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1 **Middle and Late Holocene Vegetation history of the Murcia region from a new high-resolution pollen**  
2 **sequence from the Mar Menor Lagoon**

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8 **Keywords**

9 Palynology, coastal lagoon, vegetation changes, human impact, resilience, ecological succession, Argar period,  
10 Classical Antiquity, Historic period, lead concentration, mining activities

11 **Abstract**

12 South-Eastern Spain is a particularly suitable area for studying the impact of human societies on their  
13 environment. We present a new high resolution and continuous pollen sequence from the coastal lagoon of  
14 Mar Menor in the Murcia region. This new sequence covers the last 6500 years, from the end of the Neolithic  
15 to the present period, with a robust chronological framework (17 radiocarbon dates). The history of vegetation  
16 obtained from pollen data is studied in parallel with a proxy of mining activity in the watershed of the same  
17 lagoon to disentangle the influence of human activities and climate change on the vegetation of this part of  
18 the Iberian Peninsula. While the influence of past climate variability on the vegetation in the Murcia region  
19 remains difficult to perceive, the data show a very clear concomitance between changes in the archaeological  
20 record and changes within plant communities.

- 21 • Important deforestation and changes in herbaceous communities during the Argar period (early  
22 Bronze Age)  
23 • Changes in the thermo-Mediterranean shrub communities in relation with the very important pastoral  
24 practices  
25 • Major vegetation changes linked with mining and agricultural activities during the Roman period  
26 • Impact on the regional vegetation of agricultural practices evolution between the 18<sup>th</sup> and the 19<sup>th</sup>  
27 Centuries.

28 The results obtained provide valuable indications for assessing the resilience of thermo-Mediterranean coastal  
29 plant communities to anthropogenic environmental changes.

30 **Introduction**

31 The Mediterranean area is one of the 34 biodiversity hotspots listed by Conservation International (Mittermeier  
32 2011), while being a densely populated area for several thousand years. It is therefore a key area for studying  
33 past interactions between humans, their environments and climate changes. The Mediterranean is currently the  
34 scene of a major environmental crisis. Since the middle of the 20th Century, the demographic explosion,  
35 increasing urbanization, the rise of mass tourism, the development of intensive agriculture and the ongoing  
36 global warming have made environmental protection in this part of the world a huge challenge (Thiébaud and  
37 Moatti 2016). In this context, understanding how Mediterranean ecosystems react to anthropogenic disturbances  
38 appears to be a necessity for better understanding the issues at stake in the current crisis. Paleoenvironmental  
39 studies are therefore becoming particularly crucial to understand the role of human societies in ecological  
40 dynamics in the short, medium and long terms and to assess the resilience capacity of these threatened  
41 environments.

42 South-eastern Spain is particularly suitable for studying the impact of human societies on ecosystems. Indeed,  
43 this part of the Iberian Peninsula is rich in a long history of human occupation by societies that each had a  
44 particular influence on their environment, particularly in the Bronze Age with the Argar culture, in the Roman  
45 period, during the Muslim period and finally in the 19th and 20th Centuries with industrialization and the  
46 development of intensive agriculture. Moreover, in this region, the environmental impact is exerted on a great  
47 diversity of very contrasting plant communities, from the lower thermo-Mediterranean formations of sub-  
48 tropical affinities along the coast, which are among the driest environments in Europe, to the deciduous oak  
49 formations of Euro-Siberian affinities in the mountain ranges further inland.

50 The study of vegetation history in south-eastern Spain has already been subject to numerous publications.  
51 However, the search for sedimentary environments suitable for the conservation of paleoenvironmental markers  
52 has led many studies to focus more on high-altitude sites (Carrión 2002b, Carrión et al. 2001, 2003, 2007,  
53 Jiménez-Moreno and Anderson 2012, Ramos-Roman et al. 2016, 2018a, 2018b) while the history of coastal  
54 environments is less documented (Carrión and Van Geel 1999, Pantaléon-Cano 2003, Burjachs 2012, Jiménez-  
55 Moreno et al. 2015). In addition, most of these studies concern sites relatively far from the most densely  
56 occupied areas in the past and therefore focus mainly on the influence of past climate change on ecosystems  
57 (Carrión et al. 2001, Carrión 2002b, Pantaléon-Cano 2003, Carrión et al. 2003, Carrión et al. 2007, Jiménez-  
58 Moreno and Anderson 2012, Jiménez-Moreno et al. 2015, Ramos-Roman et al. 2016, 2018a, 2018b). To date  
59 much less work has been done specifically on the influence of human societies on vegetation (Carrión et al.  
60 2007).

61 This study presents a new pollen sequence from the coastal lagoon of Mar Menor in the Murcia region. This  
62 new sequence covers continuously the last 6500 years from the end of the Neolithic to the present day, with a  
63 robust chronological framework. The history of vegetation obtained from pollen data is studied in parallel with  
64 a proxy of mining activity in the watershed of the same lagoon (Dezileau et al. in prep). The records of these  
65 two proxies are compared in detail with the regional historical and archaeological records as well as with  
66 paleoclimate data in order to disentangle the influence of human activities and climate change on the vegetation  
67 history of this part of the Iberian Peninsula.

68

## 69 Physical settings and regional vegetation

70 The studied sequence comes from the vast coastal lagoon of Mar Menor, one of the largest euhaline lagoons in  
71 Europe (Figure 1). It occupies about 135 km<sup>2</sup> with an average depth of 3.6 m and is separated from the sea by a  
72 sandy barrier, "La Manga", 22 km long and between 30 and 500 m wide, pierced by five natural channels called  
73 "Golas" (Pérez-Ruzafa et al. 2005). This lagoon is located at the limit of a vast coastal plain, the "Campo de  
74 Cartagena", delimited to the south by coastal massifs including the mining massif of "Cartagena-La Unión" and  
75 to the northwest by two massifs belonging to the Baetic Cordillera, the "Sierra de Carrascoy" and the "Sierra  
76 Espuña" (Figure 1). The Mar Menor lagoon is fed by several temporary rivers (ramblas) which are dry for most  
77 of the year but can carry large quantities of sedimentary material during torrential rainfall episodes (García-  
78 Pintado et al. 2007). The main one, the Albuñón rambla, drains a watershed of 441 km<sup>2</sup>, representing a third of  
79 the Campo de Cartagena. The MM2 core was collected far from the mouth of rivers, at about 8.5 km (Dezileau  
80 et al. 2016) and is therefore very insensitive to river inputs.

81 Figure 1 (color): a) Map of the main reliefs of the south-eastern Iberian Peninsula and distribution of the main  
82 pollen sequences of the region, b) Distribution map of the vegetation belts in the Murcia region.

83 The climate of the Murcia region is Mediterranean. It is characterized by significant seasonal contrasts with  
84 mild and humid winters and hot and dry summers. Rainfall is highest in autumn and lowest in summer. In the  
85 lowlands, the average annual rainfall is only between 250 and 330 mm. The massifs of the Baetic Cordillera act  
86 as a shield against disturbances from the west. Annual rainfall can exceed 400 mm in the mountains and fall  
87 below 190 mm in the driest coastal areas while the average annual temperature is between 16 and 17° C (Carrión  
88 2002a).

89 The Aleppo pine (*Pinus halepensis*), is one of the most abundant tree species in the Murcia region. It grows  
90 from sea level up to an altitude of 1500 m. This species colonizes degraded shrub formations in which it can  
91 form dense and extensive populations. Further up in altitude, it often coexists in mixed formations with *Quercus*  
92 *ilex* subsp. *ballota* but can also be found in pure stands. *Pinus halepensis* represents 87% of the coverage of all  
93 wooded areas in the region (Sanchez-Gomez et al. 1998). Apart from this rather ubiquitous species, the  
94 vegetation in the Murcia region is organized into four altitudinal belts (Figure 1):

- 95 • The thermo-Mediterranean belt is characterized by average annual temperatures between 18 and 19 °C,  
96 and an average temperature of the coldest month above 3° C. In the Murcia region, it extends from the  
97 coast to an altitude of between 300 and 400 m asl, covering an area that represents almost half of the  
98 Murcia region. In the lower thermo-Mediterranean belt where winter frosts are very rare, a very open  
99 vegetation develops, characterized by the presence of thermophilous species of subtropical affinities  
100 such as *Maytenus senegalensis* subsp. *europaea*, *Withania frutescens* and *Periploca angustifolia*. At  
101 higher altitudes these species of subtropical affinities disappear or become occasional while shrub  
102 formations with *Quercus coccifera*, *Pistacia lentiscus*, *Chamaerops humilis* and *Olea sylvestris* are  
103 dominant. In the places of the thermo-Mediterranean belt where annual rainfall is between 350 and 600  
104 mm these shrub formations are replaced by forests dominated by *Quercus ilex* subsp. *ballota*.
- 105 • The meso-Mediterranean belt also occupies a very large area of the Murcia region, where it extends up  
106 to an altitude of 1100 m asl. The average annual temperatures are between 13 and 18° C with average  
107 temperatures of the coldest month between 0 and 3° C. When average annual rainfall is between 200-  
108 350 mm, formations of *Quercus coccifera* and *Rhamnus lycioides* are found. They are replaced by  
109 forests of *Quercus ilex* subsp. *ballota* in areas with average annual rainfall between 350 and 600 mm  
110 and more mesophilic forests, still dominated by *Quercus ilex* subsp. *ballota* but with a significant  
111 presence of *Quercus faginea* when average annual rainfall exceeds 600 mm.
- 112 • The supra-Mediterranean level has a limited extension. It occupies restricted areas in the highest  
113 regions, above 1100 m asl. It is found mainly in the Segura massif and to a lesser extent in the Espuña  
114 massif. Two formations notably stand out (Boucher 1988). Forests of *Quercus ilex* subsp. *ballota*  
115 accompanied by *Berberis hispanica* and *Cytisus reverchonii* are located in the driest areas, while forests

116 of *Quercus ilex* subsp. *ballota* and *Quercus faginea* associated with Eurosiberian species such as  
117 *Crataegus monogyna* or *Helleborus foetidus*, are limited to the steepest parts of the massifs.  
118 • The oro-mediterranean stage is found in the Sierra de Segura above 1600 m asl. It is essentially  
119 characterized by the presence of *Pinus nigra* subsp. *salzmanni* forests (Boucher 1988).

