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1 **Reassessment of amber-bearing deposits of Provence, southeastern France**

2 **Revue des sites à ambres de Provence, sud-est de la France**

3

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24 Abstract - The presence of “geological” amber (or “succin” in old French monographs) has  
25 been reported for several centuries in the Mesozoic deposits of Provence, southeastern France.

26 Diverse amber-bearing sites were inventoried by the authors but their location and  
27 stratigraphical context remain unclear for most of them. In the past decades, various data  
28 concerning chemistry, palaeontological content and comparison with archaeological  
29 discoveries improved our knowledge of the ambers of Provence, but only those of Cretaceous  
30 age. The present paper aims at providing a comprehensive description of all the presently  
31 known amber-bearing deposits of Provence, including the description of new sites. We  
32 highlight the great potential of Provence ambers and allow to consider a wider time range, from  
33 the Early Cretaceous to the Miocene.

34

35 Key Words : Amber, geology, Cretaceous, Oligocene, Miocene, Provence, southeastern  
36 France

37

38 Résumé – La présence d’ambre « géologique » ou « succin » a été signalée en Provence depuis  
39 plusieurs siècles. Un certain nombre de gisements ambrifères crétacés, plus ou moins bien  
40 localisés précisément, avaient été ainsi répertoriés. Plus récemment des données variées  
41 concernant la chimie, le contenu paléontologique, la comparaison avec des ambres  
42 archéologiques ont amené à mieux connaître les ambres, uniquement d’âge crétacé, de la région.  
43 La présente revue des gisements ambrifères de Provence, incluant la découverte de nouveaux  
44 sites ambrifères, permet de mettre en évidence le potentiel en ambre de la Provence et  
45 d’envisager un large éventail de temps jusqu’à présent inenvisagé allant du Crétacé inférieur au  
46 Miocène.

47

48 Mots-clés : Ambre, géologie, Crétacé, Oligocène, Miocène, Sud-Ouest de la France,

49

50 **1 Introduction**

51 The nature of amber - or “succin” *in litt.* - was the subject of diverse observations and  
52 theories in the first French dictionaries as early as the 17th century (Saint Martin and Saint  
53 Martin, 2020, this volume). In those dictionaries, the knowledge of amber is limited to that of  
54 the Baltic and the amber-bearing sites of France are not mentioned.

55 The first mentions and/or the description of geographical sites providing amber in France  
56 date back from the middle of the 18th century (Anonymous 1742; Daubenton, 1751; Lavoisier,  
57 1765; Papon, 1776). In these works, the presence of amber in Provence is reported with  
58 somewhat imprecise locations and with respect to the geological knowledge at this time.

59 In the 19th century, various treaties, dictionaries and encyclopedias also mentioned amber,  
60 often referred to as succin, in Provence (Buffon, 1802; Brongniart, 1807; Chaptal, 1807; de  
61 Dree, 1811; Amione, 1813; Patrin, 1819; Cuvier and Brongniart, 1822; Brongniart, 1823, 1827;  
62 Beudant, 1829; Gras, 1862; Meunier, 1885; Vasseur, 1894). The presence of amber is usually  
63 associated with mined lignite deposits. Rare works were fully devoted to amber (Graffenauer  
64 1821; de Cessac, 1874) evoking, among others, some sites in Provence. Only the work of  
65 Bonnemère (1886) is focused on Provence. Other reports of amber are given through regional  
66 geological or stratigraphical studies (see below in the description of the deposits). An inventory  
67 of French amber occurrences was subsequently made by Lacroix (1910) in his treatise on  
68 mineralogy of France.

69 In the past decades, the Lacroix’s treatise proves useful for scientists as exemplified by the  
70 growing body of studies on French ambers which appeared in the past decade. Several synthetic  
71 studies (Nel *et al.*, 2004; Perrichot *et al.*, 2007b; Perrichot *et al.*, 2014) provided a review of the  
72 insect inclusions in the French Cretaceous, in which some sites of Provence are listed. Many  
73 authors have paid special attention to the Provence ambers. Several works aimed at analyzing  
74 the physico-chemical characteristics of those amber (Saskevitch and Popkova, 1978; Guiliano  
75 *et al.*, 2006; Onoratini *et al.*, 2009a, 2009b; Ragazzi *et al.*, 2009; Nohra *et al.*, 2015), and at

76 clarifying the relationships between geological and archaeological ambers of Provence. Other  
77 studies have focused on macroinclusions (mainly arthropods : Nguyen Duy-Jacquemin and  
78 Azar, 2004; Perrichot *et al.*, 2006; Choufani *et al.*, 2013; Nel *et al.*, 2017), and microinclusions  
79 (Saint Martin *et al.*, 2012, 2013; Saint Martin and Saint Martin, 2018) or discuss the  
80 palaeobotany aspects (Gomez *et al.*, 2003). However, no comprehensive synthesis had been so  
81 far carried out on the many Provence amber-bearing sites.

82 This review paper aims at inventorying the many amber-bearing sites of Provence based on  
83 new field observations and published results and new field observations (Fig. 1). As far as  
84 possible, these amber-bearing sites are placed in their geological context, and their ages are  
85 discussed in agreement with the current Geological Time Scale (Gradstein *et al.*, 2020).  
86 Additional information concerns the main characteristics of the amber and their inclusions when  
87 data are available.

88

## 89 **2. Materials and sources**

90 The proposed updating of knowledge on Provence amber is based on field works and the  
91 collection of samples carried out by the authors over the past few years (Fig. 1B; Tab. 1). New  
92 amber sites have thus been discovered. This *in situ* research was carried out using data from the  
93 literature but also on the basis of the presence of lignite horizons which are frequently associated  
94 with amber. Some samples of private amber collections were kindly made available to us. This  
95 report also provides for each Provence amber-bearing site a bibliographic thorough database  
96 available, including geographical, historical, archaeological, geological and palaeontological  
97 aspects. No amber sample comes from the territory of the Geological Reserves or the Geoparks  
98 of Provence. Most of the amber samples are kept in the collections of several institutions  
99 (MNHN: Muséum National d'Histoire Naturelle de Paris; MHNA: Muséum d'Histoire

100 Naturelle d'Aix-en-Provence; UP: University of Poitiers), the rest being part of private  
101 collections (see Tab. 1 for details).

102 The amber samples were observed using a binocular microscope and thin petrographic  
103 sections were performed and photographed under a Zeiss Axioskop 40 microscope. Some  
104 samples were observed in scanning electron microscopy (SEM) with two devices: Hitachi  
105 SU3500 SEM and JEOL JCM-6000 NeoScope.

106

## 107 **3 Cretaceous amber-bearing sites**

### 108 **3.1 Vaucluse**

#### 109 *3.1.1 Piolenc site (Fig. 1B, site 1 ; Fig. 2)*

110 The Piolenc site has a long history of active lignite mining between the 17th and the 19th  
111 century (Expilly, 1768; Cuvier and Brongniart, 1822; Brongniart, 1823, 1829). The presence of  
112 amber and “jayet” (= jet) was first reported by Expilly (1768). The lignitic sandy marls of  
113 Piolenc were described in detail by Gras (1862). This author considered these lignitic sandy  
114 marls as a particular distinctive stage of the Cretaceous, in correspondence to the Plan d'Aups  
115 lignitic marls (see Frau *et al.*, this volume), to the Upper Chalk of the Paris basin. Dumas (1876)  
116 and Frémy (1885) subsequently re-assigned this formation to the Cenozoic but all of these  
117 authors overlooked the presence of amber in association with the lignite deposits. In the second  
118 part of the 20<sup>th</sup> century, the geological, sedimentological and palaeoenvironmental context of  
119 the Piolenc lignite formation were studied by several authors, and the palaeontological content  
120 was partially inventoried (Mennessier, 1949, 1950; Medus 1970; Triat and Medus, 1970;  
121 Desoignies, 1971; Triat, 1982; Malartre, 1994; Gomez *et al.*, 2003). A Santonian age for the  
122 Piolenc lignites was established thanks to the co-occurrence of radiolitid rudists (Mennessier,  
123 1950).

124 The main outcrops are located northeast of the Piolenc town in a neighbourhood called  
125 “quartier de Saint Louis”. There, ancient abandoned quarries (Tab.1, site 1a) allow the  
126 observation of 20 m-thick series of the Piolenc lignite Formation. According to Gomez *et al.*  
127 (2003), nine units (from bottom to top) are observed. The sedimentological and palaeobotanical  
128 data document an intertidal to supratidal environments, with coastal ponds, marked by  
129 instability depending on the variations in the water level, under a hot humid tropical climate.  
130 Amber grains have been found in the lower unit, in foliated sandy clays (unit a).

131 The sedimentary series shows a significant lateral facies changes (Fig. 3A-C). At the base of  
132 the quarry, above yellowish sandstone exhibiting cross-bedded stratification, the presence of  
133 tiny beads or larger nodules of amber is easily observed in sandy levels (Fig. 3A-B, Fig. 4B, C)  
134 and in overhanging foliated sandy clays (Fig. 3D). Amber is also found at the base of a  
135 sandstone bed which can be clearly identified in the topography (unit d in Gomez *et al.*, 2003)  
136 and in the overlying levels (Fig. 4A), made of laminated sandy sediments (Fig. 3B). The last  
137 amber grain occurrence is found in the the root level (unit e in Gomez *et al.*, 2003) (Fig. 3E). It  
138 should be noted that amber was also harvested at the top of the hill to the northwest on the so-  
139 called “Montée de Béziers” (Tab. 1, site 1b).

140 In the richer lignite levels, the amber grains are mixed into a gangue composed of compacted  
141 plant debris (Fig. 4D). The amber grains show two types of morphology. The majority of the  
142 samples are in the form of millimetric to centimetric, more or less elongated beads or droplets  
143 (Fig. 4E-J). Some larger nodules with various shapes can reach up to 4-5 centimetres (Fig. 4G).  
144 The amber grain aspect is variable, from translucent reddish yellow (Fig. 4E, H) to completely  
145 opaque (Fig. 4F, I). They often bear a fine reddish to brownish crust (Fig. 4H, J) on the finely  
146 cracked surface.

147 Despite its abundance, the Piolenc amber has provided very few arthropod inclusions,  
148 including two species of small dolichopodid flies (Nel *et al.*, 2017) and two new species of

149 ceratopogonid midges (Choufani *et al.*, 2013). Furthermore, Saint Martin and Saint Martin  
150 (2018) showed that the Piolenc opaque grains are the result of extensive colonisation of the  
151 resin by sheathed bacteria assigned to the fossil species *Leptotrichites resinatus* Schmidt and  
152 Schäfer 2005.

153

### 154 3.1.2 Bédoin site (Fig. 1B, site 2 ; Fig. 2)

155 Lignite deposits have long been mined at Bédoin and used as firewood for silkworm rooms,  
156 for cooking lime and plaster (Perdonnet *et al.*, 1837). There, the lignite layers occur in a thick  
157 set of several tens of meters of marly, sandy and sandstone sediments in a thick set of several  
158 tens of meters of marly, sandy and sandstone sediments having partially undergone alteration  
159 phenomena (= "faciès rutilant" of Jacob, 1907). The age of these levels is between the Albian  
160 and the lower Cenomanian (Jacob, 1907; Sornay, 1945-1946). Only a more recent study (Triat,  
161 1982) mentions the presence of some yellow amber fragments at the base of green glauconitic  
162 sandy limestones. The section presented by this author is located northeast of the Bédoin village  
163 near the Damian farm (Fig. 2), along a cliff oriented approximately East-West below the hill of  
164 Piébounau (Tab. 1, site 2; Fig. 5A). The base of the cliff is made up of ochre-coloured red sands  
165 grading upward into sandstone limestone. According to Triat (1982), a more clayed level  
166 represents the passage between Albian sands (*sl*) and Vraconian deposits (*ss*) deposits. The 1/50  
167 000 geological map of Vaison-la-Romaine (Monier and Cavelier, 1991) assigns the outcrop to  
168 n7A (Albian-Vraconian) due to the alteration of red sands of marine origin. Our field  
169 investigations confirmed the presence of amber in the level indicated by Triat (1982) and  
170 representative material has been collected *in situ*. The samples were observed and collected  
171 about 1 metre above the top of the ochreous sandston, rich in oyster shells (Fig. 5B-D).



172 Amber samples are represented by large nodules associated with more or less lignitised  
173 plant debris (Fig. 5D-F). The periphery of the amber nodules develops a sandstone concretion,  
174 encompassing both amber masses, woody debris and plant remains (Fig. 5F).

175 The collected nodules and fragments of amber have a dominant reddish hue in the translucent  
176 parts (Fig. 6A). However, we often see an earthy beige-brown hue making the grains opaque  
177 (Fig. 6A-B). The amber cross sections show successive resin flows including dust residues and  
178 small bubbles of high density (Fig. 6C).

179 According to Triat (1982), the Albian sands correspond to a shallow marine environment,  
180 while the overlying Vraconian sandstone limestones mark a marine deepening.

181 It is interesting to note that a humerus of a dinosaur identified as belonging to the genus  
182 *Aepisaurus* has been found in the Albian sandy facies (Gervais, 1848-1852; Brignon, 2018). In  
183 the lack of data regarding its precise stratum, one may hypothesise that this dinosaur remain  
184 originates from the amber-bearing level which yield terrestrial elements such as plant debris.

185

### 186 3.1.3 Rustrel site (Fig. 1B, site A)

187 Gras (1862) reported the presence of amber (*succin in litt.*) associated with lignite in the  
188 Rustrel area. These lignite deposits crop out in clayed grey marls with greenish points, ontop  
189 the Urgonian limestones. Associated fossils reported by Gras (1862) pinpoint an Aptian age.  
190 More precisely, the 1/50, 000 geological map of Carpentras assigns these pyritic black marls a  
191 Gargasian age (n6a) based on the macrofauna and microfauna (Blanc *et al.*, 1975).

