0.5	1	0
<i>Acer pseudomonspessulanum</i>	0	1	1	0	0	0	0	0
<i>Carpinus orientalis</i>	1	0	0	1	1	0	1	1
<i>Carpinus suborientalis</i>	1	0	0	1	1	0.5	1	1
<i>Carya minor</i>	1	0	0	1	1	0.5	1	0
<i>Celtis</i> sp	1	0	0	1	0.5	0.5	1	0
<i>Fraxinus ornus</i>	1	0	0	1	0.5	0.5	1	0
<i>Hedera helix</i>	0.5	0.5	1	0	0	0	0	0
<i>Ilex</i> sp	0.5	0.5	0	0.5	0.5	0.25	1	0
<i>Parrotia persica</i>	1	0	1	0	0	0	0	0
<i>Populus tremula</i>	1	0	1	0	0	0	0	0
<i>Prunus</i> sp	1	0	0	1	1	0.5	1	0
cf. <i>Salix caprea</i>	1	0	0	1	1	0.5	1	0
<i>Sorbus domestica</i>	1	0	0	1	1	0.5	1	0
<i>Tilia</i> sp	1	0	0	0.5	1	0.5	0.5	1
<i>Vitis</i> sp	0.5	0.5	0	0.5	0.5	0.5	0.5	0
<i>Zelkova acuminata</i>	1	0	0	1	1	0.5	1	0
<i>Zelkova crenata</i>	1	0	0	1	1	0.5	1	0
Dicot. Indet. 1	0	1	0	1	1	0.5	0.5	0
Dicot. indet. 2	1	0	0	1	1	0.5	0.5	0
Character state score	15.5	6.5	5.5	15	14.5	7.5	14.25	3
No. character states present	22	22	22	22	22	22	22	22
Percent Score	70.45	29.55	25.00	68.18	65.91	34.09	64.77	13.64

Species	Size Character States								
	Nano-phyll	Leptop-phyll I	Lepto-phyll II	Micro-phyll I	Micro-phyll II	Micro-phyll III	Meso-phyll I	Meso-phyll II	Meso-phyll III
<i>Acer integerrimum</i>	0	0	0	0	0.5	0.5	0	0	0
<i>Acer opulifolium</i>	0	0	0	0	0.5	0.5	0	0	0
<i>Acer protojaponicum</i>	0	0	0	0.5	0.5	0	0	0	0
<i>Acer pseudomonspessulanum</i>	0	0	0	0.5	0.5	0	0	0	0

<i>Carpinus orientalis</i>	0	0	0	0.5	0.5	0	0	0	0
<i>Carpinus suborientalis</i>	0	0	0	0	1	0	0	0	0
<i>Carya minor</i>	0	0	0	0	0	0	1	0	0
<i>Celtis</i> sp	0	0	0	0.5	0.5	0	0	0	0
<i>Fraxinus ornus</i>	0	0	0	0	0.5	0.5	0	0	0
<i>Hedera helix</i>	0	0	0	0	1	0	0	0	0
<i>Ilex</i> sp	0	0	0	0	0	0	1	0	0
<i>Parrotia persica</i>	0	0	0	0	0.5	0.5	0	0	0
<i>Populus tremula</i>	0	0	0	0	0	1	0	0	0
<i>Prunus</i> sp	0	0	0	0	1	0	0	0	0
cf. <i>Salix caprea</i>	0	0	0	0	1	0	0	0	0
<i>Sorbus domestica</i>	0	0	0	1	0	0	0	0	0
<i>Tilia</i> sp	0	0	0	0	0	0.5	0.5	0	0
<i>Vitis</i> sp	0	0	0	0	0	0.5	0.5	0	0
<i>Zelkova acuminata</i>	0	0	0	0	1	0	0	0	0
<i>Zelkova crenata</i>	0	0	0	0	1	0	0	0	0
Dicot. Indet. 1	0	0	0	0.5	0.5	0	0	0	0
Dicot. indet. 2	0	0	0	1	0	0	0	0	0
Character state score	0	0	0	4.5	10.5	4	3	0	0
No. character states present	22	22	22	22	22	22	22	22	22
Percent Score	0.00	0.00	0.00	20.45	47.73	18.18	13.64	0.00	0.00