## 120 **Material and Method**

### 121 Lithology and chronology of the core

122 Only one core, MM2 (3.97 m long, Longitude 0.7502° W/Latitude 37.7233° N), was collected from the Mar  
123 Menor lagoon. Sedimentation is largely dominated by fine clays and silts all along the core with eight coarse-  
124 grained layers of sand and shell fragments around 5, 40, 60, 150, 170, 210, 255, and 290 cm, which mark storm  
125 deposits from the sandy barrier and are reported in red at the left side of the pollen diagram (Figure 3) (Dezileau  
126 et al. 2016). Those layers were not sampled for pollen analysis as they usually contain few pollen grains and  
127 display biased spectra (Azuara et al. 2015). The MM2 core age model is based on 17 radiocarbon AMS  
128 measurements performed on *Cerastoderma glaucum* shells (Dezileau et al. 2016). These <sup>14</sup>C dates, corrected  
129 for their reservoir effect (Sabatier et al. 2010, Dezileau et al. 2016), were calibrated with the Marine 13  
130 calibration curve (Reimer et al. 2013). The MM2 core covers the last 6600 years. These dates were also  
131 supplemented by <sup>137</sup>Cs and <sup>210</sup>Pb measurements in the most recent part of the sequence. A more detailed  
132 presentations of the MM2 core lithology and chronology is available in Dezileau et al. (2016). The radiocarbon  
133 dates and the age model obtained for the MM2 core are presented in Appendix 1.

134 At the beginning of the sequence, the sandy barrier that delimited the lagoon was more than 1 km toward the  
135 sea compared to its current position (Dezileau et al. 2016). Sediments at the bottom of the core contain very few  
136 faunal remains, making the sedimentary environment difficult to characterize. La Manga reached its modern  
137 position around 5400 cal. BP. Between 5400-2400 ca.l BP, faunal remains contain in sediments characterize a  
138 lagoon environment quite open to the sea. Then, after 2400 cal. BP, the Mar Menor lagoon was becoming  
139 gradually isolated from the Mediterranean (Dezileau et al. 2016).

### 140 Pollen analyses

141 The protocol to extract pollen grain content from sediment is adapted from the protocol described by Faegri and  
142 Iversen (1989). For each sample, 1 g of sediment was treated, with one lycopod spore tablet (Batch No. 483216,  
143 18 852 spores/ pellet) added before treatment to calculate the pollen concentration (Stockmarr 1971). Extraction  
144 began with hydrochloric acid to remove carbonates and then sieving at 250 µm to remove the coarser elements.  
145 It was followed by separation of the organic matter within a dense liquor bath at 20° C (sodium polytungstate,  
146 density 2.1). The supernatant was recovered, after centrifugation, by filtration on a 0.5 µm glass fiber filter. The  
147 filter was finally removed with hydrofluoric and then hydrochloric acid to retain only the organic part of the  
148 sample. For levels particularly rich in organic matter, additional filtration was carried out on a 5 µm mesh sieve.

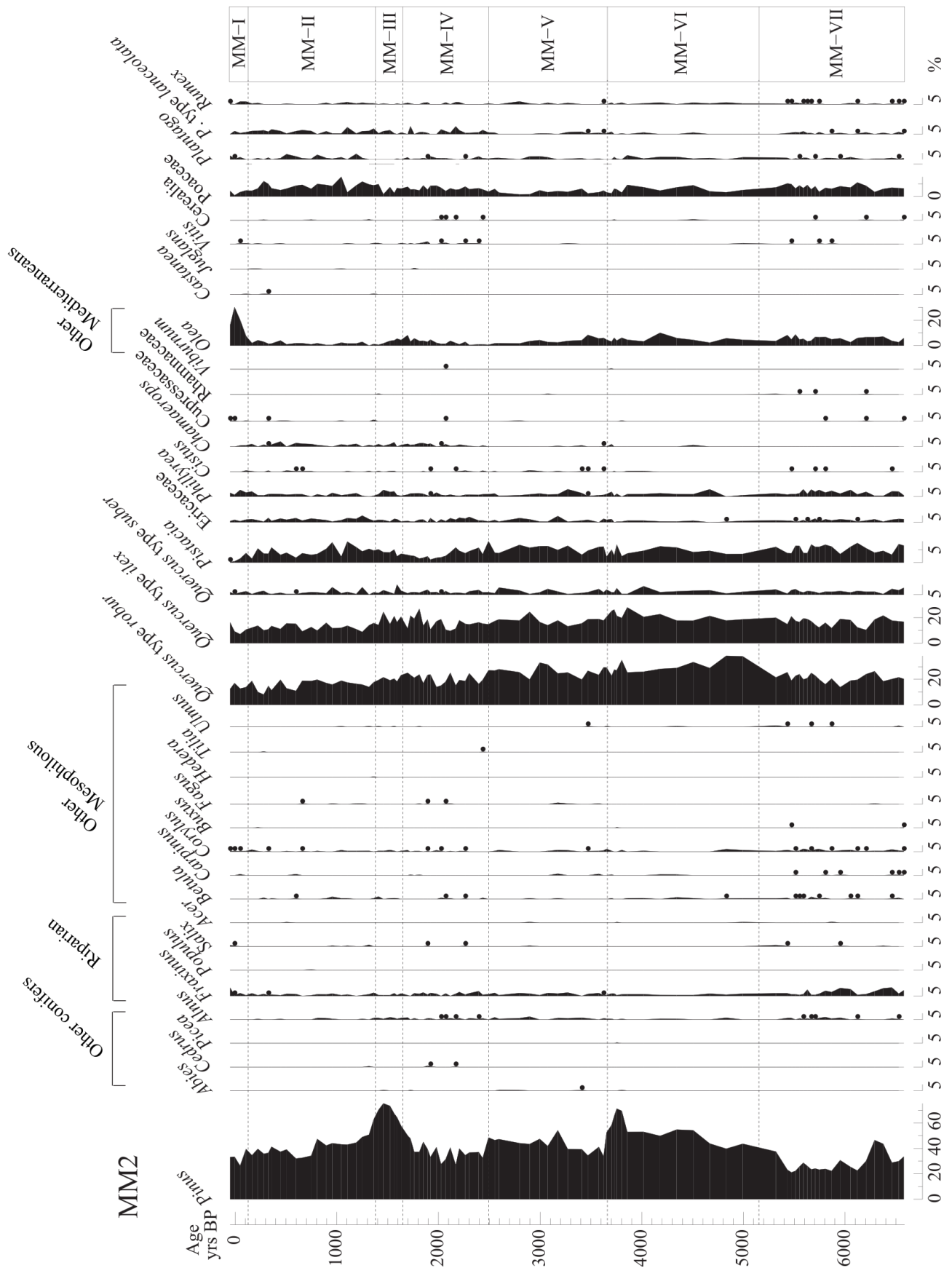
149 The residue was diluted in glycerol for observation. The counting of pollen grains on each slide was carried out  
150 under a bright field optical microscope with a x400 magnification while the identification was performed at  
151 x1000 magnification. The identification of pollen grains was based on determination pollen keys (Punt 1976-  
152 2009, Beug 1961), pollen atlases (Reille 1992), as well as the reference collection of the palynology laboratory  
153 of the Museum national d'Histoire naturelle. For each sample, a minimum of 300 pollen grains were counted  
154 excluding spores (Ralska-Jasiewiczowa and Berglund 1986). Counting was continued beyond 300 grains if a  
155 taxon represented more than 50% of a spectrum, to reach at least 150 grains outside this dominant taxon  
156 (Heusser and Balsam 1977, Turon 1984). In order to avoid problems of covariation between *Pinus* and other  
157 taxa due to the high variability of this taxon and its overwhelming dominance in some spectra, the pollen  
158 proportions of the other taxa were calculated by excluding *Pinus* from the total pollen sum. Pollen diagrams  
159 were produced using PSIMPOL software (Bennet 1992). The zonation was carried out using the CONISS  
160 method (Grimm 1987) and the number of zones was determined using the "Broken stick" method (Bennet 1996).  
161 Detailed pollen diagram are shown in Figure 2a and 2b. The most representative pollen taxa and seven groups

162 of ecological affinities for the less abundant pollen taxa have been defined to draw a simplified pollen diagram  
163 (Figure 3):

- 164 • Most representative pollen taxa : *Pinus*, *Quercus robur* type, *Quercus ilex* type, *Quercus suber* type,  
165 *Pistacia*, Ericaceae, *Phillyrea*, *Cistus*, *Chamaerops*, *Olea*, *Castanea*, *Juglans*, *Vitis*, Poaceae, *Plantago*,  
166 *Plantago lanceolata* type, *Rumex*, *Artemisia*, Amaranthaceae.
- 167 • Other conifers: *Abies*, *Cedrus* and *Picea* markers of rare and very distant contributions.
- 168 • Riparians: *Alnus*, *Fraxinus* type *excelsior*, *Populus*, *Salix*.
- 169 • Other Mesophilous: *Betula*, *Corylus*, *Ulmus*, *Acer*, *Carpinus*, *Tilia*, *Fagus*, *Hedera*, *Buxus*.
- 170 • Other Mediterranean shrubs: *Cupressaceae*, *Rhamnus*, *Viburnum*.
- 171 • Other Xerophilous: *Asphodelus*, Asteroideae, Cichorioideae, *Ephedrafragilis* type, Euphorbiaceae,  
172 *Tamarix*, *Thymeleaceae*.
- 173 • Aquatic: Alismataceae, Cyperaceae, Nymphaeaceae, *Typha*/Sparganium.
- 174 • Other herbaceous: All other herbaceous taxa not represented individually in the simplified diagrams or  
175 included in one of the previous categories.

#### 176 Geochemical analysis

177 In order to obtain the lead concentration in the sediments, elemental geochemical analyses by energy-  
178 dispersive X-ray fluorescence (XRF) spectrometry were undertaken on wet sediments with a hand-held Niton  
179 XL3t (Dezileau et al. In prep). Measurements were realized with a step size of 1 cm along the core. The  
180 elemental analyses from XRF measurement were performed in mining-type ModCFprolene mode. These  
181 data directly show concentrations in ppm or percentage values. This is a semi-quantitative  
182 measurement. International powder standards (NIST2702 and NIST2781) were used to assess the analytical  
183 error and accuracy of measurement, which is lower than 5 % for lead (Pb).