192 Unfortunately we have no other indication on this amber regarding its exact location, its  
193 appearance and its abundance. New field researches are thus required to confirm the presence  
194 of this amber and its habitus.

195

## 196 3.2 Drôme

197 Bréhéret (1995) reported south of the Eygaliers village (Fig. 1, site B), many woody debris  
198 and amber grains in glauconitic sandstones cropping out above Albian sediments. A basal  
199 Cenomanian age is tentatively assigned to these amber-bearing deposits. There is no indication  
200 of the appearance of this amber.

201

### 202 **3.3 Alpes de Haute Provence**

#### 203 *3.3.1 Salignac site (Fig. 1, site 3 ; Fig. 2)*

204 The presence of amber was repeatedly reported in the vicinity of Sisteron (Valmont de  
205 Bomare, 1774; Brongniart, 1807, 1823, 1827; Beudant, 1832; Bonnemère, 1886; Lacroix,  
206 1910) and/or more specifically in the Salignac area, ~ 5 km southeast of the nominate city  
207 (Daubenton, 1751; Lavoisier, 1765; de Cessac, 1874; Bonnemère, 1886). This interest probably  
208 results from the accumulation of amber pieces from the bottom of the local badlands  
209 (=“roubines”) after pluvial runoff. According to Bonnemère (1886), this red amber gets its local  
210 name from *peira cremarela* in Provençal dialect, probably because the peasants used it as an  
211 auxiliary light by burning it. Recent works have addressed the physico-chemical aspects of the  
212 Salignac amber (Onoratini *et al.*, 2009a; Ragazzi *et al.*, 2009) and its inclusions (Perrichot *et*  
213 *al.*, 2006; Saint Martin and Saint Martin, 2018). The geological aspects were detailed by  
214 Bréhéret (1997) who proposed a lithological section (Les Coignets - Les Coulets) in the Aptian  
215 and Albian terranes north of Salignac (Fig. 7). Several deposits, ranging from Aptian to  
216 Cenomanian ages, yield amber. They are detailed as follow.

217 The only sample of Aptian age was taken north of Salignac near the Les Coignets locality  
218 (Fig. 1B, site 3a; Fig. 7; Tab. 1) in upper Aptian (Clansayesian) blue marl deposits. The amber  
219 grains are fairly opaque flattened orange ovoid nodules (Fig. 9A). Thin sections and polished  
220 sections made on this sample show a fairly concentric irregular structure reflecting successive

221 resin flows (Fig. 9B). A central part is more translucent, reddish in color. The periphery appears  
222 as an opaque yellow-orange crust.

223 Albian amber grains can be harvested at the Les Coulets locality in the hills and ravines  
224 oriented preferentially East-West and dipping south (Fig. 1B, site 3b, Fig. 7; Tab. 1). The area  
225 exhibiting *in situ* amber samples (Fig. 8A, B) is located between two index levels: 100 metres  
226 above the “Paquier” black shale level marked by ammonite accumulations containing the lower  
227 Albian species *Leymeriella tardefurcata* (Orb. 1841) (Tribovillard and Gorin, 1991; Joly, 2008;  
228 Kennedy *et al.*, 2017) and 30 m below a sandstone limestone containing the ammonite  
229 *Idiohamites* which could mark the upper Albian (D. Bert, personal communication). According  
230 to the geological map at 1/50 000 of Sisteron, the harvesting sector is registered in the upper  
231 Albian (n6b) terranes and the boundary between the Albian and Cenomanian stages would be  
232 higher in the series, north near the Salignac village. Bréhéret (1997) noticed out the presence  
233 of driftwood in the Albian marls overlying the “Paquier” level. Amber nodules of  
234 pluricentrimetric size are scattered in foliated clayey sediments poor in fossils (Fig. 8C, D).  
235 Some smaller grains were harvested in a more calcareous level rich in bioturbations and  
236 containing belemnite rostra. The dominant colour of amber is orange-red when it is translucent  
237 (Fig. 8A). It can take a more yellowish tint and is therefore less translucent (Fig. 8D, F). The  
238 thin sections reveal the successive flows marked by impurities (Fig. 8E). Macro-inclusions are  
239 rare despite the relative large size of amber pieces. Arthropod inclusions previously described  
240 in this amber include a specimen of *Phryssonotus* belonging to the Synxenidae (bristly  
241 millipedes) (Nguyen Duy-Jacquemin and Azar, 2004) and the Heteroptera *Ebboa areolata*,  
242 belonging to the Ebboidae (Perrichot *et al.*, 2006). Microinclusions are not uncommon and yield  
243 colonies of the sheathed bacterium *Leptotrichites resinatus* characterizing the opaque parts of  
244 the amber pieces (Saint Martin and Saint Martin, 2018).

245 According to Onoratini *et al.* (2009a), amber nodules, not harvested by the authors, were  
246 found at Salignac in a black marly-sandstone level within a lower Cenomanian formation  
247 characterized by an alternation of blue marl and sandy limestone, below the mid-Cenomanian  
248 sandstone levels. However, the exact position of the sample not being given. If the stratigraphic  
249 attribution is correct this amber would come from outcrops located at the village emplacement  
250 or a little southward.

251

### 252 3.3.2 Lure Moutain sites (Fig.1, sites 4,5 ; Fig. 7)

253 The presence of amber from around the Lure Moutain region is known from old monographs  
254 (Darluc, 1784; Patrin, 1819; Brongniart, 1823, 1827; Beudant, 1832; de Cessac, 1874; Lacroix,  
255 1910; Desailly, 1930). Darluc (1784) cited the Ongles village as an amber-bearing site.  
256 However, more extensive information on the amber from around the Lure Moutain (Fig. 7) is  
257 provided by recent work of Onoratini *et al.* (2009a, b). These authors have proposed a synthetic  
258 lithostratigraphic framework in which the different amber sites are reported. However, the  
259 precise geographical locations of the samples are not given.

260 The Albian series well-exposed at Salignac outcrops west of the Durance south of the  
261 Aubignosc village (Fig. 7) and also contains amber. The 1/50,000 geological map of Sisteron  
262 indicates an Albian age for the series outcropping in this area. We harvested amber grains in a  
263 marly-sandstone series showing a slight dip to the east (Fig. 8E). The samples collected *in situ*  
264 are quite small (a few centimeters) and their colour is yellow, quite opaque (Fig. 9G). The thin  
265 sections show the presence of dense impurities (Fig. 9H, I) in the amber among which Saint  
266 and Saint Martin (2018) reveal, as for the Albian amber from Salignac, colonization by  
267 filamentous network of sheathed bacteria. Onoratini *et al.* (2009b) also report amber near  
268 Aubignosc, but in lower Cenomanian sediments, therefore stratigraphically above the level  
269 investigated by us, probably towards the eastern edge of this small massif.

270 According to Onoratini *et al.* (2009b), amber of presumably upper Albian age, was collected  
271 at Ongles (Fig. 7) in green sandstones and glauconitic marls affected by “ocrification”  
272 processes (Triat, 1982). The Revest-des-Brousses amber (Fig. 7) was harvested in an  
273 alternation of black marl and limestone beds near the Albian-Cenomanian boundary. The amber  
274 fragments from Saint-Etienne-les-Orgues (Fig. 7) originate from black marls of early  
275 Cenomanian age. These amber samples from Lure Mountain were analyzed by IRTF  
276 spectroscopy by the aforementioned authors.

277 Several indications point to the presence of amber (“succin” *in litt.*) 4 km north of Vachères  
278 (Fig. 7) in a locality called Egrillères or Equillères according to the transcriptions, currently  
279 spelled Eygrières. Thus, in the *Bulletin de la Société Française de Minéralogie* (session of  
280 March 9, 1939), a sample of amber is presented as a new mineralogical species of  
281 Pseudosuccinite defined by Buddhue (1938). This amber was subsequently analyzed by  
282 infrared spectra (Beck and Liu, 1976). According to the 1:50,000 geological map of Sault, the  
283 Eygrières amber merely come from the Cenomanian marly-sandstone terranes.

284 We have examined samples from Saint-Etienne-des-Orgues from private collections (F.  
285 Pauvel). This amber, which would therefore be of upper Albian age, appears in a dominant red  
286 hue (Fig. 9J). The thin sections reveal the abundance of small bubbles series highlighting the  
287 resin flows and altering the translucent aspect of the amber (Fig. 9K).

288

### 289 3.3.3 *Blieux site ((Fig.1, site E)*

290 The presence of amber in northwest Blieux is only known from Bréhéret (1995) who  
291 reported black horizons with driftwood and amber interspersed in Albian dark marly sediments.  
292 We do not know the characteristics of this amber.

293

### 294 3.3.4 *Sites of uncertain age and location*

295 Two amber sites are mentioned by Papon (1776) at Tour de Beuvons, today Valbelle (Fig.1,  
296 site C; Fig. 7) and by Darluc (1684) at Saint-Geniez-de-Dromont, a village located northeast of  
297 Sisteron (Fig. 1, site D; Fig. 7). These records have been then cited by Kilian (1889) and Lacroix  
298 (1910) without further details regarding their precise location and geological context. New field  
299 work is thus required to confirm the presence of amber there.

300

### 301 **3.4 Bouches du Rhône**

#### 302 *3.3.1 Santonian*

303 The Santonian of Bouches-du-Rhône has long been identified to provide amber-rich deposits  
304 (Vasseur, 1894; Lacroix, 1910). Three sites were repeatedly cited, namely Martigues-La Mède,  
305 Ensues-la-Redonne and Belcodène.

306 The Santonian amber of Martigues-La Mède (Fig. 1B and Tab. 1 site 7; Fig. 10), first  
307 mentioned by Vasseur (1894), was rediscovered and studied by Guiliano *et al.* (2006).  
308 Subsequently, Saint Martin *et al.* (2012) identified in the field the detailed lithostratigraphic  
309 succession described by Vasseur (1894) and showed the presence of amber grains in three  
310 levels. As documented by Saint Martin *et al.* (2012) and Saint Martin and Saint Martin (2018),  
311 the amber grains contain rich microinclusions including the colonies of the sheathed bacteria  
312 *Leptotrichites resinatus*.

313 The Belcodène amber (Fig. 1B and Tab.1, site 11) has been repeatedly cited in the literature  
314 (Nel *et al.*, 2004; Perrichot *et al.*, 2007b; Onoratini *et al.*, 2009; Ragazzi *et al.*, 2009) and its  
315 study was undertaken by Saint Martin *et al.* (2013) and Saint Martin and Saint Martin (2018).  
316 Amber features closely resemble those of the Martigues amber, including dense filamentous  
317 networks of a sheathed bacteria.

318 The Ensues amber (Fig. 1B, site 9) has also been evoked by various works (Perrichot *et al.*,  
319 2007b; Onoratini *et al.*, 2009; Ragazzi *et al.*, 2009), but has never been published in a

320 comprehensive description. The detailed lithostratigraphic succession of the investigation  
321 sector is moreover very difficult to define due to the strong deformations which affect the series  
322 at the heart of a syncline whose axis is parallel to the coast (Guieu *et al.*, 1996). The Santonian  
323 sediments outcrop along the coast between the localities of La Redonne and Calanque de  
324 Méjean. There, sands, marls and sandstones rest on the Méjean Coniacian sandstones rich in  
325 crinoid fragments (Guieu *et al.*, 1996; Philip and Gari, 2005). Amber grains were harvested by  
326 S.S.M., J.P.S.M. and X.V. more precisely between the “Calanque des Anthénors” and the  
327 “Calanque des Figuières” in two accessible places (Fig. 11A). In the “Calanque des Anthénors”  
328 area (Tab. 1, site 9a), the Santonian is represented at its base by heavily burrowed sandstones  
329 (Fig. 11C). The series continues with nodular sandstones and soft sandstones with lignite debris  
330 and amber grains (Fig. 11B, E). This first amber bearing level is overlain by cross-bedded  
331 sandstone, bioclastic sandstone, dark gray soft sandstone, and then by laminated marly  
332 sandstones (Fig. 11C) also containing lignite debris, rare oysters and amber grains. The rest of  
333 the outcropping series consists of alternating sandstone and masses of debris flows containing  
334 strongly disarticulated rudist constructions (Fig. 11D). East of the “Calanque des Figuières”  
335 (Fig. 11A; Tab.1, site 9b), the series are characterized by rudist buildups. According to Philip  
336 (1970) and Philip and Gari (2005), the rudist association is characteristic of a Santonian age. A  
337 lens with lignite debris yields numerous amber pieces (Fig. 11B) and contains remains of the  
338 brackish gastropod *Campylostylus galloprovincialis* (Matheron, 1843). The amber corresponds  
339 to orange-yellow translucent to reddish-brown opaque tiny grains (Fig. 11F). The thin sections  
340 reveal three types of grains: fairly translucent with a fine reddish envelope (Fig. 11G), opaque  
341 (Fig. 11H) and crystalline ones marked by intense fracturing (Fig. 11I).

342 Another potential amber-bearing spot occurrence is reported by Matheron (1839, 1843) near  
343 the Allauch locality, east of Marseille (Fig. 1, site F). In terranes equivalent to those of Piolenc,  
344 Martigues-La Mède and Sainte Baume (Var) today considered Santonian in age, a few layers

345 would contain lignite debris and amber grains (“succin” *in litt.*). Exploration in this area has so  
346 far failed to locate the amber site.