680

Species	Apex Character States				Base Characters States		
	Apex Emarginate	Apex Round	Apex Acute	Apex Attenuate	Base Cordate	Base Round	Base Acute
<i>Acer integerrimum</i>	0	0	0	1	1	0	0
<i>Acer opulifolium</i>	0	0	0	1	1	0	0
<i>Acer protojaponicum</i>	0	0	1	0	1	0	0
<i>Acer pseudomonspessulanum</i>	0	0.5	0.5	0	0.5	0.5	0
<i>Carpinus orientalis</i>	0	0	1	0	0	1	0
<i>Carpinus suborientalis</i>	0	0	1	0	0	1	0
<i>Carya minor</i>	0	0	1	0	0	0	1
<i>Celtis</i> sp	0	0	1	0	0	0	1
<i>Fraxinus ornus</i>	0	0	1	0	0	0	1
<i>Hedera helix</i>	0	0	1	0	0.5	0	0.5
<i>Ilex</i> sp	1	0	0	0	0	1	0
<i>Parrotia persica</i>	0	0	1	0	0	0	1
<i>Populus tremula</i>	0	1	0	0	0	1	0
<i>Prunus</i> sp	0	0	0	1	0	1	0



Percent Score	34.09	13.64	47.73	2.27	2.27	20.45	50.00	29.55
---------------	-------	-------	-------	------	------	-------	-------	-------

682 \* for more details about scoring of the characters: <http://clamp.ibcas.ac.cn/Clampset2.html>

683 Scores are the consensus of four independent scorers. CLAMP scores 32 character states; only those characters

684 represented in the Bernasso megaf flora are presented here. Descriptions of all character states and the details of the

685 scoring method can be found on the CLAMP web site (<http://clamp.ibcas.ac.cn>).

686

687 Table S2

	<b>Outcrop</b>	<b>Leaf level</b>	<b>Borehole</b>
<i>Abies</i>	x	x	x
<i>Acer</i>	x	x	x
<i>Alnus</i>	x	x	x
Amaranthaceae	x	x	x
Apiaceae	x		x
Araliaceae			x
<i>Artemisia</i>	x	x	x
Asteraceae Asteroideae	x		x
Asteraceae Cichorioideae	x	x	x
<i>Betula</i>	x	x	x
Brassicaceae	x	x	x
<i>Buxus sempervirens</i>	x	x	x
<i>Carpinus</i>	x	x	x
<i>Carya</i>	x	x	x
Caryophyllaceae	x		
<i>Castanea</i>	x		
<i>Cathaya</i>	x		x
<i>Celtis</i>	x	x	x
<i>Centaurea</i>			x
<i>Cladium mariscus</i> type			x
<i>Corylus</i>			x
Crassulaceae			x
<i>Cupressaceae</i>	x		x
Cyperaceae	x		x
Dipsacaceae			x
<i>Elaeagnus</i>	x		x
<i>Engelhardia</i>			x
<i>Ephedra</i>		x	x
<i>Erica</i> cf. <i>arborea</i>	x		
Ericaceae	x		x
<i>Erodium</i>			
<i>Eucommia</i>	x	x	x
<i>Fagus</i>	x		x
<i>Fraxinus</i>	x		x
<i>Galium</i>	x		
Gentianaceae		x	x
<i>Hedera</i>	x		x
<i>Helianthemum</i>			x
<i>Ilex</i>	x	x	x
<i>Ilex aquifolium</i> type	x		
<i>Juglans</i>	x		x
Lamiaceae	x		
<i>Ligustrum</i>			x
Liliaceae		x	
<i>Liquidambar</i>			x
<i>Lonicera</i>	x	x	
<i>Myrica</i>			x
<i>Myriophyllum</i>			x
<i>Olea</i>	x		
<i>Parrotia</i> cf. <i>persica</i>		x	x
<i>Parthenocissus</i>			x
<i>Phillyrea</i>		x	
<i>Phlomis</i>		x	

<i>Picea</i>	x	x	x
<b>Pinaceae</b>	x	x	x
<i>Pinus</i>	x	x	x
<i>Plantago</i>	x		
Poaceae	x	x	x
<i>Polygonum</i>		x	x
<i>Populus</i>	x		
<i>Potamogeton</i>	x		
<u><i>Pterocarya</i></u>	x		
<u><i>Quercus</i> deciduous type</u>	x		x
<i>Quercus ilex-coccifera</i> type	x		x
Ranunculaceae	x		x
<u><i>Rhammus</i></u>	x		
<i>Rumex</i>	x		
<i>Salix</i>	x		
<i>Scabiosa</i>		x	
<u><i>Tilia</i></u>	x		x
<b><i>Tsuga</i></b>	x		x
<i>Typha</i>	x		
<i>Typha</i> cf. <i>latifolia</i>		x	
<u><i>Ulmus</i></u>		x	
<i>Ulmus-Zelkova</i> type	x	x	x
Urticaceae	x		x
Monoletes spores		x	
<i>Thelypteris</i> cf. <i>palustris</i>			x
<i>Selaginella sibirica</i>			x
<i>Osmunda</i>			x
<i>Sphagnum</i>			x