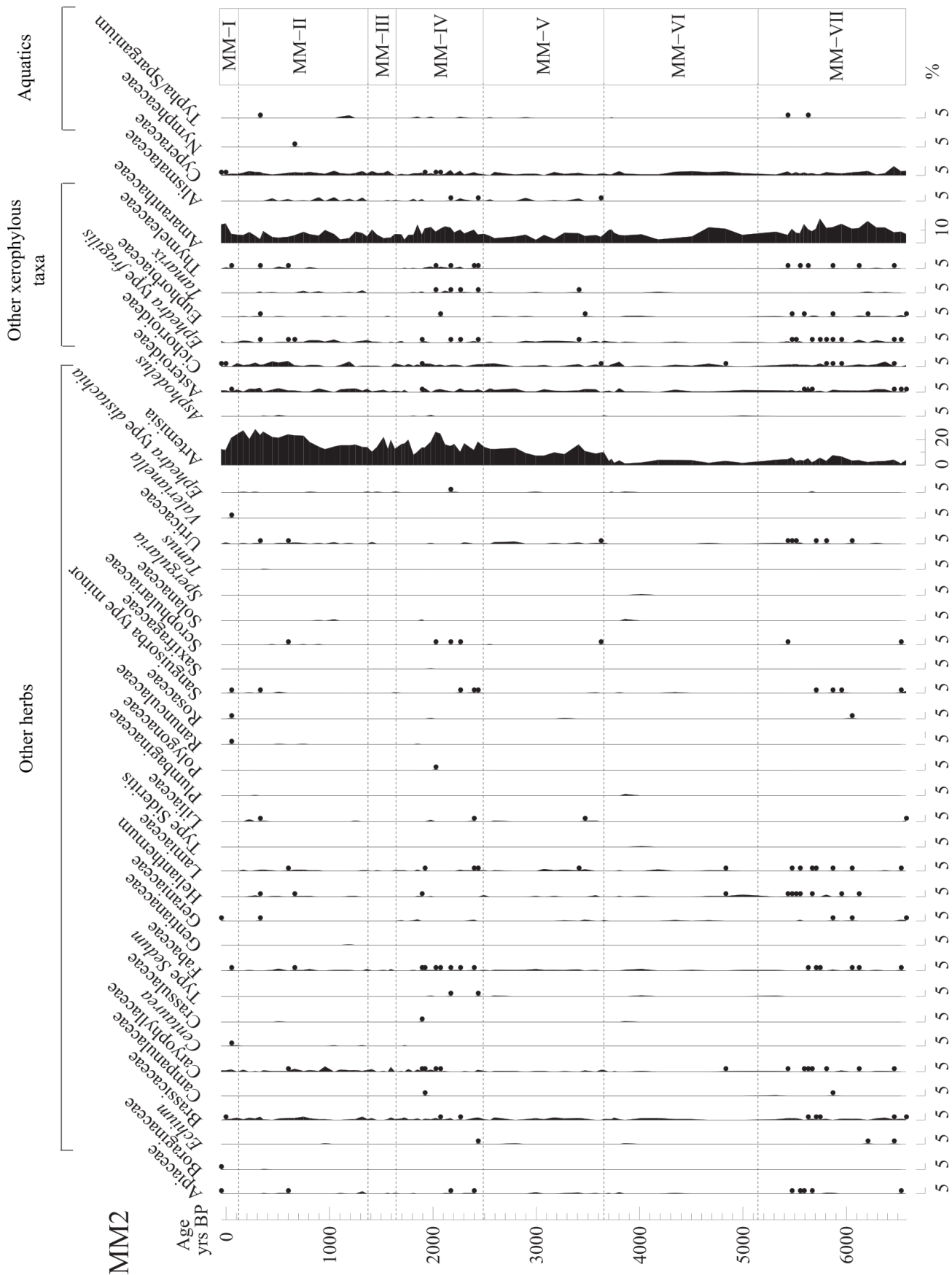


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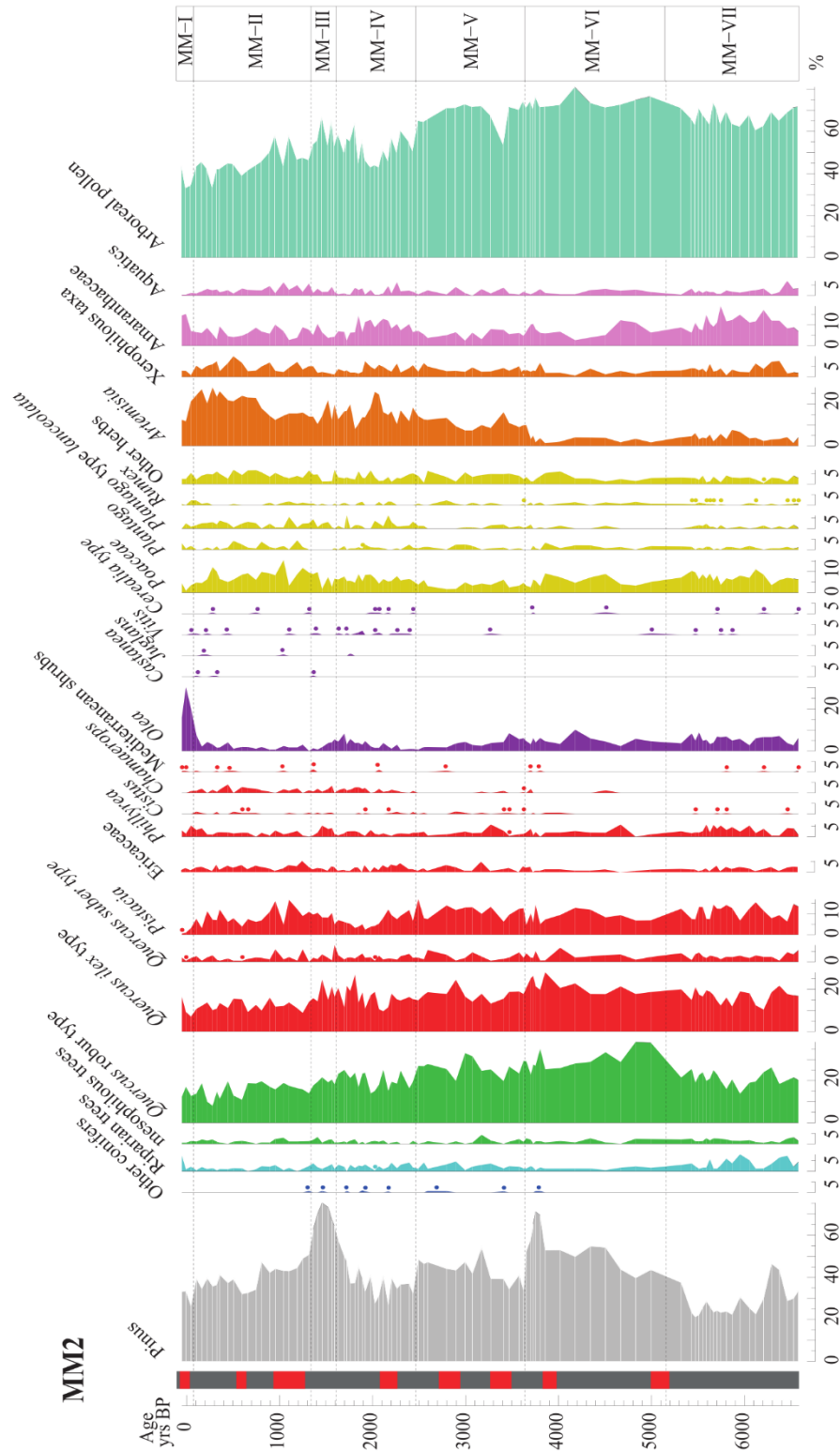
186 Figure 2a: Detailed pollen diagram of MM2 sequence (first part)

187  
188  
189

Figure b: Detailed pollen diagram of MM2 core (second part)







190

191 Figure 3 (color): Simplified pollen diagram of the Mar Menor sequence. On the left the stratigraphy is  
 192 represented in a simplified way (grey: clayey-silt levels, red: sandy levels of storm periods). Pollen taxa are  
 193 grouped according to their ecological affinities with grey/*Pinus*, light blue/riparian taxa, green/mesophilous  
 194 taxa, red/Mediterranean shrubs taxa, purple/cultivated taxa (*Olea* is included in this category even though it is  
 195 not widely cultivated in the region before the Classical antiquity, see discussion), yellow/herbaceous taxa,  
 196 orange/xerophilous taxa, pink purple aquatic and halophyte taxa.

197 **Results**

198 The Mar Menor pollen sequence consists of 93 samples forming a continuous series that covers the last 6600  
 199 years with an average timestep between two samples of 70 years (Figure 3). The preservation of pollen grains  
 200 is good with an average pollen concentration of 20 130 grains.g<sup>-1</sup>.

201 A total of 79 pollen taxa have been recorded all over the Mar Menor sequence. *Pinus* largely dominates most  
 202 of the spectra throughout the record, with proportions ranging from 20 to 75% (Figure 3). The composition of  
 203 the spectra calculated excluding *Pinus* shows a relatively balanced composition between trees and shrubs mainly  
 204 represented by *Quercus robur* type, *Quercus ilex* type, *Pistacia* and *Olea* on the one hand, and grasses mainly  
 205 represented by *Artemisia*, Poaceae and Amaranthaceae on the other hand (Figure 3). The automatic zonation of  
 206 the diagram using the CONISS (Grim 1987) and "Broken stick" (Bennet 1996) methods made it possible to  
 207 define seven significant zones for the Mar Menor sequence. Table 1 provides a brief description of each zone.

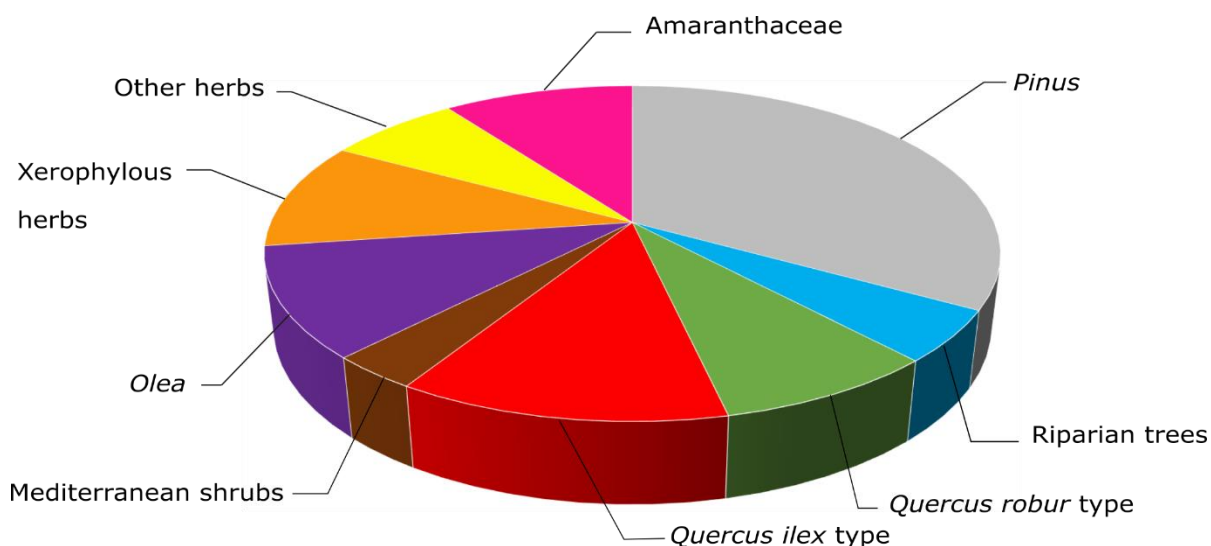
208 Table 1 : Description of the pollen zones of the diagram

Name	Depth (cm)	Dates (cal. BP)	Description
MM -VII	290-397	6580 - 5160	High arboreal pollen proportions, <i>Quercus robur</i> type (15-20 %), <i>Quercus ilex</i> type (15-20 %), <i>Pistacia</i> (7-15 %) and <i>Olea</i> (3-8 %) well represented, Amaranthaceae relatively abundant (~10 %).
MM -VI	215-290	5160 - 3640	<i>Pinus</i> increases from 40 to 70%, <i>Quercus robur</i> type (25-35 %) and <i>Q. ilex</i> type (~20 %) maxima, <i>Olea</i> and <i>Pistacia</i> (~5 %), <i>Artemisia</i> low proportions (>5%).
MM -V	152-215	3640 - 2460	<i>Artemisia</i> rises around 3650 years cal BP (x2), Poaceae low (<5%), arboreal pollen falls but no clear trends on individual taxa except for <i>Olea</i> .
MM -IV	98-152	2460 - 1710	Low <i>Pinus</i> proportions (~35 %), <i>Pistacia</i> fall (10→3 %), <i>Olea</i> rises (0.5→5 %)
MM-III	68-98	1710 - 1340	<i>Pinus</i> maximum (70-75 %), arboreal pollen and shrubs increases, <i>Olea</i> fall(8→1%).
MM-II	10-68	1340 - 80	<i>Pinus</i> increases from 60 to 40 % and <i>Artemisia</i> from 15 to 30 %), minimum arboreal pollen proportions (25-35%).
MM-I	0-10	80 - (-50)	<i>Olea</i> increases from 2 to 30 % followed by a decrease (-15%), <i>Quercus ilex</i> type increases from 7 to 15 % and <i>Artemisia</i> falls from 25 to 12 %.