347

### 348 3.4.2 Upper Campanian

349 The Martigues-Terres d’Ocre locality (MTO) is situated 2,5km northwest from the city  
350 centre of Martigues (Fig. 10, locality 1). The locality, consisting in a lenticular fluviolacustrine  
351 deposits, was studied thanks to two outcrops and excavation sites in three different sectors  
352 following building construction works in a new residential area (MTO1-3 ; Fig. 12A). Each  
353 sector presents the same general sedimentological succession with some slight differences in  
354 layers thickness, depending on the presence/absence of an additional marly horizon and on the  
355 position in the deposit structure (Fig. 12D ; Tortosa, 2014). The serie begins with red marls  
356 (Level 1), then overlain by a lenticular deposit of sandstone including some vertebrate  
357 macroremains (Level 2). In MTO2, this Level 2 becomes a very thin yellow sandy marls  
358 horizon (Fig. 12D). It corresponds to an alluvial fan constituting a deltaic structure penetrating  
359 into a lacustrine environment. The alluvial material takes its origin from the ancient southern  
360 Pyreneo-Provençal mountain chain (Anglada *et al.*, 1979). This horizon is overlain by massive  
361 black marls (Level 4), rich in vertebrate macroremains (Fig. 12B, D-E). In MTO2, there is an  
362 intercalation of thin grey marl layers between the levels 2 and 4 (Fig. 12B and D). This level 3  
363 is rich in fossil plant detritus (see bellow in text). It is followed by the level 4 which is rich in  
364 vertebrate macroremains. Its base is a grey marl horizon with some very thin discontinued  
365 yellowish layers. The top is a dark grey horizon including some little greenish sandy lenses.  
366 This layer ends with a thin shelly horizon and continues with the Level 5. In MTO3, the Level  
367 4 becomes greyish hard marls, less rich in vertebrate remains, exhibiting hardgrounds in some  
368 spots (Fig. 12C-D). The series continues with level 5 which is a thick compact layer of grey  
369 calcareous marls. The levels 3-5 are indicative of lacustrine environment with a limited



370 fluvial input. The following levels 6 and 7 are respectively orange marls and red marls. This  
371 series is located in 400 m-thick red marls represented here by levels 1 and 7 and conglomerates  
372 formation corresponding to the local « Begudian facies » (Babinot *et al.*, 1980). Those facies is  
373 dated to the base of upper Campanian (Cojan and Moreau, 2006 ; Gradstein *et al.*, 2020).

374 Beside of the stratigraphical repositioning based on local continental facies, the only  
375 available biomarkers are gastropods which were collected in levels 2 to 5. The collected  
376 palaeomalacofauna is a mix of terrestrial and freshwaters species represented by internal molds.  
377 They include in Level 2 *Melania cf. colleti*, *Palaeostoa cureti*, *Physa galloprovincialis*, *Physa*  
378 *michaudii*, *Physa patula*, *Proalbinaria (= Clausilia) matheroni*, *Rognacia abbreviata*,  
379 *Viviparus beaumontianus* and various undetermined species. Above level 2, the fauna is  
380 poorly preserved and we were only able to determine the species *Palaeocyclophorus*  
381 *galloprovincialis* in Level 5. The palaeomalacofauna presents a taxa usually found in the Valdo-  
382 Fuvelian facies (upper Santonian-lower Campanian), *Melania cf. colleti*, whereas the others are  
383 known from upper Campanian to Maastrichtian (Begudo-Rognacian facies) such as  
384 *Palaeocyclophorus galloprovincialis*, *Palaeostoa cureti*, *Physa galloprovincialis*, *Physa*  
385 *michaudii*, *Physa patula*, *Proalbinaria matheroni*, *Rognacia abbreviata* (Fabre-Taxy, 1951,  
386 1959). It is interesting to note the absence of common « Rognacian » taxa such as *Bauxia*,  
387 *Lychnus* and *Pyrgulifera* which are usually abundant in Rognacian facies. The MTO locality  
388 offers a palaeomalacofauna composition reminiscent of another observed in the upper  
389 Campanian (Begudian facies) of Pourrières-La Neuve in the Var department (Garcia *et al.*,  
390 2000). Indeed, both localities have specimens reduced in size much compared to their original  
391 descriptions. The most of the specimens have not been identified because of their fragmentary  
392 nature. Moreover, it is currently difficult to distinguish juveniles, dwarves or new small species  
393 since they do not correspond to any published taxa to date. Following these stratigraphical and

394 palaeontological observations, we confirm the position of MTO locality in the upper  
395 Campanian but restricted to its lower part (~c33).

396 Both levels 2 and 4 have also yielded dozen of macrofossiles corresponding to a rich faunal  
397 assemblage, including freshwater and terrestrial taxa such as pisces (lepisosteids), squamates,  
398 turtles (undetermined Cryptodira and Pleurodira), crocodiles (cf. *Acynodon*, cf.  
399 *Allodaposuchus*), and dinosaurs (nodosaurids, the ornithopod *Rhabdodon*, titanosaurs and the  
400 dromaeosaurid cf. *Richardoestesia*) (Tortosa, 2014). Micro- and macrofossils will be the object  
401 of further studies in detail.

402 As regarding flora, the Level 3 is remarkable for having yielded some trunks fragments likely  
403 belonging to conifers (Gomez, pers. com.) and some amber grains, objects of this study.

404 The amber samples (Fig. 12F, G) correspond to millimetric grains, reaching sometimes 1cm.  
405 Some of them exhibit a drop shape, but many are fragments only. The samples show all the  
406 intermediaries between translucent reddish grains and completely opaque grains, from red to  
407 whitish in external appearance. Some grains have a peripheral crust (Fig. 12 I), darker red in  
408 section (Fig. 12H). Many opaque grains show a dark red hue in section with inclusions of dark  
409 unidentifiable organic debris. One can observe under SEM the imprints of a mineral belonging  
410 to the cubic system (Fig. 12K). This could correspond either to pyrite crystals already  
411 mentioned in some amber but apparently absent in the samples, or to salt crystals dissolved  
412 subsequently. Among the inclusions particularly difficult to identify, there are ovoid structures  
413 with a wrinkled surface which could perhaps correspond to spores (Fig. 12J). It is important  
414 that during the mounting of thin sections process, the amber tended to creep like a resin which  
415 is not fully consolidated (Fig. 12H).

416

417 **3.5 Var**

418 The amber-bearing sites of Santonian age are distributed in a direction approximately East-  
419 West at the foothill of the Sainte-Baume Massif (Fig. 1B, sites 12, 13).

420 The only mentions of the presence of amber in the Var department were given during the  
421 19th century works of Coquand (1861, 1864) and Collot (1890) at the Plan d'Aups village.  
422 Onoratini *et al.* (2009a) confirmed the presence of amber there by the record of a single grain  
423 at Plan d'Aups. Subsequently, Saint Martin and Saint Martin (2018) found new amber spot  
424 occurrence eastward (Glacières de Pivaut; Tab. 1, site 13b). New field investigations have led  
425 to the discovery of new sites at Plan d'Aups (Tab. 1, sites 12a,b) as well as at Mazaugues (Tab.  
426 1, site 13a), in two different stratigraphic levels. More data on these sites, and their  
427 palaeoenvironmental context can be found in Frau *et al.* (this volume).

428

## 429 **4 Cenozoic amber sites**

### 430 **4.1. Oligocene amber from Venelles**

431 The discovery of amber grains in the uppermost Oligocene of Venelles results from the  
432 collection of a rich continental vertebrate fauna (Aguilar *et al.*, 1978; Buffetaud and Cornée,  
433 1982; Nury, 1988; Nury, 1994). This site is located about 10 km northeast of Aix-en-Provence  
434 (Fig. 1B, site 10) and is part of a succession of marls and lignite levels. The sedimentary  
435 deposits correspond to a calm fluvial environment, perhaps in an estuarine system with a  
436 mixture of continental and brackish faunas (Nury, 1988).

437 A millimeter-sized grain of amber was extracted from the matrix of an undetermined turtle  
438 shell (Fig. 13). The grain has a thick opaque beige crust of around 200  $\mu\text{m}$  around a more  
439 translucent centre with a dominant red hue. No inclusion could be highlighted in the translucent  
440 part.

441

### 442 **4.2. Lower Miocene amber from the Côte Bleue (NW Marseille)**

443 The outcrops along the Côte Bleue, between Carry-le-Rouet and Sausset-les-Pins, stand out  
444 as the reference Oligocene-Miocene shallow-water deposits of southern France. The Aquitanian  
445 deposits consist of several lithostratigraphic units already described in detail in the past  
446 (Andréieff *et al.*, 1972) and more recently reassessed (Oudet *et al.*, 2010; Demory *et al.*, 2011;  
447 Conesa *et al.*, 2014) including from bottom to top: the “Cap de Nautes” formation containing  
448 the Oligocene-Miocene boundary at its base, the so-called brackish « Formation de Rousset »,  
449 the bioclastic « Formation de Carry-le-Rouet » and the biodetritic « Formation de Sausset-les-  
450 Pins ». The amber sample comes from the bioclastic « Formation de Carry-le-Rouet », near the  
451 “Anse Rousset” (Fig. 1B, site 8; Figs. 10,14A; Tab. 1). Above key bed marker rich in turritellid  
452 gastropods at the base of this formation, a level of sandy clays containing numerous plant debris  
453 is overlain by massive calcareous sands (Fig. 14B-C) in which the amber comes, then by  
454 bioclastic deposits with bryozoans.

455 The harvested amber grain is quite translucent, orange-red in colour. Its globular shape is  
456 approximately 1,6 cm in size (Fig. 14D). Examination does not reveal any inclusion.

457

## 458 **5 Discussion-Perspectives**

### 459 **5.1. Stratigraphical range**

460 Although with some age uncertainties, the amber spot occurrences of Provence have a long  
461 stratigraphic range, from the Lower Cretaceous to the Miocene.

462 The oldest known ambers in Provence originate from Salignac (Aptian), and doubtfully that  
463 of Rustrel. The Aptian amber-bearing deposits are rare in France. Lacroix (1910), and  
464 subsequently Du Gardin (1986), have mentioned Aptian amber in the Saint-Suzanne  
465 Costebarbe marls in the department of Pyrénées Atlantiques, southwest France. However, we  
466 have no more details about this amber and its deposit environment.

467 The presence of amber between the upper Albian and the lower Cenomanian in Provence is  
468 to be compared with other amber deposits from France, in particular those of the southwest  
469 regions (Charentese ambers). Following the first report by Néraudeau *et al.* (2002) a large  
470 number of studies have focused on this amber (see overview in Perrichot *et al.*, 2010). One of  
471 the common points is the appearance of amber with big nodules from large successive flows  
472 and a smaller proportion of drop-shaped grains. By comparison, the richness in macroinclusions  
473 is lower in the Provence amber. This can be explained by the depositional environment of which  
474 is dominated by open marine conditions In Provence while it corresponds to paralic settings in  
475 southwestern France at that time (Néraudeau *et al.*, 2002; 2003, 2009). The amber of the  
476 marshes and the amber of the litters in southwestern France correspond to an evolution of the  
477 resin almost *in situ*. The deposition of amber from Provence is the result of a process involving  
478 sorting, stream transport and reworking in coastal marine environment by flotation before  
479 sedimentation. It is therefore possible that the amber samples only partially reflect the original  
480 characteristics of the resins.

481 Many Provence amber sites are of Santonian age. They have very homogeneous characters.  
482 The majority of the grains are small with more or less oval drop shapes. In the rest of France,  
483 Santonian deposits are rather rare.

484 The case of the uppermost Cretaceous amber from Martigues is interesting from a  
485 palaeogeographical point of view, with the evolution of the region towards continental  
486 environments beginning in the Santonian-Campanian times, but also the relationship between  
487 amber and the resin producing forest, and the vertebrate populations (e.g. dinosaurs). It is indeed  
488 one of the remarkable sites where the remains of dinosaurs and amber grains are found together  
489 (e.g. Néraudeau *et al.*, 2003, 2005, 2009 for France or McKellar *et al.*, 2019 and Cockx *et al.*,  
490 2020 for Canada) especially at the end of the Cretaceous, shortly before the K/Pg event, which  
491 heightens its interest.

492 Compared to the rest of France, Provence is free of Eocene amber deposits. The Oligocene  
493 amber from Venelles is unfortunately too fragmentary to provide further information regarding  
494 its palaeoenvironmental context. Nevertheless, its report is of crucial importance since this is  
495 the only known occurrence of Oligocene amber in France.

496 The most recent amber of Provence is those from the Aquitanian of Carry-le-Rouet, with an  
497 magnetostratigraphical age estimated at -22.30 million years by Demory *et al.* (2011). Until  
498 now the younger amber known in France seemed to be that reported in Allinges (department of  
499 Haute Savoie) and named *allingite* by Aweng (1894). In fact, several works report the presence  
500 of amber supposed to come from the Lower Miocene “molasse” the in the Voirons Massif south  
501 of Allinges (Lacroix, 2010; Galippe, 1920; Saskevitch and Popkova, 1978). The problem is that  
502 the exact age of the sediments is not clearly defined. A reexamination of the geological situation  
503 (Tercier, 1928) rather suggests an Eocene to Oligocene age more recently confirmed (Jan du  
504 Chêne *et al.*, 1975; Ospina-Ostios, 2013; Ragusa, 2015). If this should prove correct, the Carry-  
505 le-Rouet amber constitutes the younger occurrence in France.