688

689

690 Table S3.

Regression equation for MAT	Standard error of estimate (°C)	Sources	Region	MAT (°C)
Reg1 = 30.6P + 1.14	0.8	Wolfe, 1979	East Asia	8.79
Reg2 = 28.6P + 2.24	2.0	Wilf, 1997	North America, Caribbean	9.39
Reg3 = 27.5P + 1.36	3.3	Gregory-Wodzicki, 2000	North America, Japan, Caribbean, South Pacific	8.24
Reg4 = 24.9P + 3.53	2.2	Gregory-Wodzicki, 2000	North America, Japan, Caribbean, South Pacific	9.76
Reg5 = 22.0P + 1.32	3.0	Greenwood et al., 2004	Eastern Australia	6.82
Reg6 = 27.0P - 2.12	2.2	Greenwood et al., 2004	Eastern Australia	4.63
Reg7 = 31.4P + 0.512	1.7	Traiser et al. 2005	Europe	8.36
Reg8 = 28.99P + 1.32	0.12	Miller et al., 2006	Central and North America	8.57

691

692 Table S4.

Calibration*	MAT (°C)	CMMT (°C)	WMMT (°C)	3DRY (mm)	3WET (mm)	LMP (mm)	HMP (mm)
Calib1	4.95 ± 2.0	-6.33 ± 3.4	17.30 ± 2.7	142.1 ± 13.7	525.6 ± 20.6	951.9 ± 61.7	1718.9 ± 75.5
Calib2	5.53 ± 2.1	-6.01 ± 3.4	17.80 ± 2.5	316.2 ± 5.9	436.6 ± 22.9	1385.2 ± 40.6	1626.0 ± 74.6
Calib3	7.42	-3.79	19.19	141.3	537.2	961.1	1752.9



	± 2.8	± 4.0	± 3.1	± 13.2	± 19.4	± 59.0	± 71.4
Calib4	7.42 ± 2.8	-4.23 ± 3.8	19.67 ± 3.0	313.7 ± 5.9	446.7 ± 22.1	1387.8 ± 39.8	1653.8 ± 72.2
Calib5	7.46 ± 2.5	-3.59 ± 4.1	18.56 ± 3.0	174.7 ± 10.4	609.6 ± 23.9	1133.7 ± 55.0	2003.5 ± 82.0
Calib6	7.51 ± 2.3	-3.23 ± 3.6	19.51 ± 2.8	184.2 ± 9.5	664.3 ± 35.8	1216.9 ± 64.2	2177.1 ± 116.9
Calib7	2.15 ± 4.0	-13.46 ± 6.7	17.18 ± 3.9	87.1 ± 13.0	500.5 ± 32.2	761.8 ± 71.2	1588.6 ± 109.5

693 \* The calibrations Calib1 and Calib2 correspond to Physg3brcAZ calibration (based on 144 modern vegetation sites  
694 from the Northern Hemisphere temperate regions; Calib2 was obtained thanks to a meteorological correction applied in  
695 Calib1). The calibrations Calib3 and Calib4 correspond to Physg3arcAZ calibration (based on 173 modern vegetation  
696 sites from the Northern Hemisphere including samples from areas with pronounced winter cold; Calib4 was obtained  
697 thanks to a meteorological corrections applied in Calib3). Calib 5-7 respectively correspond to calibrations for Asian  
698 vegetations that suffer strong monsoonal climate (Calib5 and Calib6) and for 378 sites from all continents (Calib7). Due  
699 to their specificity, these 3 last calibrations were not analysed in this study, but results are presented in this table. For  
700 more details, see CLAMP online: <http://clamp.ibcas.ac.cn/>

701 MAT – Mean annual temperature; CMMT – Mean temperature of the coldest month; WMMT – Mean temperature of  
702 the warmest month; GSP – Precipitation during the growing season; 3DRY – Precipitation during the 3 driest months;  
703 3WET – Precipitation during the 3 wettest months; LPM – Lower estimation of the mean annual precipitation; HPM –  
704 Higher estimation of the mean annual precipitation; RH – Relative humidity.