209 **Discussion**

210 Origin of pollen inputs within the Mar Menor lagoon nowadays

211 The comparison of the present spectrum from the core top (Figure 4) with the vegetation of the Murcia region  
 212 allows us to discuss the origin of pollen inputs within the Mar Menor lagoon nowadays. Pines are the best  
 213 represented taxon in the spectrum with 33%. However, they are currently very abundant in the region (Aleppo  
 214 Pine up to 1500m altitude and Salzman Pine at higher altitudes) and are important pollen producers. This  
 215 percentage is therefore perfectly consistent with the regional vegetation and does not indicate an over-  
 216 representation of this taxon. Halophyte (Amaranthaceae) and riparian vegetations (*Salix* and *Fraxinus*) along  
 217 the lagoon and its tributaries represent only 15% of the spectrum. On the other hand, evergreen oaks,  
 218 Mediterranean shrubs, xerophilous herbs (mainly *Artemisia*) and other herbaceous plants (mainly Poaceae) from  
 219 the more or less open shrublands in the thermo and meso Mediterranean belts represent together 33% of the  
 220 spectrum (respectively 12, 3.5, 10.5 and 7%). The proportions of deciduous oak pollen from the distant forest  
 221 formations in the meso and supra-Mediterranean belt reach 8%. All these results suggest a regional, rather than  
 222 local vegetation record with mainly aerial pollen inputs. This is consistent with sedimentological analyses that  
 223 do not show any significant marine or fluvial influence at the end of the sequence and the very large size of the  
 224 lagoon, which theoretically implies a very large pollen source area (Sugita 2007, Azuara et al. 2019). The  
 225 agricultural areas that now cover almost the entire Campo de Cartagena are only visible through the presence  
 226 of *Olea* pollen, some of which probably also comes from wild olive trees. The dominant fruit and vegetable  
 227 crops are not recorded. Finally, the hottest and driest environments in the lower thermo-mediterranean region  
 228 are not recorded either. The most characteristic taxa of these environments, such as *Ziziphus lotus*, *Periploca*  
 229 *angustifolia* or *Maytenus senegalensis* subsp. *europaeus*, are absolutely absent in relation to their very low  
 230 pollen productivity (Carrión 2002a).



231  
 232 Figure 4 (color): Simplified present pollen spectrum of Mar Menor lagoon.

233

234

235 Influence of sedimentation on pollen record

236 Sedimentation changes must be controlled as they may impact the integrity of the pollen assemblages and the  
 237 reliability of the results in terms of vegetation changes. A very rapid increase in the proportions of *Quercus*  
 238 *robur* type (deciduous oaks) and *Pinus* pollen is recorded around 5400 years cal BP, followed by a gradual  
 239 decrease and then a sudden drop around 2400 years cal BP (Figure 3). However, during this interval, a clear  
 240 marine influence is precisely recorded by the faunal remains contained in the sediments (Dezileau et al. 2016).  
 241 It was around 5400 years BP that the sandy barrier separating the lagoon from the Mediterranean stabilizes  
 242 around its current position near the coring site. Then around 2400 years cal BP, communications between the  
 243 lagoon and the sea were interrupted. Consequently, the higher proportions of *Quercus robur* type and *Pinus*

244 between these two dates probably reflect enhanced marine influences and not vegetation changes. Indeed,  
245 marine pollen sequences from this part of the Mediterranean similarly display higher proportions of these two  
246 taxa compared with continental coastal sequences (Combourieu-Nebout et al. 2009, Fletcher et al. 2013). On  
247 the other hand, since the sedimentary environment remains stable during this period and pollen concentrations  
248 remain very high (10 000-35 000 grains.g<sup>-1</sup>), there is no reason to suspect that pollen data are not reliable.  
249 Moreover, an examination of the variations of the other taxa around 5400 and 2400 cal BP shows that only  
250 *Pinus* and *Quercus robur* type appear to be visibly affected by this bias. No other taxa show sudden and  
251 significant variations towards these dates (Figure 3).

252 The influence of marine storms on the pollen record was also controlled by plotting the position of sandy levels  
253 in the simplified pollen diagram (Figure 3). No anomalies related to storm levels are visible on any taxon.  
254 Detailed examination of the sequence does not show any sudden and recurrent variations in spectra that could  
255 be associated with these sedimentary events. Then, aside from the variations of *Quercus robur* type and *Pinus*  
256 proportions around 5400 and 2400 years cal BP, the other variations observed in the Mar Menor pollen sequence  
257 can therefore be related to vegetation changes and not to pollen taphonomic processes.

### 258 Climate influence on vegetation changes

259 The increasing aridity of the Mediterranean climate during the second part of the Holocene has been identified  
260 in many pollen sequences from south-eastern Spain. This increasing aridity is evident by gradual vegetation  
261 changes beginning between 6000-4500 years cal BP in several sites (Carrión et al. 2001, Jimenez-Moreno and  
262 Anderson 2012, Jiménez-Moreno et al. 2015, Ramos-Roman et al. 2016, 2018a, 2018b) as well as in the form  
263 of more brutal transitions at variable dates: around 5200 years BP at Siles (Carrión 2002b), around 5000 years  
264 cal BP at San Rafael (Pantaléon-Cano 2003), between 4000 and 4500 at Elx (Burjachs 2012) and finally around  
265 4000 years cal BP in Gador (Carrión et al. 2003). It might also have played a crucial role in major and very  
266 rapid vegetation transitions in the near Balearic Islands before any permanent human occupations between 5800  
267 and 4600 cal. BP (Burjachs et al. 2017).

268 In the Mar Menor sequence, between 5000 and 4200 years cal BP, the proportions of *Quercus robur* type  
269 (deciduous oaks) gradually decrease in favor of *Pinus* (pines) proportions which increase by more than 10%  
270 (Figure 3). Such substitution of deciduous oaks for pines is also observed in the Siles and Gador pollen  
271 sequences (Carrión 2002b, Carrión et al. 2003) (Figure 1). In these two sequences, the correlation between  
272 pollen, microcharcoals and *Pseudoschizaea*, a “non pollen palynomorph” (NPP) indicator of soil erosion and  
273 used as an aridity marker in this case, shows that this vegetation change is related to increasing aridity and  
274 increased fire frequency (Carrión 2002b, Carrión et al. 2003). However, since these last two proxies have not  
275 been studied in the Mar Menor sequence, it is difficult to address the causes of this partial substitution of  
276 deciduous oak for pines, especially since these variations lie within the time window of enhanced marine  
277 influence within the lagoon, leading to an obvious bias for these two taxa.

278 On the other hand, the proportions of *Artemisia* that were relatively low (<5%) at the beginning of the sequence  
279 suddenly rise to around 10% at ca. 3800 years cal BP and then keep rising to reach 20% (Figure 3). Such an  
280 increase reminds of the abrupt transitions registered in some regional sequences towards a more xerophytic  
281 vegetation (Carrión 2002b, Carrión et al. 2003), especially in the near coastal sequence of San Rafael (Figure  
282 1) where a similar increase in *Artemisia* is also recorded around 5000 years cal BP (Pantaléon-Cano 2003).  
283 However, the interpretation of this last vegetation change is rather unambiguous. The sudden increase in  
284 *Artemisia* observed in the Mar Menor sequence occurs 1000 years later than in the San Rafael sequence which  
285 is only 160 kilometers further south. Moreover, it is concomitant with major changes in the archeological  
286 records during the Bronze Age. Thus, in this specific case, *Artemisia* is more likely to record anthropogenic  
287 impact than climate changes. This hypothesis will be discussed later in further detail.

288 As with the long term aridification trend, the shorter-scale aridity crises observed in many pollen sequences in  
289 south-eastern Spain and the Balearic Islands (Carrión 2002b, Jiménez-Moreno et al. 2015, Burjachs et al. 2017,

290 Ramos-Roman et al. 2016, 2018a, 2018b) do not seem to have any obvious impact in the Mar Menor record.  
291 Indeed, none of these events seems to lead to a particular change in vegetation. However, this does not mean  
292 that the vegetation in the Mar Menor region did't respond to climate change. The absence in the pollen record  
293 of low pollen producing taxa from the driest environments of the lower thermo-Mediterranean level (*Maytena*,  
294 *Periploca*, *Ziziphus*,...) together with the ubiquity of pines and evergreen oaks in the Murcia region could explain  
295 the inability to extract a clear climatic signal. Other proxies such as NPPs or additional data analyses are needed  
296 to go further on these issues. Moreover, it is also possible that the impact of human activities was so great that  
297 it completely masks the effects of climate variability on vegetation. Thus, we will now compare the pollen  
298 record with the archeological and historical records.

### 299 Impact of human activities on vegetation

#### 300 *Neolithic period*

301 In the Murcia region, the Neolithic period begins more than 7500 years ago (mid 6th millennium BC) and ends  
302 around 5000 years cal BP (Martínez-Sánchez and San Nicolas-Del Toro 2003). The base of the Mar Menor  
303 sequence is dated around 6600 years cal BP. Thus, only the final part of the Neolithic is recorded. Between  
304 6600 and 5000 years cal BP, vegetation does not change significantly. Only an isolated peak of *Pinus*, *Quercus*  
305 *robur* type and *Quercus ilex* is observed around 6400 years cal BP (Figure 3). However, its position at the  
306 beginning of the sequence makes it difficult to interpret.