506

## 507 **5.2. Characteristics, botanical origin and amber depositional environments**

508 Amber chemistry has been a domain of investigations for a very long time and various  
509 methods have been used. Provence amber has thus been subject of various works aiming at  
510 chemically characterizing amber as well for archaeological or historical reasons as with the  
511 objective of determining the botanical origin of the amber. All the studies document a difference  
512 between the Provence ambers and the Baltic ones, which has made it possible to definitively  
513 reject the hypothesis of the use of local amber in the archaeological interest in Provence and of  
514 favour the Baltic source (Buddhue, 1938; Beck and Liu, 1976; Onoratini et al., 2009a). The first  
515 study by Beck and Liu (1976) on amber from the Montagne de Lure concludes that it is close  
516 to the Cenomanian amber from Gard department. On the basis of various Fourier transform

517 infrared spectroscopy analyzes (IRTF) concerning the oxygen function, the exomethylene  
518 group or carbonyl groups, Onoratini *et al.* (2009a, 2009b) highlighted the separation into two  
519 groups of amber also corresponding to two stratigraphic age groups: the Albo-Cenomanian  
520 ambers from the “Montagne de Lure” and the Santonian ambers from various sites (Piolenc,  
521 Martigues-La Mède, Ensues, Belcodène, Plan d'Aups). Another study using the techniques of  
522 Infrared Spectroscopy, Solid-State CPMAS <sup>13</sup>C NMR Spectroscopy and Thermochemolysis -  
523 GC-MS on different ambers from France (Nohra *et al.*, 2015) also leads to distinguish the  
524 Salignac samples those from Santonian (here Piolenc and Belcodène). Finally, the thermal  
525 analysis of Cretaceous amber from France (Ragazzi *et al.*, 2009) leads to a similar result  
526 separating the Salignac amber (associated with a site in the west of France) from all of the  
527 Santonian ambers from Provence (Piolenc, Ensues, and Belcodène). This distinction is also  
528 related to the appearance of amber. Thus, the Albo-Cenomanian ambers are mainly large  
529 nodules with a dominant yellow to red colour while the Santonian amber is represented by  
530 grains of smaller size, often preserved in the form of drops of original resin, from translucent  
531 to fully opaque. This differentiation seems to result from two factors which can possibly  
532 combine. The first cause would be related to the conditions of geological evolution of the  
533 sediments containing the amber (temperature, pressure, tectonics). The age of the amber could  
534 thus explain a differential maturation: the oldest ambers would show greater maturity. According  
535 Onoratini *et al.* (2009a), slight differences observed between amber of the same age, as is the  
536 case for the Santonian amber, would be due to the fact that the amber of deposits from the  
537 coastal environment were blocked in their maturation by the return of marine conditions  
538 (Martigues-La Mède, Ensues, Belcodène) while others remained in continental environments  
539 (Piolenc) experienced a greater maturation. However, it should be noted that in Piolenc there is  
540 also a marine intercalation within the lignite series. The nature of the plants producing the resin  
541 is also one of the causes of the differences observed. This is a very often discussed subject

542 which aims to determine the botanical origin of the resin from which amber originates (see  
543 synthesis in Seyfullah *et al.*, 2018). With regard to Provence, the replacement during the  
544 Cretaceous period of forests dominated by gymnosperms (especially Araucariaceae and  
545 Cheirolepidiaceae) by forests with more abundant angiosperms (Philippe *et al.*, 2008) could  
546 have resulted in a different nature of the trees producing resin. The amber from Santonian  
547 deposits would then have another botanical origin than the Albo-Cenomanian ambers,  
548 involving so angiosperm trees (Onoratini *et al.*, 2009a; Ragazzi *et al.*, 2009a, b). However,  
549 according to Nohra *et al.* (2015) the Santonian amber is rather the result of resins from other  
550 gymnosperms, as the Cupressaceae, even if the only conifers identified at Piolenc are  
551 Araucariaceae (Gomez *et al.*, 2015). Cupressaceae are thus more often invoked in the  
552 production of resin from the Late Cretaceous (Seyfullah *et al.*, 2018). The problem is that direct  
553 evidence is generally lacking to support these claims. Besides chemistry analyses of amber, the  
554 nature of the associated plant remains in the deposits can constitute another indication.  
555 Unfortunately, few deposits, in particular for the Albo-Cenomanian sites, have delivered  
556 exploitable botanical associations, except at Piolenc (Gomez *et al.*, 2005) and in the Sainte-  
557 Baume Massif where Santonian remains of *Frenelopsis* are reported (gymnosperms  
558 Cheirolepidiaceae) (Frau *et al.*, this volume and references therein). The problem of the resin  
559 origins arises all the more for the new deposits presented in this work. Thus, the upper  
560 Campanian amber from Martigues has characteristics that distinguish it from other Cretaceous  
561 ambers. The fluidity of the slightly heated grains could sign a low degree of maturity and/or be  
562 related to another botanical source. Oligocene amber from Venelles cannot provide any  
563 information, since the vertebrate deposit did not deliver identifiable plant remains. Finally, the  
564 Miocene amber from Carry-le-Rouet is included in a series of sedimentary layers which contain  
565 numerous very small lignite debris which have never been identified. For lower and mid  
566 Miocene amber deposits in the world, the involvement of angiosperm is quite often highlighted,



567 in particular the Fabaceae (Antoine *et al.*, 2006; Calvillo-Canadell *et al.*, 2010; Penney, 2010;  
568 Solórzano Kraemer, 2010; Seyfullah *et al.*, 2018). This could be the case with Carry-le-Rouet  
569 amber, and chemical analyses would provide valuable information.

570 The part of the processes involved in the genesis of amber deposits is difficult to determine  
571 precisely and the comparison between deposits of different origin and age remains delicate  
572 (Knight *et al.*, 2010 and discussion in Saint Martin *et al.*, 2013). Depending on the deposits,  
573 these differences must take into account the necessary distinction between the sedimentary  
574 deposit environment and the resin formation environment, that is to say the modes of transport,  
575 burial and taphonomy. Schematically, three main types of depositional environments  
576 characterize the Provence amber sites: 1) open marine to distal environments; 2) coastal, lagoon  
577 or estuarine environments; 3) continental environments. In the first category ranks the Aptian  
578 and Albo-Cenomanian sites; the deposit medium can be rather deep and distal, as is probably  
579 the case for the Salignac amber. The abundance of amber harvested from very ancient times  
580 therefore implies a very active secretion of resin, subsequently floated and deposited in the  
581 seabed, which cannot be directly illustrated. In relation, it should be noted that driftwood is  
582 known in several Albian basins in south-eastern France (Cotillon and Lemoigne, 1971). The  
583 second category concerns ambers of various ages such as the Albian amber from Bédoin, the  
584 Santonian ambers (Gomez *et al.*, 2003; Guiliano *et al.*, 2007; Saint Martin *et al.*, 2012, 2013;  
585 Frau *et al.*, this volume) or the Aquitanian amber from Carry-le-Rouet (for similar depositional  
586 environment of Lower Miocene, see Serrano-Sánchez *et al.*, 2015) which can be framed  
587 respectively for the latest in the evolution of carbonate to rudist platforms or coastal  
588 environments with coral reef development. The third type of depositional environment consists  
589 on continental deposits of a lake and river character such as that of the Upper Campanian of  
590 Martigues. The wide range of ages from the Aptian to the Miocene of the ambers produced in  
591 Provence thus reflects a complex geological history having undergone the same tectono-

592 sedimentary evolution with the setting up of the Durancian uplift and the compression tectonics  
593 which influenced the sedimentary structure and the evolution of landscapes till the mid-  
594 Cretaceous times (Guyonnet-Benaize et al., 2010; Onoratini *et al.*, 2009a, b). For more recent  
595 periods, it is the Oligocene-Miocene rifting on the margin of the Gulf of Lion which constitutes  
596 the tectono-sedimentary framework conditioning the landscapes where amber was formed  
597 (Oudet, 2010).

598

### 599 **5.3. Future orientations**

600 Provence amber represents a potential for perfecting knowledge of the evolution of  
601 environments, climatic conditions and resin-producing trees in a given region. To exploit this  
602 potential, it would be important to unify by integrated studies the data resulting from field  
603 observations, physico-chemical characterization of amber, and macroinclusions and  
604 microinclusions content. Thus studies in inorganic chemistry have demonstrated a difference in  
605 composition between the periphery and the core of the grains, this due to the development in  
606 some cases of a crust due to colonization by microorganisms (Aquilina *et al.*, 2013). The  
607 appearance of amber is in fact largely determined by the colonization of the initial resin by  
608 microorganisms (see Frau *et al.*, this volume; Néraudeau *et al.*, this volume; Valentin *et al.*, this  
609 volume). An adaptation of the characterization techniques of amber according to these organic  
610 parameters conditioning the real nature of the amber found would undoubtedly be desirable. In  
611 addition, the recent discovery of several amber deposits of various ages shows the possibility  
612 of extending investigations in the field, especially for the presence of amber reported in the  
613 literature but not verified since. This is all the truer for a period rich in lignite observed locally  
614 between the Santonian and the Maastrichtian in the Basin de l'Arc, which would offer the  
615 possibility to continuously follow the development of resin production at a key moment in the  
616 Upper Cretaceous.

617

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635

## 636 **References**

637 Aguilar JP, Michaux J, Nury D, Sudre J, Touraine F, Vianey-Liaud M. 1978. Découverte d'un  
638 gisement très riche (Mammifères et Mollusques principalement) à Venelles (Bouches-  
639 duRhône), premier niveau repère important dans la série du "Gypse d'Aix". *Comptes Rendus*  
640 *de l'Académie des Sciences de Paris D 287* : 439-442.

641 Amione L. 1813. Essai sur le succin. Imp. Soffieti, Turin, 15 p.

642 Andreieff P, Anglada R, Carbonnel G, Catzigras F, Cavelier C, Chateaneuf JJ, Colomb E,  
643 Jacob C, Lai J, l'Homer A, Lezaud L, Lorenz C, Mercier H, Parfenoff A. 1972. Contribution  
644 à l'étude de Carry-le-Rouet (Bouches du Rhône). *Mémoires du BRGM* 3, 132 p.

645 Anglada R, Arlhac P, Blanc JJ, Blanc-Vernet L, Catzigras F, Colomb E, Damiani L, Durand  
646 JP, Durozoy G, Guieu G, Masse JP, Nury D, Philip J, Picard J, Rouire J, Rousset C, Roux  
647 RM, Triat H. 1979. Notice explicative de la Carte géologique de la France (1/50 000), feuille  
648 Martigues-Marseille, 2ème édition (1020-1043). Bureau de Recherches Géologiques et  
649 Minières, 52p.

650 Anonyme. 1742. Sur le succin. *In Histoire de l'Académie royale des Sciences*. Imprimerie  
651 Royale, Paris, 47-50.

652 Antoine P-O, de Franceschi D, Flynn JJ, Nel A, Baby P, Benammi M, Calderon Y, Espurt N,  
653 Goswami A, Salas-Gismondi R. 2006. Amber from western Amazonia reveals neotropical  
654 diversity during the middle Miocene. *Proceedings of the National Academy of Sciences of*  
655 *the United States of America* 103: 13595-13600.

656 Aquilina L, Girard V, Henin O, Bouhnik-Le Coz M, Vilbert D, Perrichot V, Néraudeau D.  
657 2013. Amber inorganic geochemistry: New insights into the environmental processes in a  
658 Cretaceous forest of France. *Palaeogeography, Palaeoclimatology, Palaeoecology* 369:  
659 220-227.

660 Aweng E. 1894. Über den succinit. *Archiv f. Pharmacie*, CCXXXII : 660-688.

661 Babinot J-F, Durand J-P. 1980. Les étages continentaux du Crétacé supérieur et du Paléocène  
662 en Provence. *Mémoires du BRGM* 109: 171-192.

663 Beck WC, Liu T. 1976. II Origine de l'ambre des grottes du Hasard et du Prevel. *Gallia*  
664 *préhistoire* 19(1) : 201-207

665 Beudant FS. 1832. Traité élémentaire de minéralogie. Tome II, Verdière éditeur, 797 p.

666 Blanc JJ, Masse JP, Triat JM, Truc G, Anglada R, Colom E, Clauzon G, Durozoy G, Damiani  
667 L, Glintzboeckel G, Rouire J. 1975. Carte géologique de la France à 1/50 000, Carpentras.  
668 BRGM, Orléans, 24 p.

669 Bonnemère L. 1886. L'ambre dans le département des Basses-Alpes. *Bulletins et Mémoires de*  
670 *la Société d'Anthropologie de Paris* IIIème série 9 : 122-123.

671 Bréhéret JG. 1997. L'Aptien et l'Albien de la fosse Vocontienne (des bordures au bassin) :  
672 évolution de la sédimentation et enseignements sur les évènements anoxiques. *Publication*  
673 *de la Société Géologique du Nord* 25, 614 p.

674 Brignon A. 2018. Nouvelles données historiques sur les premiers dinosaures trouvés en France.  
675 *Bulletin de la Société Géologique de France* 189(1), 4, doi.org/10.1051/bsgf/2018003, 19 p.

676 Brongniart A. 1807. Traité élémentaire de minéralogie avec des applications aux arts. Deterville  
677 éditeur, Paris, 443 p.

678 Brongniart A. 1823. Lignite. In : *Dictionnaire des Sciences Naturelles*, Levrault éditeur, tome  
679 26 : 239-240.

680 Brongniart A. 1827. Succin. In : *Dictionnaire des Sciences Naturelles*, Levrault éditeur, tome  
681 51 : 229-240.

682 Brongniart A. 1829. Théorie de la structure de l'écorce terrestre, ou des terrains qui la  
683 composent. In : *Dictionnaire des Sciences Naturelles*, Levrault éditeur, tome 54 : 1-256.

684 Buddhue J. D. 1938. *The mineralogist*, 6(1) : 20-21.

685 Buffetaut E, Cornée JJ. 1982. Le crocodylien *Diplocynodon* (*Eusuchia*, *Alligatoridae*) dans la  
686 « série du gypse d'Aix » à Venelles (Bouches-du-Rhône, France). *Geobios* 15(2) : 209-215.

687 Buffon Leclerc de L. 1802. Histoire naturelle, générale et particulière des minéraux, t. 9. Dufart,  
688 Paris, 477 p.

689 Calvillo-Canadell L, Cevallos-Ferriz S, Rico-Arce L. 2010, Miocene Hymenaea flowers  
690 preserved in amber from Simojovel de Allende, Chiapas, México. *Review of Palaeobotany*  
691 *and Palynology* 160: 126-134.

692 Cessac de M.P. 1874. L'ambre en France aux temps préhistoriques. Ambre noir (jayet) – Ambre  
693 jaune (succin). Réponse à M. Cartailhac. *Bulletin Monumental* 4 : 347-373.