705

706 Table S5.

Parameter*	MAT (°C)	MTC (°C)	MTW (°C)	MAP (mm)	RH (%)
Leaf level	11 – 15 – 20	-2 – 1.6 – 5	24 – 25 – 27	700 – 1100 – 1350	66 – 75 – 80
Borehole & outcrop	11 – 15.5 – 20	-2.2 – 3.2 – 8	24 – 25.7 – 27.7	700 – 1055 – 1320	66 – 75 – 81

707 \* MAT – mean annual temperature; MTC – mean temperature of the coldest month; MTW – mean temperature of the  
708 warmest month; MAP – mean annual precipitation; RH – relative humidity. All parameters are given as an interval and  
709 a Most Likely Value which corresponds to a weighted mean.

710

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714

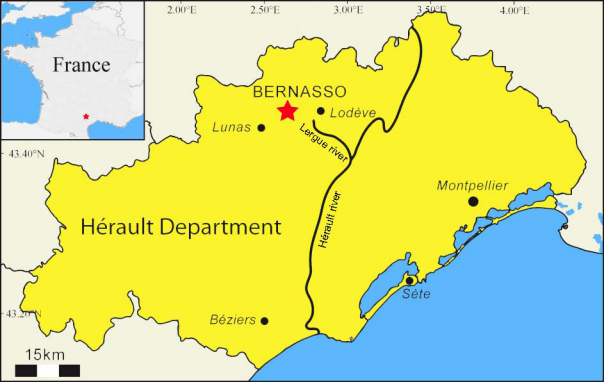
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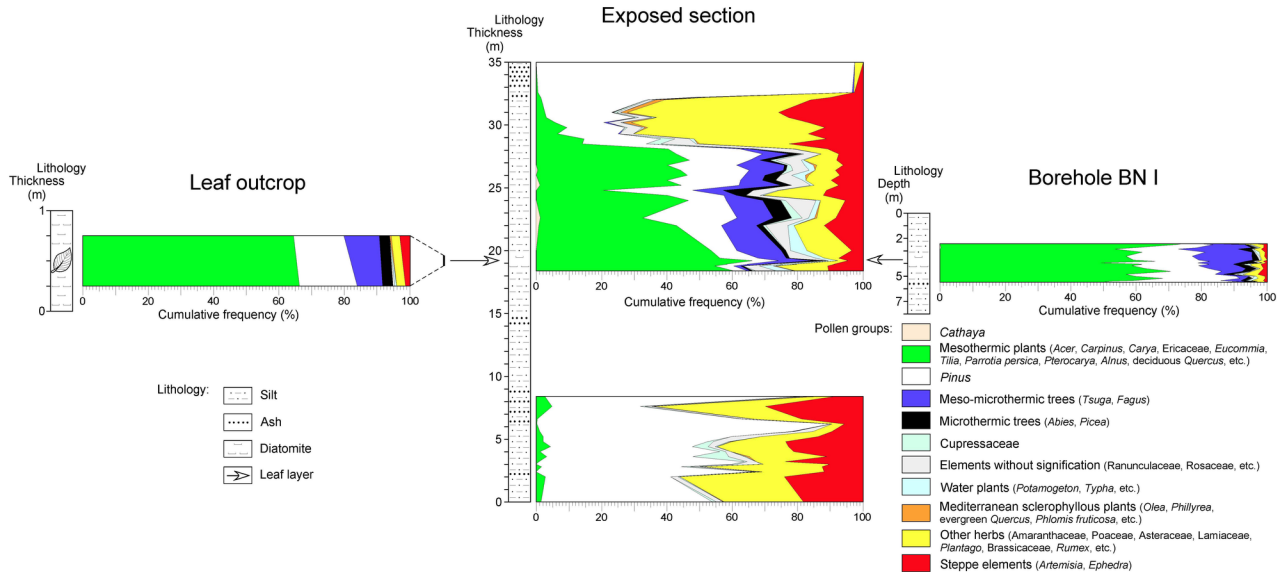
716