307 The presence of cereal pollen (*Cerealia* type) in three samples from this period is particularly remarkable, given  
308 the size of the lagoon and the low representation of this taxa throughout the sequence (Figure 3). These pollen  
309 grains certainly indicate the presence of cereal crops near the lagoon during the Neolithic period. Indeed, the  
310 very low representation of cultivated grasses in pollen records and the very large size of the lagoon make the  
311 *Cerealia* type one of the most tenuous pollen indicators of agriculture to be recorded in this type of context.  
312 This Neolithic cereal cultivation index is perfectly consistent with the archaeological record attesting to human  
313 occupation at the edge of the lagoon directly on the sandy barrier at that time, with the nearby site of Las  
314 Amoladeras reported to the final Neolithic (Garcia-Del Toro 1987).

315 Finally, four occurrences of *Vitis* pollen grains (grapevine) are recorded between 6000 and 5000 years cal BP,  
316 after that this taxon did not reappear regularly before Classical Antiquity (Figure 3). Since there is no  
317 archaeological evidence of grapevine cultivation in south-eastern Spain before the Iron Age (Precioso-Arevalo  
318 and Rivera Nuñez 2005), the *Vitis* pollen grains identified in Mar Menor in the late Neolithic most certainly  
319 comes from wild vines (*Vitis vinifera* subsp. *sylvestris*). However, the very arid conditions around the lagoon  
320 today do not allow the development of this species, which is found only further inland (Sanchez-Gomez et al.  
321 1998) and the *Vitis* pollen grains, like the *Cerealia* type, are generally poorly recorded in pollen sequences  
322 because vines are very poor pollen disperser (Turner and Brown 2004). Therefore, their identification in Mar  
323 Menor could suggest that wild grapevines were growing locally. It would imply that the climate at that time was  
324 sufficiently humid near the coast to allow wild grapevines to grow spontaneously, which is consistent with  
325 regional pollen data showing during that period the maximum development of mesophilic forests in the massifs  
326 (Carrión 2002b, Carrión et al. 2001, 2003, 2007). Moreover, human populations could also have favored its  
327 establishment near occupation sites by cultivation of vines which seeds morphology had not been influenced by  
328 domestication or simply by seed dispersal due to regular consumption as wild vines are zoochorous plants. Both  
329 hypothesis are plausible when considering the grapevine seeds found in archaeological contexts in several  
330 Neolithic sites in Catalonia and south-eastern Spain, which attests to early exploitation of wild grapevines in  
331 the Iberian Peninsula (Precioso-Arevalo and Rivera Nuñez 2005).

332

### *Chalcolithic period*

333 In the Murcia region, the first Chalcolithic occupations of "Los Millares" culture began around 5000 years cal  
334 BP (Garcia-Del Toro 1987). Apart from the decrease already mentioned in deciduous oaks in favor of pines, no  
335 other significant change in vegetation is visible during the Chalcolithic period (Figure 3). However, the  
336 Neolithic/Chalcolithic transition is difficult to study from Mar Menor sequence. Pollen spectra are biased around  
337 5400 years cal BP due to the stabilization of the sandy barrier inducing an increase in *Pinus* and *Quercus robur*  
338 type. In addition, the temporal resolution around 5000 years cal BP is low due to a storm level that does not  
339 allow an adequate sampling in this part of the core.

340 On the other hand, this absence of vegetation change during the Chalcolithic period in the Mar Menor sequence  
341 is not an isolated observation. The Baza pollen sequence, located about 200 km to the south in the Sierra de los  
342 Filabres (Figure 1), has also been compared in detail with a very extensive archaeological record (Carrión et al.  
343 2007). Examination of the Chalcolithic period shows a remarkably stable vegetation throughout this time period  
344 despite numerous and very well documented human occupations. Thus, it would appear that the Chalcolithic  
345 populations of south-eastern Spain have had a rather moderate or at least local impact on their environment  
346 which was therefore not recorded at the regional scale. It is also possible that the forest ecosystems of this period  
347 were resilient enough to absorb the disruptions induced by the activities of the Chalcolithic societies that had a  
348 profound impact on the regional archaeological record (Carrión et al. 2007).

349

### *The Bronze Age period*

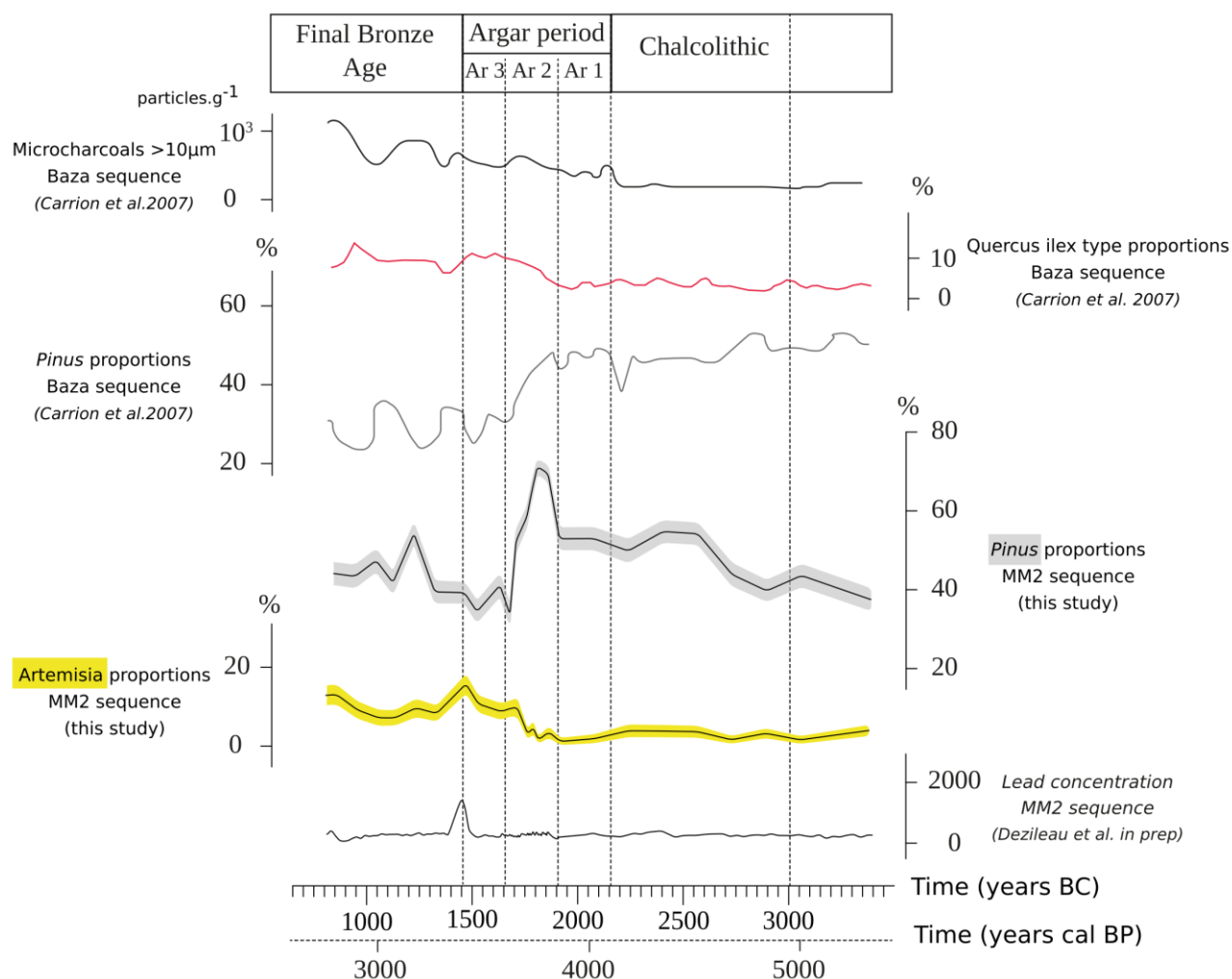
350 Between 3900 and 3700 years cal BP (1950-1750 BC) major vegetation changes occurred around the Mar  
351 Menor lagoon. First, the already high proportions of *Pinus* increased dramatically, from 50% to 70% in only  
352 100 years. This increase, which is not linked to any sedimentary events, indicates a significant expansion of  
353 pioneer vegetation at a regional scale and therefore reflects highly disturbed landscapes. Thereafter, *Pinus*  
354 proportions declined by 35% in about 200 years, followed shortly after by arboreal pollen proportions  
355 (excluding pines) that decreased by 15% indicating a major deforestation (Figure 5). Simultaneously, the general  
356 composition of herbaceous vegetation also changed dramatically. Poaceae (grasses), which previously ranged  
357 from 5 to 10%, became rarer while *Artemisia* increased by 2 to 10% (Figure 5). The study of the Sebkhia Boujmel  
358 pollen sequence located in sub-desert areas of Tunisia shows that such an increase in *Artemisia* proportions may  
359 correspond to a degradation of meadow environments related to pastoral activities (Jaouadi et al. 2016). Indeed,  
360 some *Artemisia* species, in particular *Artemisia campestris* which is very common in the Murcia region  
361 (Sanchez-Gomez et al. 1998), are not very palatable and therefore less consumed by livestock (Gamoun and  
362 Zammouri 2014). Thus, in some environments severely degraded by grazing, *Artemisia campestris* can  
363 proliferate to become very abundant (Genin et al. 2006).

364 All these vegetation changes occurred in a very short time, just after a major transition in the archaeological  
365 record, around 4200 years cal BP (2250 BC), between the Chalcolithic "Los Millares" culture and the Argar  
366 culture. The Argar culture characterizes the first part of the Bronze Age in the southeastern part of the Iberian  
367 Peninsula and occupies a very important place in the archaeological record of the Murcia region (Eiroa 2004).  
368 Comparison of pollen data with the precise chronology of the Argar period shows that almost all the vegetation  
369 changes mentioned above correspond very precisely to the Middle Argar period (Ar 2) between 3850 and 3600  
370 years cal BP (1900-1650 BC) (Eiroa 2004). This period corresponds to the political, cultural and economic  
371 zenith of this culture. This is the period during which large sites became individualized, particularly important  
372 defensive bastions. At that time, the diversity of the occupied environments was the most important (Eiroa  
373 2004). In the Late Argar between 3600 and 3400 cal. BP (1650-1450 BC, Ar 3), *Pinus* proportions stopped  
374 falling and those of *Artemisia* stabilized. Only the arboreal pollen proportions of trees (excluding pines) that  
375 have been fairly stable so far, fell in turn.

376 The pollen sequence of Baza in Andalusia also shows a very marked impact of human activities on vegetation  
377 during the Argar period, with exactly the same rate as in Mar Menor (Figure 5). Vegetation remained stable

378 during the Early Argar between 4100 and 3850 years cal BP (2150-1900 BC, Ar 1), despite a slight increase in  
 379 the fire signal. Very rapid deforestation and development of sclerophyllous vegetation occurred during the  
 380 Middle Argar (Ar 2), then finally vegetation stabilized in a degraded state in the Late Argar (Ar 3) (Carrion et  
 381 al. 2007).