694 Chaptal JA. 1807. Chimie appliquée aux arts. Tome 2, Deterville libraire, Paris, 544 p.

695 Choufani J., Perrichot V., Girard V., Garrouste R., Azar D., Nel A. 2013. Two new biting  
696 midges of the modern type from Santonian amber of France (Diptera: Ceratopogonidae). In  
697 Azar D, Engel MS, Jarzembowski E, Krogmann L, Nel A. and Santiago-Blay J. (Editors).  
698 *Insect Evolution in an Amberiferous and Stone Alphabet*. Proceedings of the 6th  
699 International Congress on Fossil Insects, Arthropods and Amber, Brill, 73-95.

700 Cockx P, McKellar R, Tappert R, Vavrek M, Muehlenbachs K. 2020. Bonebed amber as a new  
701 source of paleontological data: The case of the Pipestone Creek deposit (Upper Cretaceous),  
702 Alberta, Canada. *Gondwana Research* 81: 378-389

703 Cojan I., Moreau M-G. 2006. Correlation of terrestrial climatic fluctuations with global signals  
704 during the upper Cretaceous/Danian in a compressive setting (Provence, France). *Journal of*  
705 *Sedimentary Research* 76: 589-604.

706 Collot L. 1890. Description du terrain créacé dans une partie de la Basse-Provence. *Bulletin de*  
707 *la Société géologique de France* (sér.3) XVIII : 49-102.

708 Conesa G, Demory F, Le Doussal C, Londeix L, Pagès JS. 2014. L'Aquitainien en France. In :  
709 *Stratotype Aquitainien*, Muséum national d'Histoire naturelle de Paris, Biotope, Meze, 163-  
710 180.

711 Coquand H. 1860. Rapports qui existent entre les groupes de la craie moyenne et de la craie  
712 supérieure de la Provence et du sud-ouest de la France. *Bulletin de la Société Géologique de*  
713 *France* (sér.2) XVIII: 133-162.

714 Coquand H. 1864. Description géologique de la Sainte-Baume (Provence). Ed. Arnaud et  
715 Comp., Marseille, 85 p.

716 Cotillon P, Lemoigne Y. 1971. A propos d'une découverte de fragments ligniteux dans l'Albien  
717 d'Hyèges (Basses-Alpes). Précisions sur la répartition de bois flottés de Gymnospermes dans  
718 l'Albien moyen de Haute-Provence. *Publications de la Société Linnéenne de Lyon* 40(8) :  
719 249-250.

720 Cuvier G, Brongniart A. 1822. Description *géologique des environs de Paris*. Chez P. Dufour  
721 et E. d'Ocagne libraires, Paris, 685 p.

722 Darluc M. 1784. Histoire naturelle de la Provence. Tome 2. Jean Mossy imprimeur, Marseille,  
723 315 p.

724 Daubenton L. 1751. Ambre jaune. In: Diderot D. and D'Alembert (eds.) *Encyclopédie ou*  
725 *dictionnaire raisonné des sciences, des arts et des métiers*, 1<sup>ère</sup> édition, Volume 1, 324-326.

726 Demory F, Conesa G, Oudet G, Mansouri H, Münch P, Borgomano J, Thouveny N, Lamarche  
727 J, Gisquet F, Marié L. 2011. Magnetostratigraphy and paleoenvironments in shallow-water  
728 carbonates: the Oligocene-Miocene sediments of the northern margin of the Liguro-  
729 Provençal basin (West Marseille, southeastern France). *Bulletin de la Société géologique de*  
730 *France* 182(1): 37-55.

731 Desailly L. 1930. L'Ambre jaune fossile en France et en Belgique. *Bulletin de la Société*  
732 *préhistorique de France* 27(6) : 360-362.

733 Desoignies J. 1971. Notice explicative de la feuille Orange à 1/50000 (914) Bureau de  
734 Recherche Géologique et Minière, 13 p.

735 Drée de E. 1811. Catalogue des huit collections qui composent le musée minéralogique. Potey,  
736 Paris, 295 p.

737 Dumas E. 1876. Statistique géologique, minéralogique, métallurgique et paléontologique du  
738 département du Gard. Paris, Nimes, Alais, 2<sup>ème</sup> partie, 723 p.

739 Expilly JJ. Abbé, 1768. Dictionnaire géographique, historique et politique des Gaules et de la  
740 France. Tome 5, Desaint & Saillant Libraires, Paris, 1064 p.

741 Fabre-Taxy S. 1951. Faunes lagunaires et continentales du Crétacé supérieur de Provence II :  
742 le Campanien fluvio-lacustre. Masson et Cie edition, Paris, 51p.

743 Fabre-Taxy S. 1959. Faunes lagunaires et continentales du Crétacé supérieur de Provence III :  
744 le Maestrichtien et le Danien. Masson et Cie edition, Paris, 75p.

745 Frémy E. (1885). Encyclopédie chimique Tome 2. Dunod éditeur, Paris, 508 p.

746 Frau C, Saint Martin J-P, Saint Martin S, Mazières B. 2020. An overview of the Santonian  
747 amber-bearing deposits of the Sainte-Baume Massif, southeastern France. *Bulletin de la*  
748 *Société Géologique de France*, this volume.

749 Galippe V. 1920. Recherche sur la résistance des microzymas à l'action du temps et sur leur  
750 survivance dans l'ambre. *Comptes Rendus de l'Académie des Sciences de Paris*170: 856-  
751 858.

752 Garcia G., Duffaud S., Feist M., Marandat B., Tambareau Y., Villatte J. and Sigé B. 2000. La  
753 Neuve, gisement à plantes, invertébrés et vertébrés du Bégudien (Sénoniens supérieur  
754 continental) du bassin d 'Aix-en-Provence. *Geodiversitas* 22: 325-348.

755 Gardin du C. 1986. La parure d'ambre à l'âge du Bronze en France. *Bulletin de la Société*  
756 *préhistorique française* 83(11-12) : 546-588.

757 Gervais P. 1848-1852. Zoologie et paléontologie françaises (animaux vertébrés) ou nouvelles  
758 recherches sur les animaux vivants et fossiles de la France. Arthus Bertrand, Paris, 271 p.

759 Gomez B, Barale G, Saad D, Perrichot V. 2003. Santonian Angiosperm-dominated leaf-  
760 assemblages from Piolenc (Vaucluse, Sud-Est de la France). *Comptes Rendus Palevol* 2:  
761 197-204.

762 Gradstein F, Ogg J, Schmitz M. and Ogg G. 2012. *The Geologic Time Scale 2012*. Elsevier  
763 Science Ltd., 1176p.



764 Gradstein FM, Ogg JG, Schmitz MB, Ogg GM. 2020. Geologic Time Scale 2020. Elsevier  
765 Science & Technology, 1300 p.

766 Graffenauer J.P. 1821. Histoire naturelle, chimique et technique du succin ou ambre jaune.  
767 Levrault, Paris, 99 p.

768 Gras S. 1862. Description géologique du département de Vaucluse. F. Savy Édité., Paris, 438 p.

769 Guieu G, Ricour J, Rouire J. 1996. Découverte géologique de Marseille et de son décor  
770 montagneux. Editions Jeanne Lafitte, Marseille, 215 p.

771 Guiliano M, Mille G, Onoratini G, Simon P, 2006. Présence d'ambre dans le Crétacé supérieur  
772 (Santonien) de La Mède à Martigues (Sud-Est de la France); caractérisation IRTF. *Comptes*  
773 *Rendus Palevol* 5 : 851-858.

774 Guyonnet-Benaize C, Lamarche J, Masse JP, Villeneuve M, Viseur S. 2010. 3D structural  
775 modelling of small-deformations in poly phase faults pattern, Application to the Mid-  
776 Cretaceous Durance uplift, Provence (SE France). *Journal of Geodynamics* 50: 81-93.

777 Jacob C. 1907. Études paléontologiques et stratigraphiques sur la partie moyenne des terrains  
778 crétacés dans les Alpes françaises et les régions voisines. Allier Frères, Grenoble, 315 p.

779 Jan Du Chêne R, Gorin G, Van Stuijvenberg J. 1975. Etude géologique et stratigraphique  
780 (palynologie et nannoflore calcaire) des Grès des Voirons (Paléogène de Haute-Savoie,  
781 France). *Géologie Alpine* 51 : 51-78.

782 Joly B. 2008. Aptian and Albian Phylloceratids (Ammonoidea) from the Vocontian Basin (SE  
783 France). *Carnets de Geologie, Carnets de Géologie*, CG2008 (M04) : 1-60.

784 Kennedy JW, Gale Andy S, Huber BT, Petrizzo MR, Bown P, Jenkyns C. 2017. The Global  
785 Boundary Stratotype Section and Point (GSSP) for the base of the Albian Stage, of the  
786 Cretaceous, the Col de Pré-Guittard section, Arnayon, Drôme, France. *Episodes* 40(3):177-  
787 188.

788 Kilian W. Description géologique de la montagne de Lure (Basses Alpes). Masson éditeur,  
789 Paris, 458 p.

790 Lacroix A. 1910. Résines fossiles. In: Lacroix, A. (Ed.) *Minéralogie de la France et de ses*  
791 *colonies*, 4. Librairie polytechnique, Paris, pp. 637-645.

792 Lavoisier AL. 1765. Sur des morceaux de succin ou ambre jaune qui se trouvent dans une fouille  
793 aux environs de Dangu. In : *Œuvres de Lavoisier publiées par les soins du Ministre de*  
794 *l'Instruction Publique*, Imprimerie Nationale, tome V, 1892 : 287-289.

795 Matheron P. 1839. Essai sur la constitution géognostique du département des Bouches-du-  
796 Rhône. *Répertoire des travaux de la Société de Statistique de Marseille* 3 : 5-133.

797 Matheron P. 1843. Catalogue méthodique et descriptif des Corps organisés fossiles du  
798 département des Bouches-du-Rhône et lieux circonvoisins ; précédé d'un Mémoire sur les  
799 terrains supérieurs au grès bigarré du S.E. de la France. *Répertoire des travaux de la Société*  
800 *de Statistique de Marseille* 6 : 81-341.

801 Médus J. 1970. Une analyse morphologique de quelques populations polliniques du Santonien  
802 de Piolenc (France). *Palaeontographica*, B. 130: 1–11.

803 Malartre F. 1994. Stratigraphie séquentielle du Crétacé supérieur du bassin vocontien  
804 occidental. Comparaison avec d'autres bassins. *Documents du Laboratoire de Géologie de*  
805 *Lyon* 131, 219 p.

806 Mennessier G. 1949. Sur la présence de Rudistes dans un sédiment hautement ligniteux à  
807 Piolenc. *Comptes Rendus sommaires de la Société Géologique de France* 19 : 215-217.

808 Mennessier G. 1950. Monographie géologique du Massif d'Uchaux (Vaucluse). *Bulletin du*  
809 *Service de la Carte géologique de France* 227, XLVIII, 50p.

810 Meunier S. 1885. Combustibles minéraux. In : Frémy (éd.) *Encyclopédie chimique*. Tome II.-  
811 Complément 1ère partie : 35-509.

812 McKellar RC, Jones E, Engel MS, Tappert R, Wolfe AP, Muehlenbachs K, Cockx P, Koppelhus  
813 EB, Currie PJ. 2019. A direct association between amber and dinosaur remains provides  
814 paleoecological insights. *Scientific Reports* **9**, 17916: 7 p.

815 Monier P., Cavelier C. 1991. Carte géologique et notice de la carte géologique de Vaison-la-  
816 Romaine au 1: 50 000. BRGM, Orleans, 53 p.

817 Nel A, de Ploëg G, Menier JJ, Waller A. 2004. The French ambers: a general conspectus and  
818 the Lowermost Eocene amber deposit of Le Quesnoy in the Paris Basin. *Geologica Acta* **2**:  
819 3-8.

820 Nel A, Garrouste R, Daugeron C. 2017. Two new long-legged flies in the Santonian amber of  
821 France (Diptera: Dolichopodidae). *Cretaceous Research*, **69**: 1-5.

822 Néraudeau D, Allain A, Perrichot V, Videt B, De Lapparent De Broin F, Guillocheau F,  
823 Philippe M, Rage JC, Vullo R. 2003. Découverte d'un dépôt paralique à bois fossiles, ambre  
824 insectifère et restes d'Iguanodontidae (Dinosauria, Ornithopoda) dans le Cénomaniens  
825 inférieur de Fouras (Charente-Maritime, Sud-Ouest de la France). *Comptes Rendus Palevol*  
826 **2** : 221-230.

827 Néraudeau D, Perrichot V, Batten D, Boura A, Girard V, Jeannau L, Nohra YA, Polette F, Saint  
828 Martin S, Saint Martin J-P, Thomas R. 2017. Upper Cretaceous amber from Vendée, north-  
829 western France: Age dating and geological, chemical, and palaeontological characteristics.  
830 *Cretaceous research* **70**: 77-95.

831 Néraudeau D, Vullo R, Gomez B, Perrichot V, Videt B. 2005. Stratigraphie et paléontologie  
832 (plantes, vertébrés) de la série paralique Albien terminal-Cénomaniens basal de Tonnay-  
833 Charente (Charente-Maritime, France). *Comptes Rendus Palevol* **4** : 79-94.

834 Néraudeau D, Vullo R, Gomez B, Girard V, Lak M, Videt B, Perrichot V. 2009. Amber, plant  
835 and vertebrate fossils from the Lower Cenomanian paralic facies of Aix Island (Charente-  
836 Maritime, SW France). *Geodiversitas* **31**: 13-28.

837 Nguyen Duy-Jacquemin M, Azar D. 2004. The oldest records of Polyxenida (Myriapoda,  
838 Diplopoda): new discoveries from the Cretaceous ambers of Lebanon and France.  
839 *Geodiversitas* 26 : 631–641.

840 Nohra Y, Perrichot V, Jeanneau L, Le Pollès L., Azar D. (2015). Chemical characterization and  
841 botanical origin of French ambers. *Journal of Natural Products* 78, 1284-1293.