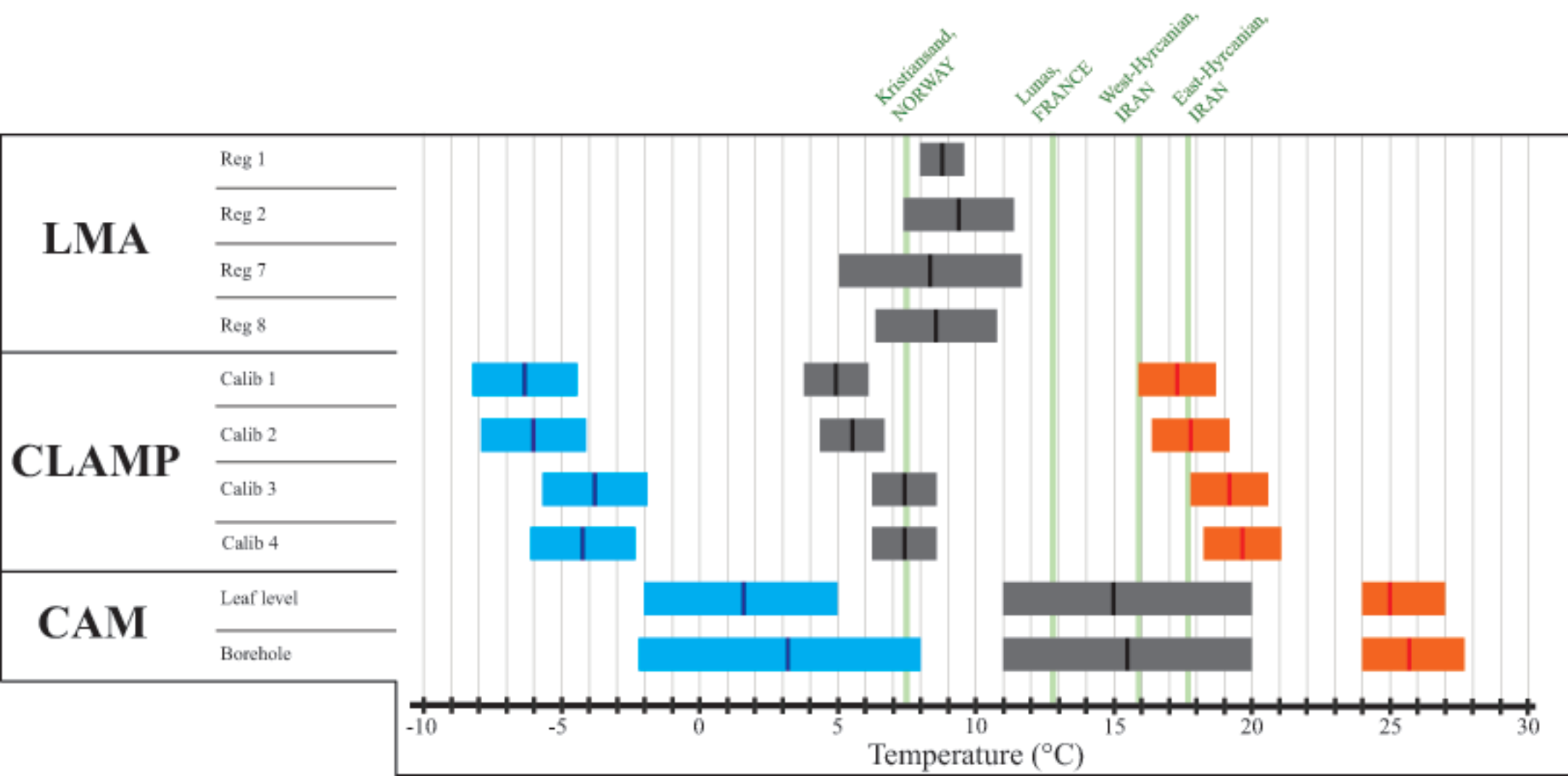
717 Table S6.

Parameters*	MTC (°C)	MAT (°C)	MTW (°C)	DMP (mm)	MAP (mm)	WMP(mm)
West Hyrcanian region	6.65	15.77	25.85	37.15	1377.6	220.55
East Hyrcanian region	8.0	17.51	27.75	16.2	671.95	112.8
Kristiansand (Norway)	0.1	7.5	15.5	57	1260	160
Lunas (France)	4.8	12.8	21.3	33	723	82

718 \* MTC - mean temperature of the coldest month; MAT – mean annual temperature; MTW – mean temperature of the  
719 warmest month; DMP – precipitation during the driest month; MAP – mean annual precipitation; WMP – precipitation  
720 during the wettest month.







# CLAMP

Calib 1

Calib 2

Calib 3

Calib 4

# CAM

Leaf level

Borehole

East-Hyrcanian,  
IRAN  
Lumas,  
FRANCE

Kristiansand,  
NORWAY  
West-Hyrcanian,  
IRAN