382 Finally, the lead concentration in lagoon sediments increased for the very first time in the sequence at the end  
 383 of Late Argar around 1500-1400 BC (Figure 5). This lead pollution strongly supports the presumptions of  
 384 mining and metallurgical activities suggested by the archaeological corpus for this period (Eiroa 2004) and is  
 385 consistent with previous studies on lead pollution in this area (Manteca et al. 2017). Figure 5



386 Figure 5 (color): Comparison of Mar Menor pollen data with lead concentration in MM2 core (Dezileau et al.  
 387 in prep), and with pollen and microcharcoal data from the Baza sequence (Carrion et al. 2007) for the Argar  
 388 period. The shaded areas around the pollen curves of Mar Menor represent the theoretical uncertainty of pollen  
 389 proportions computed from a multi-nomial law (Faegri and Iversen 1989).

390 After the Argar period began the final Bronze Age period around 3400 years cal BP (1450 BC). The Mar Menor  
 391 sequence shows a moderate increase of the proportions of *Pinus* and arboreal pollen (Figure 5). However,  
 392 Mediterranean shrubs were more abundant and the proportions of *Artemisia* remained high. These observations  
 393 suggest a moderate recovery of vegetation after the major changes of the Argar period. The presence of final  
 394 Bronze Age sites in the region suggests that there was some continuity in anthropogenic pressure on the  
 395 environments that would explain the persistence of such degraded environments. On the other hand, since  
 396 *Artemisia* and Mediterranean shrubs are taxa of rather xerophyte affinity, it is also possible that they were also

397 favoured by the increasing aridity during the second half of the Holocene. While the close coincidence between  
398 environmental degradation in the region and the development of Argar culture strongly supports a human trigger  
399 for this radical change, it cannot be ruled out that a change in climate may have been decisive in maintaining  
400 this new degraded vegetation, which is probably better adapted to frequent disturbances, regardless of their  
401 origin.

#### 402 *Iron Age period*

403 The exploitation of the mining resources of the Cartagena-La Union massif during the Iberian Period (Domergue  
404 1990), is well visible in the Mar Menor sequence through the rapidly increasing lead concentration in lagoon  
405 sediments between the beginning of the 5<sup>th</sup> century and the settlement of Carthaginians (227 BC) (Figure 6).  
406 Unfortunately, the vegetation of this key period is difficult to study due to the closure of the lagoon at about the  
407 same time, which biases the pollen record. Nevertheless, from 3500 years cal BP, the proportions of *Olea* which  
408 were relatively stable around 5% since the beginning of the sequence, gradually declined to near zero around  
409 2400 years cal BP and only reappeared during the Classical Antiquity (Figure 3). This decrease certainly  
410 indicates a progressive scarcity of wild olive trees (*Olea europea* subsp. *sylvestris*) in thermo-Mediterranean  
411 shrub formations. This near disappearance of the wild olive tree coincides with the beginning of the regular  
412 occurrences of *Chamaerops* pollen grains (dwarf palm) which until then had only been represented very  
413 episodically (Figure 3). This substitution shows a late change in the composition of shrub formations that seems  
414 difficult to explain from a climatic point of view. *Chamaerops humilis*, the dwarf palm, may be abundant in  
415 some of the more thermophilic formations of the lower thermo-Mediterranean region. However, it is mainly  
416 found in the same environments as the wild olive tree in the Murcia region ([Martinez-Parras et al. 1992](#)).  
417 Ecological studies conducted in south-eastern Spain have shown that wild olive trees are extremely sensitive to  
418 grazing and that their disappearance could be an indicator of disturbance by pastoral activities (Alados et al.  
419 2004, Navarro et al. 2006). The same studies also show that on the contrary, the dwarf palm is particularly  
420 resistant to moderate grazing pressure. Therefore, it seems likely that the observed change in the composition  
421 of shrub formations resulted from degradation of these environments by pastoral activities.

#### 422 *Classical Antiquity*

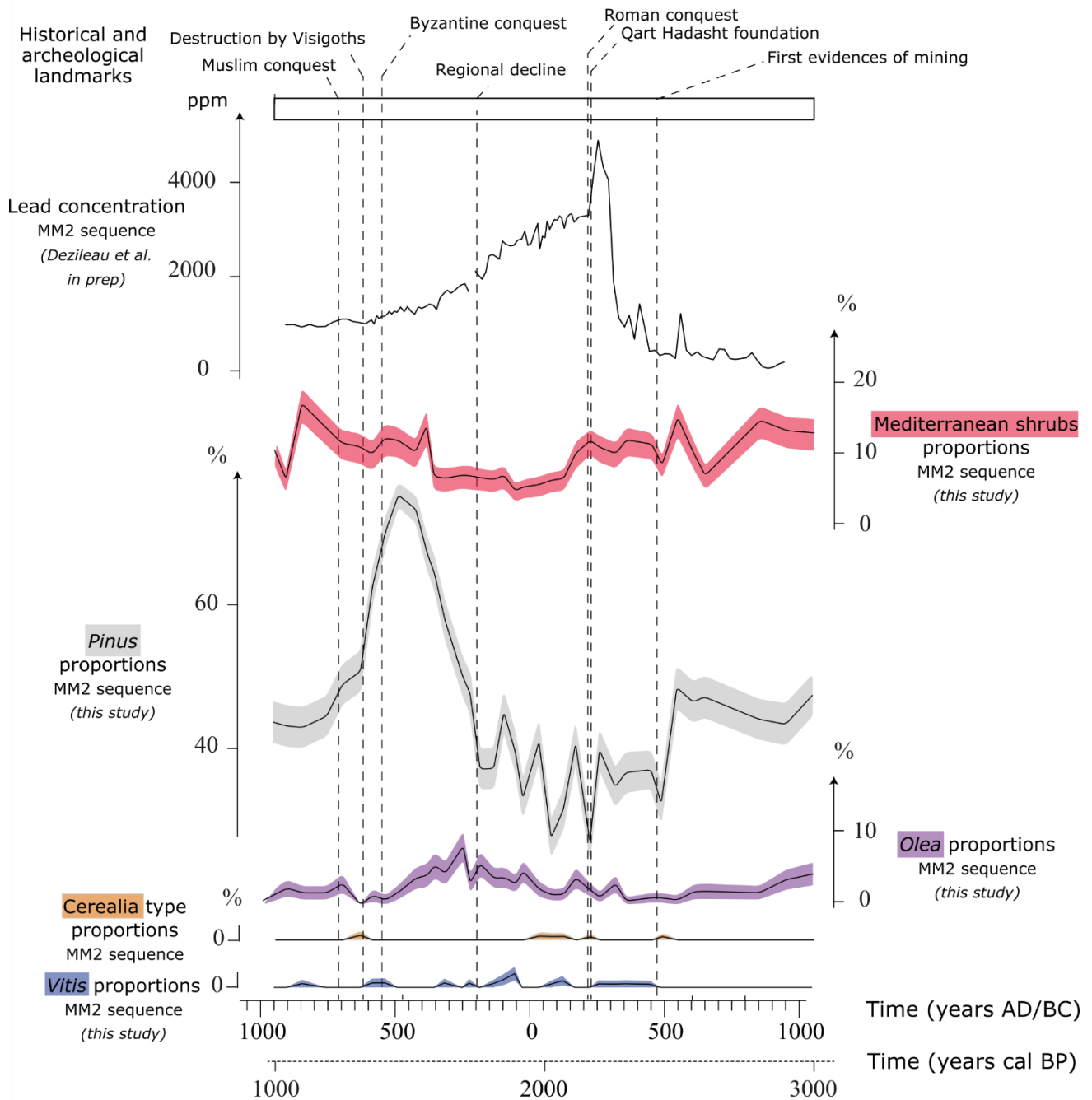
423 The Roman conquest at the end of the third Century BC (~2150 cal. BP), the exploitation of silver and lead  
424 mines and the very important agricultural development of this period are perfectly visible in the Mar Menor  
425 sequence. From the end of the Iberian period in the middle of the 4<sup>th</sup> Century BC (2300 cal. BP), *Olea* which  
426 had almost disappeared from the pollen sequence previously, is recorded again (Figure 6). After the  
427 Carthaginian and Roman conquests, its proportions increased steadily until reaching values close to 10% in the  
428 3<sup>rd</sup> Century AD (1750 cal. BP) (Figure 5). In this context, and considering the historical evidence, it is reasonable  
429 to assume that this increase in *Olea* proportions corresponds to the major development of olive growing, which  
430 has been very well documented by historians and archaeologists in this region (Orejas and Ramallo 2004,  
431 Noguera Celdrà and Antolinos Marin 2009, 2010). At the same time, *Vitis* and *Cerealia* type were well  
432 represented throughout this period (Figure 6) considering the size of the lagoon.

433 Mining, on the other hand, resulted in a peak in lead concentration which could coincide with the founding of  
434 the city of Qart Hadasht (future *Carthago Nova*) by the Carthaginians followed by the Roman conquest after  
435 few decades, if age model errors are taking into account. Then lead concentrations remain high between the  
436 Roman conquest and the 2<sup>nd</sup> Century AD (Figure 6). From an archaeological point of view, the exploitation of  
437 the galena deposits of Cartagena by the Carthaginian first and then the Romans was of such a magnitude that it  
438 has masked until a relative recent period any trace of previous exploitation. During the Republican era and then  
439 at the very beginning of the Imperial period, Carthago Nova mines were at their height. They were one of the  
440 largest producer of silver and lead in the Roman world. In the middle of the 2<sup>nd</sup> Century BC, the historian  
441 Polybe mentioned more than 40,000 workers mobilized for ore extraction (Baron et al. 2017).



442 The pollen data allow the assessment of the impact on the vegetation of this unprecedented economic  
443 development. The pollen proportions of Mediterranean shrubs, particularly *Pistacia*, declined sharply from the  
444 Roman period onwards, clearly showing a very marked decline in shrubland formations. On the other hand, the  
445 main tree taxa, in particular *Pinus*, *Quercus robur* type (deciduous oaks) and *Quercus ilex* type (Mediterranean  
446 oaks), appear to be slightly affected. They display proportions equivalent to those observed at the end of the  
447 Neolithic period (Figure 3 and 4). These elements suggest that the important development of agriculture and  
448 mining activities around Carthago Noua has been to the detriment of the shrublands of the Thermo-  
449 Mediterranean belt rather than that of the Meso-Mediterranean forests. An examination of the distribution of  
450 Roman sites from the Republican and Early Imperial periods seems to confirm this observation. The listed  
451 archeological sites are mainly distributed in Thermo-Mediterranean plains, such as the Campo de Cartagena,  
452 the Segura and Guadalentin valleys and coastal reliefs of Carthagena-la Union and Mazarron at altitudes of less  
453 than 500 m (Orejas and Sanchez-Palencia 2002).