842 Nury D. 1988. L'Oligocène de Provence méridionale : stratigraphie, dynamique sédimentaire,  
843 reconstitutions paléogéographiques. *Doc. B.R.G.M.* 163: 1-411.

844 Nury D. 1994. Relations géométriques entre carbonates et évaporites. Exemple de l'Oligocène  
845 terminal de la région d'Aix-en-Provence, Marseille (France). *Géologie Méditerranéenne*  
846 21(1-2) : 85-94

847 Onoratini G, Guiliano M, Asia L, Mille G, Simon P. 2009a. L'ambre dans le Sud-Est de la  
848 France, ressources géologiques et utilisation archéologique. *Bulletin du Musée*  
849 *d'Anthropologie préhistorique de Monaco* 49 : 3-20.

850 Onoratini G, Guiliano M, Mille G, Simon P. 2009b. L'ambre albo-cénomaniens de la montagne  
851 de Lure (Alpes-de-Haute-Provence), outil stratigraphique et paléogéographique. *Geobios*  
852 42: 89-99.

853 Ospina-Ostios LM, Ragusa J, Wernli R, Kindler P. Planktonic foraminifer biostratigraphy as a  
854 tool in constraining the timing of flysch deposition: Gurnigel flysch, Voirons massif (Haute-  
855 Savoie, France). *Sedimentology* 60 : 225-238.

856 Oudet J, Münch P, Borgomano J, Quillévéré F, Melinte Dobrinescu MC, Demory F, Viseur S,  
857 Cornée JJ. 2010. Land and sea study of the northeastern golfe du Lion rifted margin. *Bulletin*  
858 *de la Société géologique de France* 181(6) : 591-607.

859 Papon JP. 1776. Histoire générale de Provence. Moutard éditeur, Paris, 689 p.

860 Patrin E.M.L. 1819. Succin. In : *Nouveau dictionnaire d'histoire naturelle*. Deterville éditeur,  
861 Paris, tome 32 : 262-271.

- 862 Penney D. (2010). Dominican amber. In Penney D. (ed.) *Biodiversity of Fossils in Amber from*  
863 *the Major World Deposits*, Siri Scientific Press, Manchester, 22-41.
- 864 Perdonnet A., Flachet E., Burat J., Burat A. 1837. Notice sur les combustibles minéraux  
865 reconnus en France. *Journal de l'industriel et du capitaliste* 3 : 321-365.
- 866 Perrichot V., Nel A., Guilbert E., Néraudeau D. 2006. Fossil Tingoidea (Heteroptera:  
867 Cimicomorpha) from French Cretaceous amber, including Tingidae and a new family,  
868 Ebboidae. *Zootaxa* 1203: 57-68.
- 869 Perrichot V, Néraudeau D, Nel A, de Ploëg G. 2007. A reassessment of the Cretaceous amber  
870 deposits from France and their palaeontological significance. *African Invertebrates* 48: 213-  
871 227.
- 872 Perrichot V, Néraudeau D, Tafforeau P. 2010. Charentese amber. In: Penney D. (ed.).  
873 *Biodiversity of Fossils in Amber from the Major World Deposits*, Siri Scientific Press,  
874 Manchester, 192-207.
- 875 Philip J. 1970. Les formations calcaires à Rudistes du Crétacé supérieur Provençal et  
876 Rhodanien. Unpublished Thesis, Univ. Provence, Marseille, France. 438 p.
- 877 Philip J, Gari J. 2005. Late Cretaceous heterozoan carbonates: Palaeoenvironmental setting,  
878 relationships with rudist carbonates (Provence, south-east France). *Sedimentary Geology*  
879 175: 315-337.
- 880 Philippe M, Gomez B, Girard V, Coiffard C, Daviero-Gomez V, Thevenard F, Billon-Bruyat  
881 JP, Guiomar M, Latil JL, Le loeuff J, Néraudeau D, Olivero D, Schlög J. 2008. Woody or  
882 not woody? Evidence for early angiosperm habit from the Early Cretaceous fossil wood  
883 record of Europe. *Palaeoworld* 17 : 142-152.
- 884 Ragazzi E, Giaretta A, Perrichot V, Néraudeau D, Schmidt AR, Roghi G. 2009. Thermal  
885 analysis of Cretaceous ambers from southern France. *Geodiversitas* 31: 163-175.

886 Ragusa J. 2015. *Péetrographie, stratigraphie et provenance du Flysch des Voirons: nappe du*  
887 *Gurnigel, Haute-Savoie, France*. Unpublish thesis, Université de Genève, 384 p..

888 Saint Martin JP., Saint Martin S. 2018. Exquisite preservation in Cretaceous French ambers of  
889 a widespread but controversial filamentous microorganism. *Comptes Rendus Palevol* 17:  
890 415-434.

891 Saint Martin JP., Saint Martin S. 2020. Amber, from deposit to inclusions: new data. *Bulletin*  
892 *de la Société Géologique de France*, ce volume.

893 Saint Martin S, Saint Martin JP, Girard V, Néraudeau D, Grosheny D. 2012. Filamentous micro-  
894 organisms in Upper Cretaceous amber (Martigues, France). *Cretaceous Research*. 35: 217-  
895 229.

896 Saint Martin S, Saint Martin JP, Girard V, Néraudeau D. 2013. Organismes filamenteux de  
897 l'ambre du Santonien de Belcodène (Bouches-du-Rhône, France). *Annales de Paléontologie*  
898 99(4): 339-360.

899 Saskevitch SS, Popkova TN. 1978. Données nouvelles dans l'étude minéralogique de résines  
900 fossiles de France. *Bulletin de Minéralogie* 101 (4): 442-447.

901 Serrano-Sánchez M de L., Hegna TA, Schaaf P, Pérez L, Centeno-García E, Vega FJ. 2015.  
902 The aquatic and semiaquatic biota in Miocene amber from the Campo LaGranja mine  
903 (Chiapas, Mexico) : Paleoenvironmental implications. *Journal of South American Earth*  
904 *Sciences* 62: 243-25.

905 Seyfullah LJ, Beimforde C, Dal Corso J, Perrichot V, Rikkinen J, Schmidt AR. 2018.  
906 Production and preservation of resins - past and present. *Biological reviews* 93: 1684-1714.

907 Solórzano Kraemer MM. 2010. Mexican amber. In: Penney D. (ed.). *Biodiversity of Fossils in*  
908 *Amber from the Major World Deposits*, Siri Scientific Press, Manchester, 42-56.

909 Sornay J. 1945-1946. Le crétacé supérieur dans l'ouest du département de la Drôme et dans les  
910 régions voisines. *Travaux du Laboratoire de Géologie de Grenoble* 25: 9-31.

911 Tercier J. 1928. Géologie de la Berra. *Matériaux pour la Carte géologique de la Suisse* 60 : 1-  
912 111.

913 Tortosa T. 2014. Vertébrés continentaux du Crétacé supérieur de Provence (Sud-Est de la  
914 France). Unpublish thesis, Université Paris 6, 582p.

915 Triat JM, Médus J. 1970. Données sédimentologiques et palynologiques sur le Santonien  
916 inférieur gréseux à lignites de Piolenc (Vaucluse). *Comptes Rendus de l'Académie des*  
917 *Sciencesde Paris*, Ser D 271 : 1256-1259.

918 Triat JM. 1982. Paléaltérations dans le Crétacé supérieur de Provence rhodanienne. *Sciences*  
919 *Géologiques*, Strasbourg 68 : 1-202.

920 Tribovillard N-P, Gorin GE. 1991. Organic facies of the Early Albian Niveau Paquier, a key  
921 black shales horizon of the Marnes Bleues Formation in the Vocontian Trough (Subalpine  
922 Ranges, SE France). *Palaeogeography, Palaeoclimatology, Palaeoecology* 85: 227-237.

923 Valmont de Bomare JC. 1774. Minéralogie ou nouvelle exposition du règne minéral. t. 2,  
924 Vincent Imp., Paris, 637 p.

925 Vasseur G. 1894. Compte rendu d'excursions géologiques aux Martigues et à l'Estaque  
926 (Bouches-du-Rhône). *Bulletin de la Société Géologique de France* 22: 413-444.

927

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930 Table 1: List of Provence amber-bearing sites visited and sampled with indication of age,  
931 location and studied material status. MNHN: Muséum National d'Histoire Naturelle de Paris ;  
932 MHNA: Muséum d'Histoire Naturelle d'Aix-en-Provence ; UP : University of Poitiers ; PC :  
933 private collection.

934 Figure 1. Distribution map of amber-bearing sites in Provence. A: Situation in France of the  
935 area concerned; B: Amber sites verified: 1. Piolenc (Vaucluse), 2. Bédoin (Vaucluse), 3.  
936 Salignac (Alpes de Haute Provence), 4. Aubignosc (Alpes de Haute Provence), 5. Forcalquier  
937 sector (Alpes de Haute Provence), 6. Martigues (Bouches du Rhône), 7. Martigues-La Mède  
938 (Bouches du Rhône), 8. Carry-le-Rouet (Bouches du Rhône), 9. Ensues (Bouches du Rhône),  
939 10. Venelles (Bouches du Rhône), 11. Belcodène (Bouches du Rhône), 12. Plan d'Aups (Var),  
940 13. Mazaugues (Var). Amber sites reported not yet verified : A. Rustrel (Vaucluse), B.  
941 Eygaliers (Drôme), C. Valbelle-Tour de Bevons (Alpes de Haute Provence), D. Saint-Geniez-  
942 de-Dromont (Alpes de Haute Provence), E. Blioux (Alpes de Haute Provence), F. Allauch  
943 (Bouches du Rhône). © d-maps.com.

944 Figure 2. Location of the two main amber-bearing sites in the Vaucluse department, Piolenc  
945 and Bédoin. © Google Earth 2020.

946 Figure 3. Piolenc site. A: view of the outcrops at the quarry level showing the different amber  
947 harvesting points (arrows); B: view of the lower part of the section with the reference level  
948 (level e of Gomez *et al.*, 2003); C: side view of the section; D: occurrence of amber grains in  
949 the lower woody level; E: grains of amber in the root level.

950 Figure 4. Piolenc site. A: amber grains in a sandstone level; B: nodule and grain of amber  
951 (arrows) in sandy marls; C: opaque orange amber nodule in more or less flaky sandy marl. D:



952 grains of amber in a gangue made up of woody fragments; E: Appearance of translucent amber  
953 grains; F: completely opaque earthy-looking amber grains; G: thin blades of amber nodules  
954 showing the gangue rich in vegetable organic matter; H: thin blades of translucent amber grains  
955 in the form of drops with their characteristic red envelope; I: thin blades of opaque amber grains  
956 showing the invasion of the grain by impurities; J: views of amber grains in SEM with a  
957 translucent appearance (two copies on the left) with possibly a visible crust (arrow) or opaque  
958 (two copies on the right). (MNHN collection).

959 Figure 5. Bédoin site. A: view of the cliffs showing the sandstone series ocrified towards the  
960 base with the situation of the amber level (arrow); B: view of the outcrops showing the ocher  
961 sandstones overlain by the amber level (arrow); C: detail of the cliff and situation of sampled  
962 amber nodules (arrow); D: view of the level containing several amber nodules (arrows); E:  
963 detail of an amber nodule *in situ*; F: detail of an amber nodule *in situ* showing the co-occurrence  
964 of black plant debris.

965 Figure 6. Bédoin site. A: Appearance of harvested amber, from reddish to opaque transluents  
966 grains; B: Opaque nodule; C: thin sections showing the arrangement of the various resin flows  
967 underlined by blackish impurities in section. (MNHN collection).

968 Figure 7. Situation of the outcrops and sites described in the Sisteron and Montagne de Lure  
969 areas, with location of the samples (red arrows): 1. Salignac, Les Coignets (Upper Aptian) ;  
970 Salignac, Les Coulets (Upper Albian) ; 3. Aubignosc (Upper Albian). © Google Earth 2020.

971 Figure 8. Albian sites of the Sisteron area. A-D: Salignac. A: succession of Albian sediments  
972 and zone of presence of amber *in situ*; B: situation of a sampled amber nodule (arrow) within a  
973 marl-limestone succession; C: amber nodule (arrow) in a marly sediment; D: detail of the amber  
974 nodule showing its characteristic dominant red appearance. E: Outcrops containing grains of  
975 amber (arrow) in the Albian deposits cropping out at Aubignosc.

976 Figure 9. Amber from the Sisteron-Montagne de Lure region. A-B: Aptian from Salignac. C-F:  
977 Albian from Salignac. G-I: Albian from Aubignosc. J-K: Cenomanian of Saint Etienne-les-  
978 Orgues. A: nodule with an opaque orange exterior appearance showing the various resin flows  
979 which compose it; B: thin section of the nodule in photo A showing the different layers of resin;  
980 C: nodule with a characteristic reddish appearance; D: nodule with translucent court and opaque  
981 periphery; E: thin sections of nodules with translucent specimens (left), heterogeneous opaque  
982 (center), homogeneous opaque (right); F: amber nodule seen under SEM with an area (arrow)  
983 marked by filamentous networks; G: amber grain in its sandstone gangue; H: thin sections of  
984 amber grain from Aubignosc showing an opaque heterogeneous appearance; I: view of  
985 fragment of amber grain from Aubignosc under SEM; J: translucent amber grains from Saint-  
986 Etienne-les-Orgues; K: thin sections of grains showing the presence of numerous small bubbles.  
987 (MNHN collection).

988 Figure 10. Amber-bearing sites in the Martigues area. 1: Upper Cretaceous site of Martigues  
989 north; 2: Santonian site of Martigues-La Mède; 3: Aquitanian site of Carry-le-Rouet; 4:  
990 Santonian site of Ensues. © Google Earth 2020.

991 Figure 11. Santonian amber from Ensues-la-Redonne. A: Situation of the sampling areas (white  
992 squares), © Google Earth 2020.; B: Lens rich in lignite debris and amber grains east of Anse  
993 des Figuières; C: contact between the burrowed bioclastic sandstone limestone and the flaky  
994 sandy marls that yielded amber grains (arrow) (Anse des Anthénors); D: view of outcropping  
995 upper levels with masses of debris flow limestone (arrows); E: amber grains (arrows) in a  
996 marly-sandstone sediment; F: variety of harvested amber grains; G: thin sections of translucent  
997 amber grains with a thin red peripheral crust; H: thin sections of opaque grains sometimes  
998 showing great heterogeneity (example at the bottom); I: thin sections of highly fractured,  
999 crystal-like grains. (MNHN and UP collections).

1000 Figure 12. Amber from Martigues-Terres d'Ocre locality (MTO1-3). A : plan of the locality  
1001 with the three sites ; B: excavations of the zone 2 in MTO2 site (white arrow : level rich in  
1002 macro-remains of vertebrates, red arrow : level rich in amber grains) ; C : outcrop in MTO3  
1003 site ; D: logs of the three sites MTO1-3 with occurrences of fossiles in each levels ; E : outcrop  
1004 in MTO1 site (white arrow : location of MTO2 site, « F » : fault) ; F-G: amber grains coming  
1005 from the fossiliferous Level 3; H: thin sections of amber grains; I: SEM view of a grain with a  
1006 thick peripheral cracked crust (arrow); J: SEM view of an inclusion resembling a spore; K:  
1007 SEM view of the imprint of crystals of the cubic system. F-G: amber grains coming from the  
1008 fossiliferous black level; H: thin sections of amber grains; I: SEM view of a grain with a thick  
1009 peripheral cracked crust (arrow); J: SEM view of an inclusion resembling a spore; K: SEM  
1010 view of the imprint of crystals of the cubic system. (MNHN and MHNA collections).

1011 Figure 13. Oligocene amber from Venelles (white box) and views of the turtle in the matrix of  
1012 which an amber grain was found (MHNA collection).

1013 Figure 14. Carry-le-Rouet site. A: Situation of the outcrop containing the Aquitanian amber, ©  
1014 Google Earth 2020; B: view of the Aquitaine series at Anse Rousset with *Turritella* limestone  
1015 at the base (arrow) surmounted by limestones and clays with lignitous debris and bryozoans  
1016 from the Carry bioclastic Formation situation with the situation of the level sampled (red line);  
1017 C: detail of view B, the arrow indicating the location of the extraction of the amber grain; D:  
1018 view of the Aquitanian amber grain from of Carry-le-Rouet (MNHN collection).

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Table 1

<b>AMBER-BEARING SITES</b> <b>Number in Fig. 1B</b>	<b>AGE</b>	<b>LOCALISATION</b> <b>WGS 84 coordinate</b>	<b>STATUS</b>
1. Piolenc 1a. Quartier Saint Louis quarry 1b. « Montée des Béziers »	Santonian	44°11'08.8"N, 4°46'00.3"E 44°11'02.1"N, 4°45'49.6"E	MNHN-PC PC
2. Bédoin	Late Albian	44°07'36.1"N, 5°11'35.3"E	MNHN-PC
3. Salignac 3a. Les Coignets 3b. Les Coulets	Upper Aptian Upper Albian	44°10'40.0"N 5°59'17.9"E 44°10'34.6"N 5°59'29.9"E	MNHN-PC- MNHN
4. Aubignosc	Upper Albian	44°06'59.8"N, 5°57'54.4"E	MNHN-PC
6. Martigues north	Upper Campanian	43°25'31.7"N, 5°02'24.3"E	MHNA
7. Martigues-La Mède	Santonian	43°23'57.1"N, 5°04'26.9"E	MNHN
8. Carry-le-Rouet	Aquitanian	43°19'40.6"N, 5°09'35.6"E	MNHN-PC
9. Ensues-la-Redonne 9a. Calanque des Anthénors 9b. Calanque des Figuières	Santonian	43°19'52.5"N, 5°12'13.2"E 43°19'50.1"N, 5°12'27.2"E	MNHN-PC UP
10. Venelles	Upper Oligocene	43°35'53.6"N, 5°29'32.8"E	MHNA
11. Belcodène	Santonian	43°24'34.0"N, 5°34'46.0"E	MHNA-PC
12. Plan d'Aups 12a. La Brasque 12b. Downtown	Santonian	43°19'24.9"N, 5°42'23.2"E 43°21'06.2"N, 5°51'15.8"E	MNHN-PC PC
13. Mazaugues 13a. Equireuil Quarry 13b. Glacières de Pivaut	Santonian	43°21'39.6"N, 5°57'23.8"E 43°21'12.5"N, 5°51'14.2"E	MNHN-PC MNHN-PC

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Figure 1

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Figure 2

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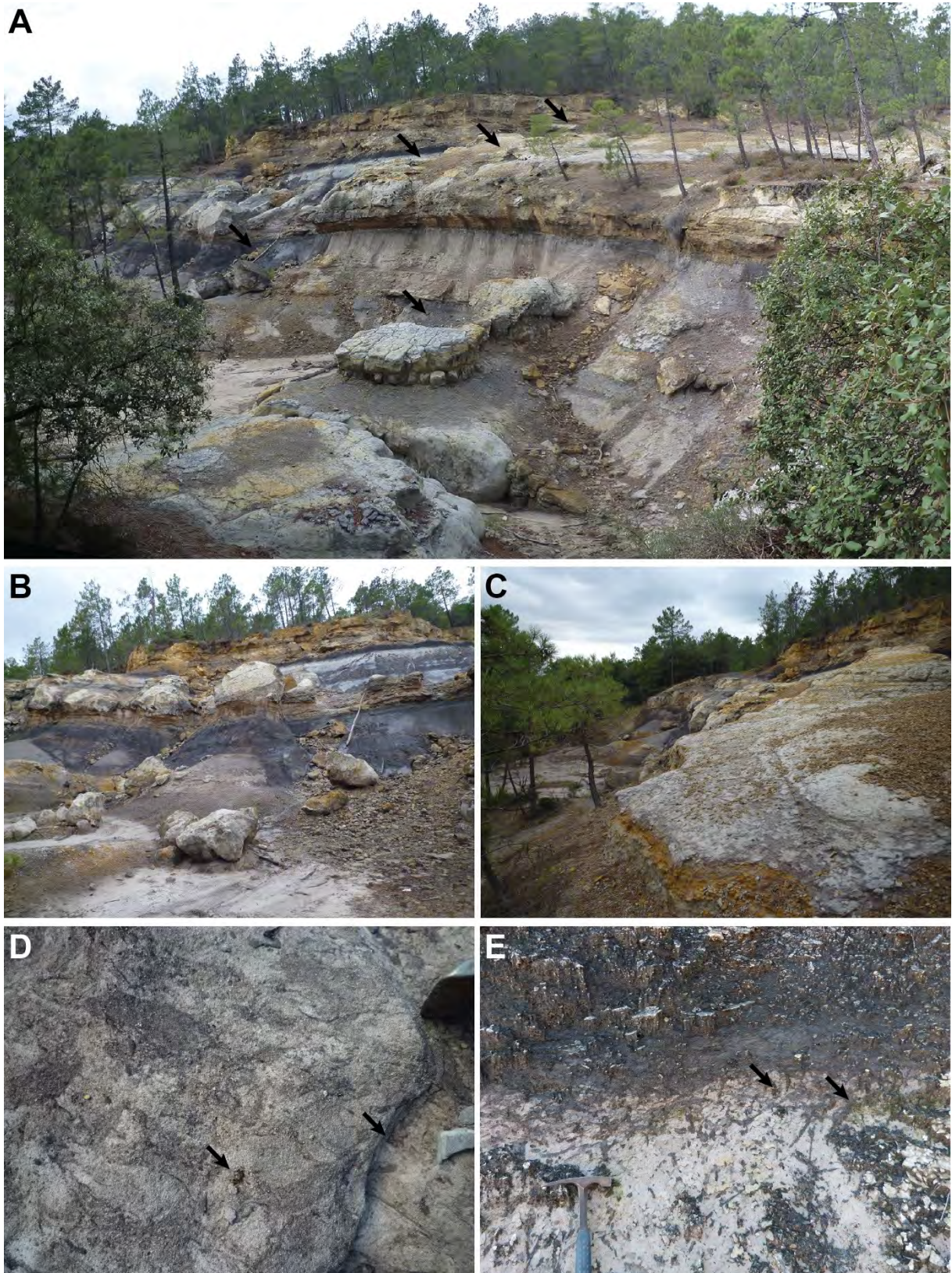
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Figure 3

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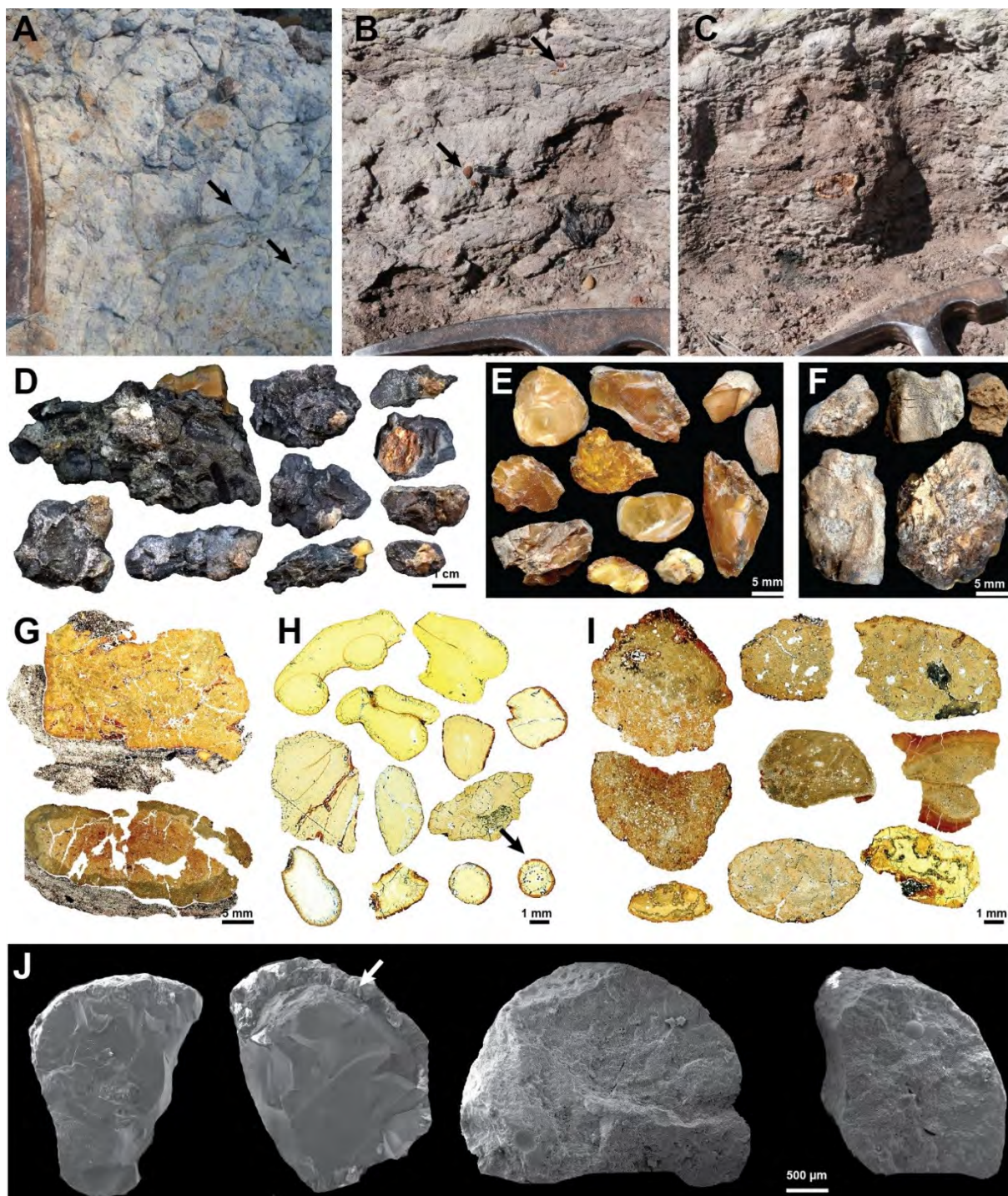