454 From the second Century AD, the lead concentration in the sediments of the lagoon decreased until it returned  
455 to very low values. This decrease in lead pollution was followed by a gradual decrease in *Olea* proportions and  
456 an unprecedented increase in *Pinus* proportion from 40 to about 80% at the beginning of the third Century.  
457 These changes indicate a significant industrial and agricultural decline in the region (Figure 6) which is perfectly  
458 consistent with the historical and archaeological records that document the decline of mining and agricultural  
459 activities respectively from the 2<sup>nd</sup> and 3<sup>rd</sup> Centuries AD. Many of the agricultural settlements related to the  
460 beginning of the Roman Empire declined and disappeared at this time (Orejas and Ramallo 2004). These  
461 abandonments particularly affected the establishments closest to the city and therefore concerned the immediate  
462 surroundings of the lagoon. Further inland in the Guadalentin Valley or the Jumilla Highlands, the rural  
463 economy was more resilient and some sites still experienced a long period of prosperity. However, even in these  
464 relatively preserved regions, agricultural activities were undergoing significant changes, including a decline in  
465 olive growing that was probably no longer profitable in the new economic context (Noguera-Celdrà and  
466 Antolinos-Marin 2009, 2010).



467

468 Figure 6 (color): Comparison of Mar Menor pollen data with lead concentrations in lagoon sediments and  
 469 with the main historical events affecting the region for the protohistoric, Classical Antiquity and early Middle  
 470 Ages. The shaded areas around the pollen curves of Mar Menor represent the theoretical uncertainty of pollen  
 471 proportions computed from a multi-nomial law (Faegri and Iversen 1989).

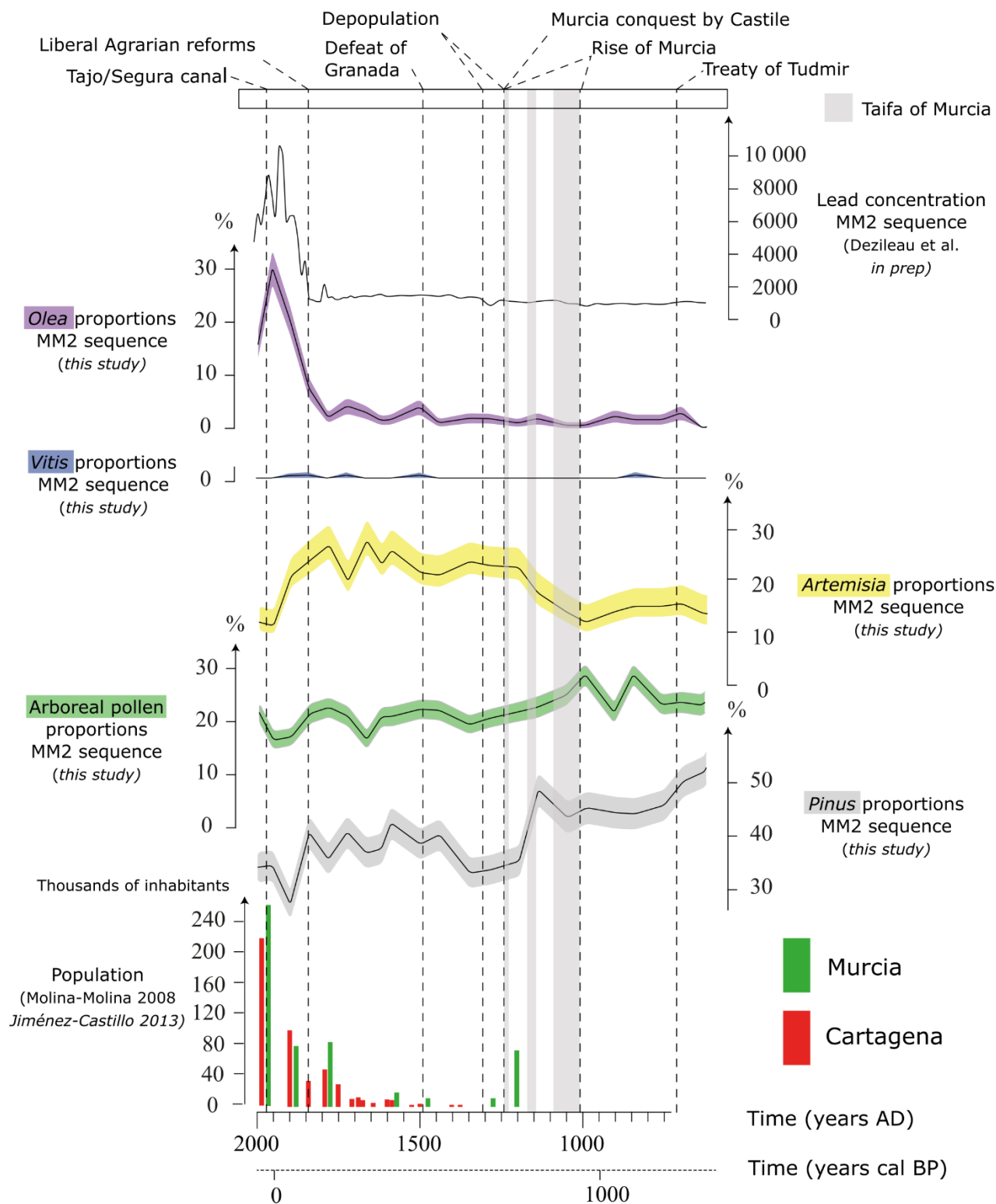
472 The increase in *Pinus* proportion characterizing this economic decline is quite extraordinary. It certainly reflects  
 473 a rapid recolonization by *Pinus halepensis* (Aleppo pine) of all the abandoned land following this decline. This  
 474 pioneer species, which is very well adapted to the Mediterranean summer drought, is heliophilous, disperses its  
 475 seeds very efficiently and has a high growth rate (Rameau 2008). In fact, *Pinus halepensis* is one of the main  
 476 pioneering trees in the Murcia region where it forms large stands in degraded shrublands from sea level to an  
 477 altitude of 1500m (Sanchez-Gomez 1998). Agricultural and mining activities in the early Roman period mainly  
 478 affected low-altitude Thermo-Mediterranean shrublands. In addition, the economic decline was particularly  
 479 significant in the coastal massifs and the Campo de Cartagena, in other words, as close as possible to the lagoon.

480 Consequently, the degraded shrub formations, favorable to the development of pine forests, must have been  
481 very abundant in the surroundings of Mar Menor from the 3rd Century AD, which would explain this spectacular  
482 recolonization. Pines are also very important pollen producers, so it is consistent that this change in vegetation  
483 appears clearly in the pollen record.

484 The *Pinus* proportions continued to increase until the middle of the 5<sup>th</sup> Century AD and only then started to  
485 decrease marking the beginning of the decline of pine formations (Figure 6). This decline in *Pinus* proportions  
486 coincided with a renewal of the city of Cartagena and a period of economic recovery (Molina Molina 2008). It  
487 is therefore possible that this led to a new period of deforestation. However, it is also during this period that  
488 Mediterranean shrub formations, which were at their lowest since the Roman conquest, increased again to return  
489 to their previous values (Figure 6). The closure of the landscape due to the redevelopment of shrublands  
490 probably led to the disappearance of environments favorable to the germination of the heliophilous *Pinus*  
491 *halepensis* (Rameau 2008), thus explaining its decline. Furthermore, it must be considered that after the 5th  
492 Century AD, the rural economy in the Cartagena region entered again into recession while the accelerated  
493 decline of pine forests continued until the 7th Century AD, after the destruction of the city by the Visigoths  
494 (Figure 6). These elements rather support the hypothesis of a natural regression of pines in the context of an  
495 ecological succession rather than a new deforestation. These observations therefore provide important  
496 information on the resilience of Mediterranean shrub ecosystems, in particular the time required for their  
497 regeneration. In that case, pollen data show that it takes about 100 years for Mediterranean shrublands to return  
498 to their optimum development, and another 200 years for pioneer pines to disappear from the environments they  
499 colonized, as they cannot regenerate (Figure 6). This is consistent with the life expectancy of *Pinus halepensis*,  
500 which is about 200 years (Rameau et al. 2008).

#### 501 *The Muslim period*

502 For the Muslim period (713-1245 AD), the pollen record from Mar Menor seems to be divided in two parts.  
503 Between the 8th and 10th Centuries AD, vegetation remained relatively stable around a composition close to  
504 that of the pre-Roman period with slightly higher proportions of *Pinus* and arboreal pollen (Figure 7). This is  
505 consistent with a moderate impact of human activities on vegetation, reflecting the relatively modest  
506 development of the region according to historical sources during that period. Indeed, despite the foundation of  
507 the city of Murcia by the Umayyads in 825 AD, the region remained poorly urbanized and populated mainly by  
508 the descendants of pre-Muslim populations (Jiménez-Castillo 2013). In contrast, in the 11th and 12th Centuries  
509 AD, the proportions of *Pinus* and arboreal pollen (excluding pine) fell rapidly while the proportions of *Artemisia*  
510 increased from 10 to 20% (Figure 7). This vegetation change probably reflects a deforestation, mainly affecting  
511 shrublands and pine forests, as well as a degradation of open environments, due to pastoralism as suggested by  
512 the increase in *Artemisia* at the expense of Poaceae (Genin et al. 2006, Gamoun 2014). It corresponds very  
513 precisely to the period of economic prosperity and demographic growth of the city of Murcia and its  
514 surroundings. Indeed, at that time, Al-Andalus (Muslim Spain) experienced an alternation of centralizing  
515 periods under the domination of the Almoravids (1091-1144 AD) then the Almohads (1172-1224 AD),  
516 interspersed with periods of break-up into many small independent kingdoms, the Taifas. Murcia and its  
517 surroundings considerably developed, especially during the periods of independence of the city (Jiménez-  
518 Castillo 2013). In the 11th and 12th Centuries AD, a vast and very complex irrigation network developed around  
519 the city of Murcia in the valley of the Segura River, the "Huerta de Murcia". It allowed the development of a  
520 diversified and intensive agriculture in a relatively large area (Jiménez-Castillo 2013). Further south, in the  
521 Campo de Cartagena, a more extensive agriculture was developing in the absence of irrigation systems. Water  
522 reservoirs, wells and facilities to take advantage of irregular ramblas inflows were built to partially compensate  
523 for the aridity of this plain. However, most of this area was more likely to be under non-irrigated and livestock  
524 cultivation (Jiménez-Castillo 2013).



525  
 526 Figure 7 (color): Comparison of pollen data from the Mar Menor sequence with the lead concentration of  
 527 lagoon sediments and with population data for the cities of Murcia and Cartagena from the 13<sup>th</sup> and 15<sup>th</sup>  
 528 centuries respectively to the modern period. The shaded areas around the pollen curves of Mar Menor  
 529 represent the theoretical uncertainty of pollen proportions computed from a multi-nomial law (Faegri and  
 530 Iversen 1989).  
 531

532

*Late Middle Ages and Early Modern Period*

533 From the middle of the 13<sup>th</sup> Century to the 19<sup>th</sup> Century, the proportions of *Pinus* and Arboreal pollen (excluding  
 534 pines) remained low, while *Artemisia* proportions stabilized around very high values (20-25%) (Figure 7). The  
 535 pollen record does not show any reforestation or vegetation recovery, even though the region was losing a large  
 536 part of its inhabitants (Figure 7). Indeed, the Murcia region was experiencing a major and lasting crisis. The  
 537 middle of the 13<sup>th</sup> Century marked the end of Muslim domination in this region, and in 1243 the city of Murcia  
 538 became a Castilian protectorate. After that, the harshly repressed revolt of the Muslim populations in 1264, the  
 539 internal wars within the Christian camp, and the resistance of the kingdom of Granada against Christians (which  
 540 turned the Murcia region into a border zone) led to episodes of mass exodus one after the other and gradually  
 541 emptied the area of its inhabitants (Jiménez-Castillo 2013). During the second half of the 13<sup>th</sup> Century, the  
 542 population of the city of Murcia decreased from 70,000 to 10,000 inhabitants (Manzano- Martínez 2002). This  
 543 general depopulation particularly affected the coast, which was regularly threatened by raids of Barbary  
 544 privateers (Torres-Fontes 1976, Molina-Molina 2008). However, historical data show that these neglected  
 545 territories were not completely abandoned (Lillo 1981, Eiroa 1986, Pérez-Ruzafa et al. 1987). A highly  
 546 specialized regional economy almost exclusively oriented towards extensive livestock farming developed,  
 547 explaining the low *Pinus* and arboreal pollen proportions coinciding with the high proportions of *Artemisia*.  
 548 Moreover, at the very end of the 15<sup>th</sup> Century AD, after the fall of the kingdom of Granada, the large and  
 549 powerful herd owners who had prospered for the last 200 years influenced the councils in charge of land  
 550 redistribution after the end of the Christian conquest in order to protect their interests (Molina-Molina and  
 551 Jiménez Alcazar 1996). Therefore, the region remained occupied by vast areas of pasture until the 19<sup>th</sup> Century,  
 552 which is consistent with the pollen data showing the highest *Artemisia* proportions of the sequence (20-30%).

553

*The Late Modern Period*

554 From the 19<sup>th</sup> Century onwards, the proportions of *Olea* increased dramatically (from around 5 to 30%) while  
 555 the proportions of *Artemisia* were divided by two and the proportions of *Pinus* and arboreal pollen also  
 556 decreased (Figure 7). These vegetation changes at the regional scale were linked to profound changes in the  
 557 economy of the Murcia region. Political reforms (liberal agrarian reforms) put an end to the extensive livestock  
 558 farming that had been going on since the 13<sup>th</sup> Century. It gave way to pig and goat farms with a much more  
 559 limited territorial hold, while non-irrigated agriculture, with cereals, vines, olives, almonds, figs and carob trees,  
 560 was invading the territory (Pérez-Picazo and Lemeunier 1990). The 19<sup>th</sup> Century AD was also the period of  
 561 resumption of mining activities around Cartagena, which saw its population explode (Vilar et al. 1985) (Figure  
 562 7). In 1907 AD, 1151 mining concessions were exploited in the Cartagena-La Union massif (Baron et al 2017).  
 563 This new mining activity is perfectly recorded by the evolution of the lead concentration in the sediments of the  
 564 lagoon (Figure 7). It is probably one of the main causes of deforestation highlighted by the decline in *Pinus* and  
 565 arboreal pollen proportions (excluding pines) (Figure 7). Indeed, agricultural development during this period  
 566 was essentially the result of a transformation of activities on land already in use and probably had little impact  
 567 on this clearing (Pérez-Picazo and Lemeunier 1990).

568 Finally, the *Olea* proportions are divided by two at the end of the Mar Menor sequence during the second half  
 569 of the 20<sup>th</sup> Century. This final drop in *Olea* proportions corresponds to the development of intensive agriculture  
 570 which began in the 1950s and accelerated greatly in the 1980s after the construction of the Tajo-Segura canal.  
 571 Olive, almond and cereal crops then declined sharply in favour of fruit trees and market gardening (Pérez-Picazo  
 572 and Lemeunier 1990).

**573 Conclusion**

574 The MM2 core from the Mar Menor lagoon in the Murcia region has provided a high-resolution pollen record  
 575 covering the last 6500 years. Some elements in the sequence could suggest an influence of climate fluctuations  
 576 on the vegetation; yet their interpretation remains ambiguous. Such difficulties in recording a climate signal  
 577 could be related to the low representation of the driest environments of the Thermo-Mediterranean belt and/or

578 to the ubiquity of pines and evergreen oaks in the Murcia region together with the very important impact of  
579 human activities on the vegetation. Further work including complementary proxies and finer data analysis will  
580 have to be investigated to better address this issue. On the other hand, the comparison with archaeological and  
581 historical records makes it possible to highlight a vegetation history strongly linked to human occupations. The  
582 Argar period in the Bronze Age, the Classical Antiquity and finally the Modern Period are the three key  
583 archaeological and historical periods of this sequence in terms of human impact. *Pinus* (probably *Pinus*  
584 *halepensis*) is the pollen taxon which best records this signal of anthropogenic impact. Pines have been a major  
585 component of the ecosystem of the Murcia region for at least 6500 years, and appear to have been extremely  
586 sensitive to land-use changes. The Mar Menor sequence provides very interesting elements to investigate the  
587 resilience of semi-arid ecosystems to anthropogenic disturbances. Interdisciplinary approaches combining the  
588 comparison of the observed vegetation dynamics with detailed archeological and historical data and results of  
589 ecosystems modeling could be of great interest to better understand the mechanisms involved in these vegetation  
590 changes.

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596

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## Appendix 1

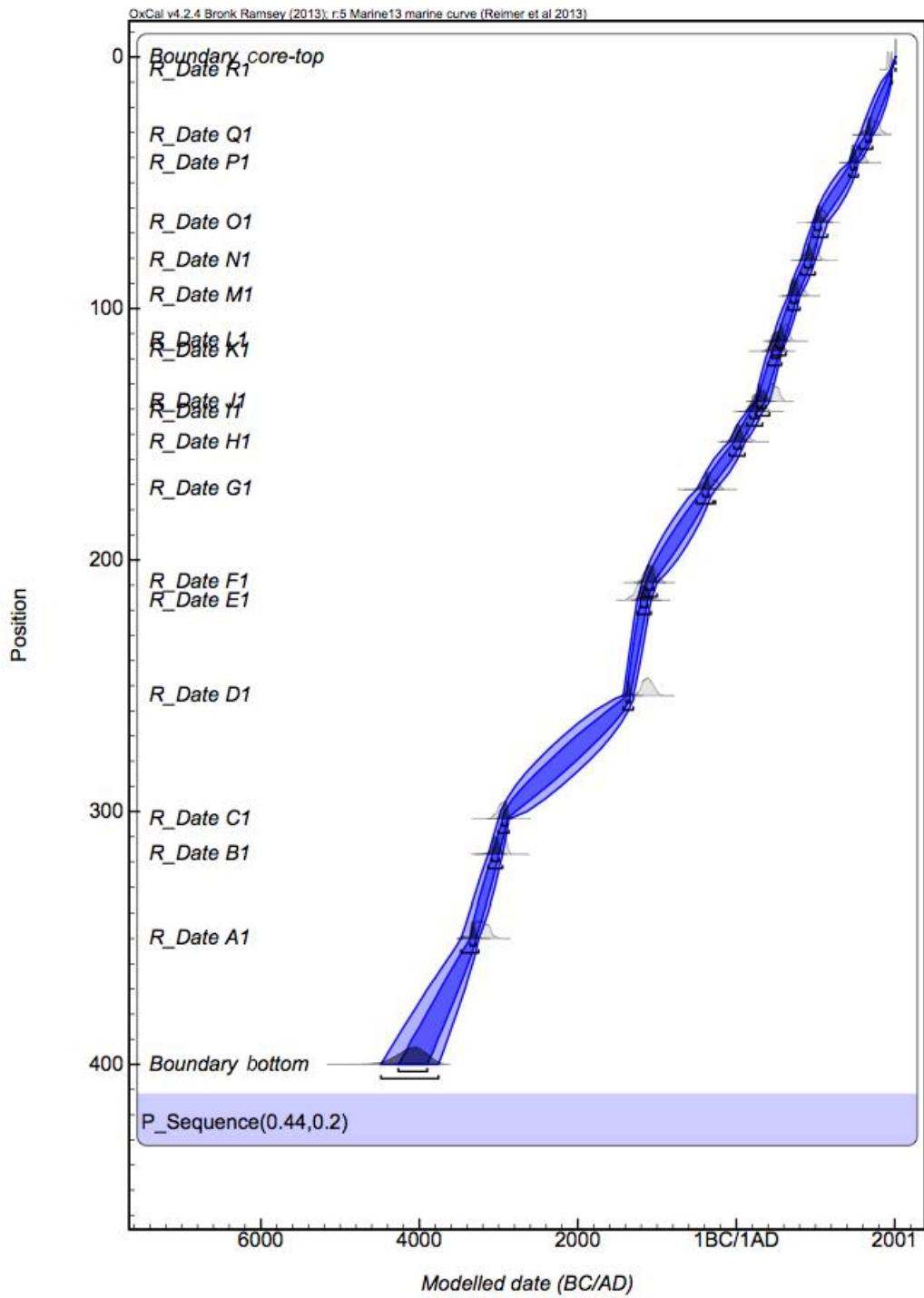


Figure A: Age model of MM2 core from Mar Menor lagoon (Dezileau et al. 2016)

<b>Samples</b>	<b>depth (cm)</b>	<b>14C Age</b>
<b>MM2A005</b>	<b>5</b>	<b>500 ±30</b>
<b>MM2A031</b>	<b>31</b>	<b>1190 ±30</b>
<b>MM2A-42</b>	<b>42</b>	<b>1395 ±30</b>
<b>MM2A066</b>	<b>66</b>	<b>1950 ±30</b>
<b>MM2A-81</b>	<b>81</b>	<b>2025 ±30</b>
<b>MM2A095</b>	<b>95</b>	<b>2230 ±30</b>
<b>MM2A113</b>	<b>113</b>	<b>2395 ±31</b>
<b>MM2A-117</b>	<b>117</b>	<b>2520 ±30</b>
<b>MM2A137</b>	<b>137</b>	<b>2545 ±30</b>
<b>MM2A-141</b>	<b>141</b>	<b>2710 ±30</b>
<b>MM2A-153</b>	<b>153</b>	<b>2875 ±30</b>
<b>MM2A172</b>	<b>172</b>	<b>3210 ±32</b>
<b>MM2B-09</b>	<b>209</b>	<b>3835 ±30</b>
<b>MM2B016</b>	<b>216</b>	<b>3930 ±30</b>
<b>MM2B103</b>	<b>303</b>	<b>5290 ±34</b>
<b>MM2B-117</b>	<b>317</b>	<b>5300 ±30</b>
<b>MM2B150</b>	<b>350</b>	<b>5470 ±35</b>

Table I : Radiocarbon dates along the MM2 core reported with a 1 $\sigma$  uncertainty