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Figure 4

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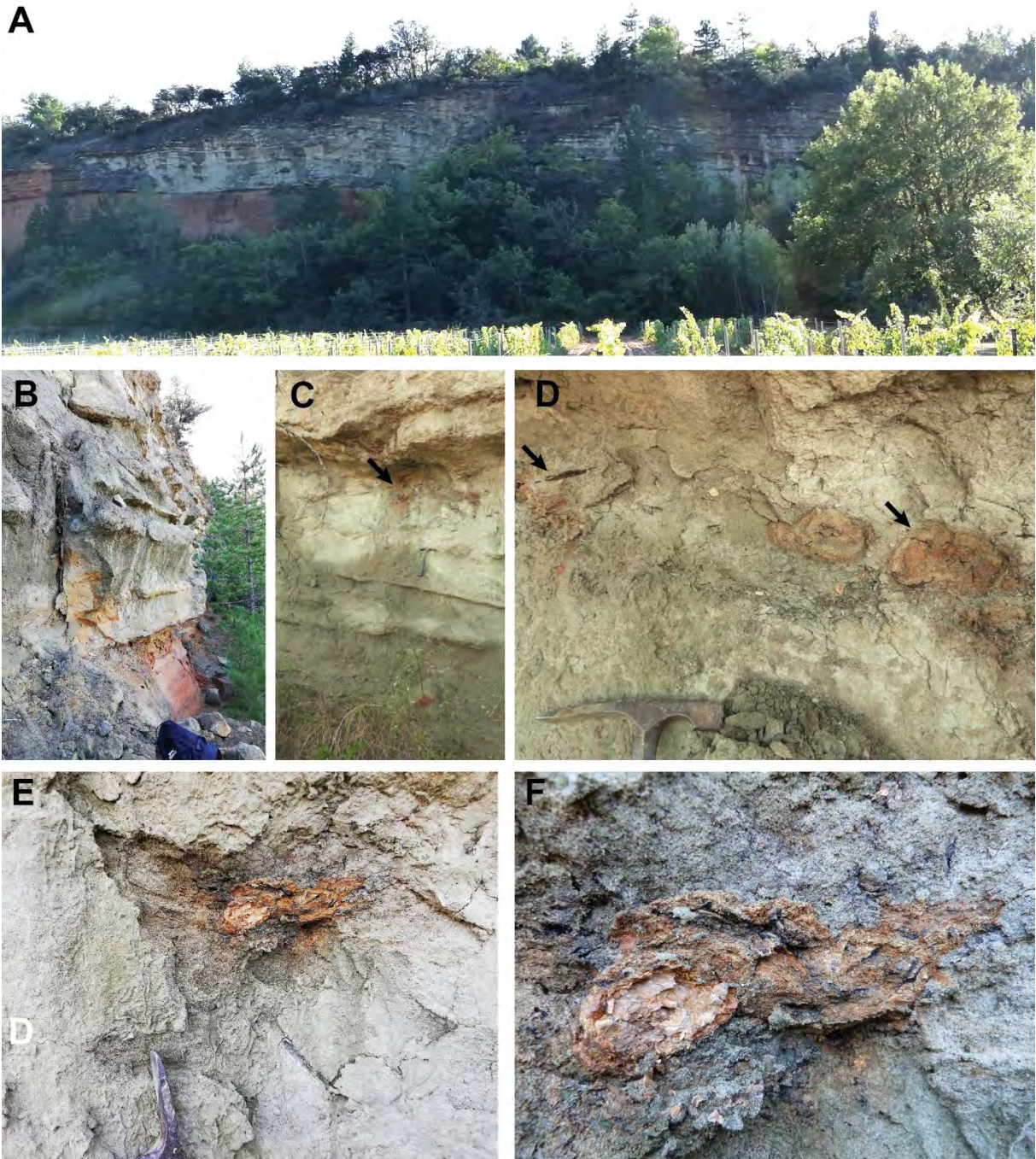
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Figure 5

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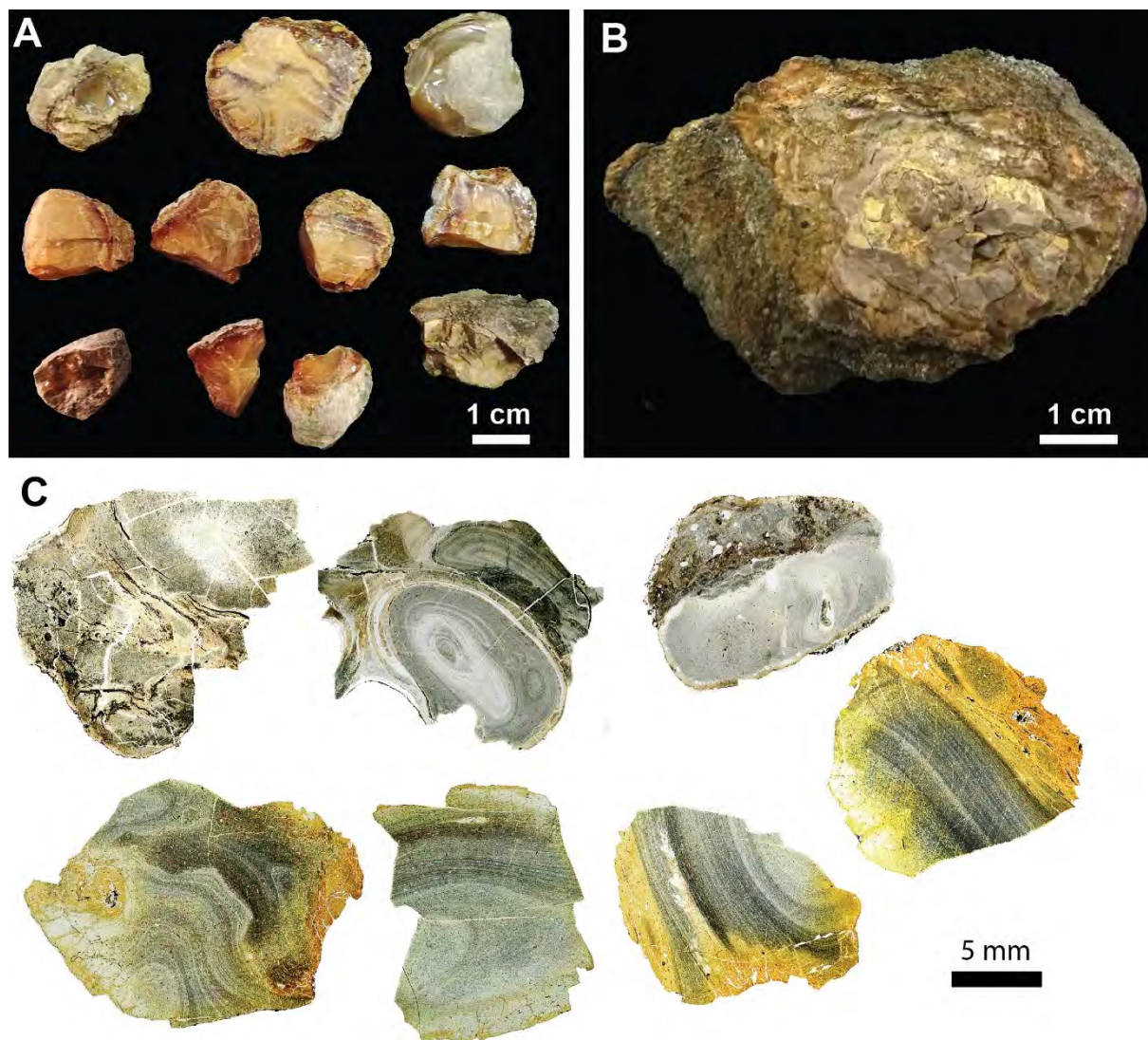
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Figure 6

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Figure 7

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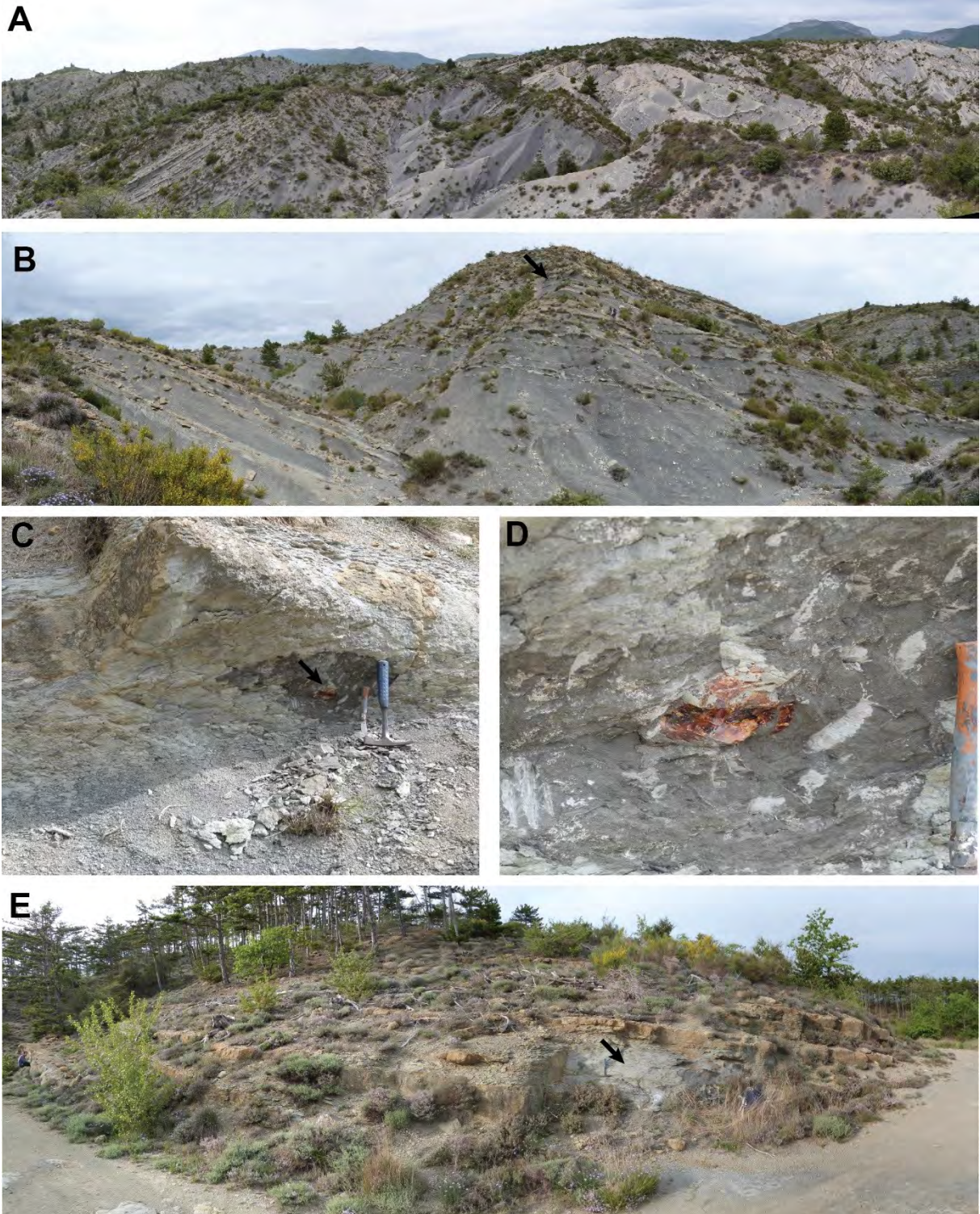
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Figure 8

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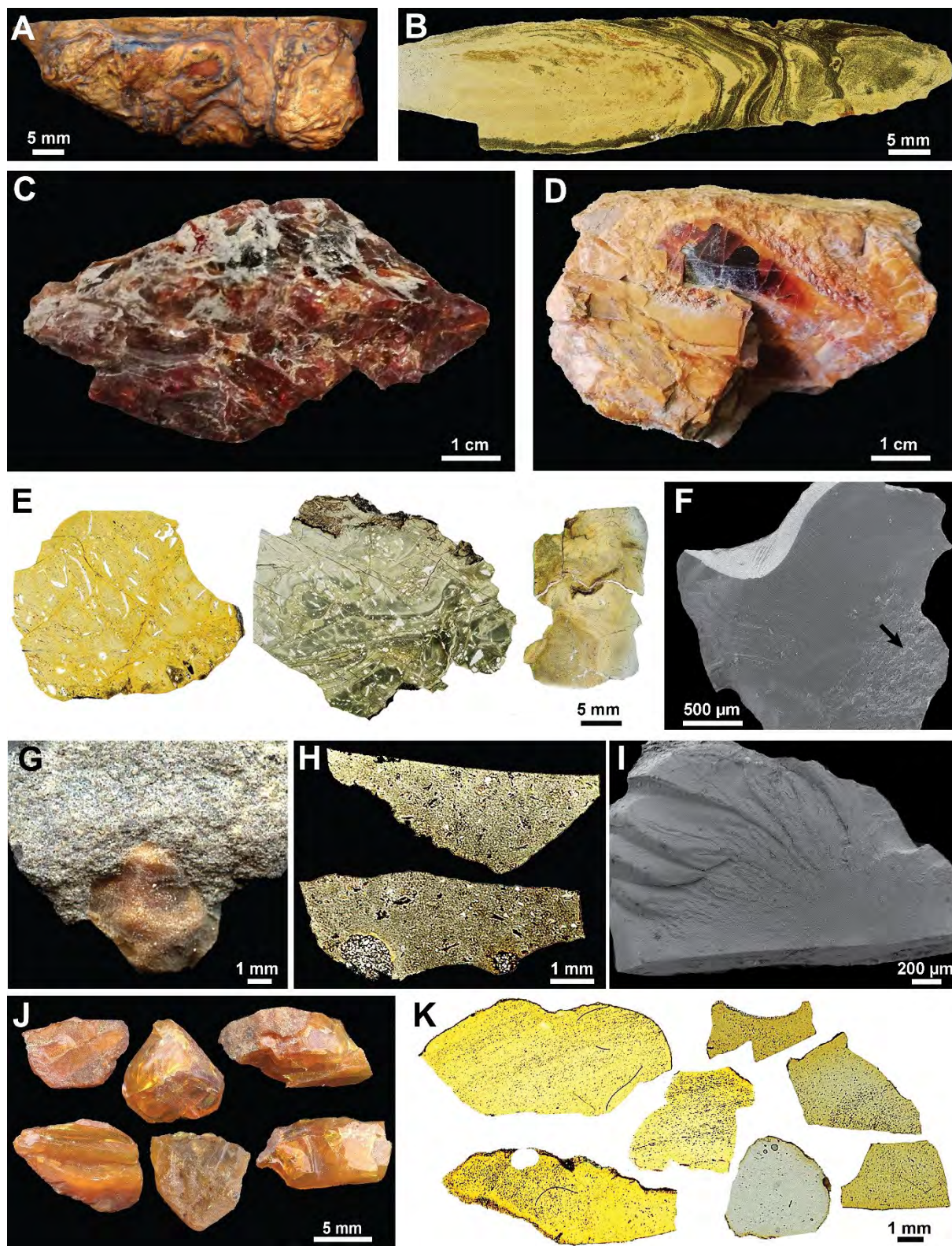
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Figure 9

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Figure 10

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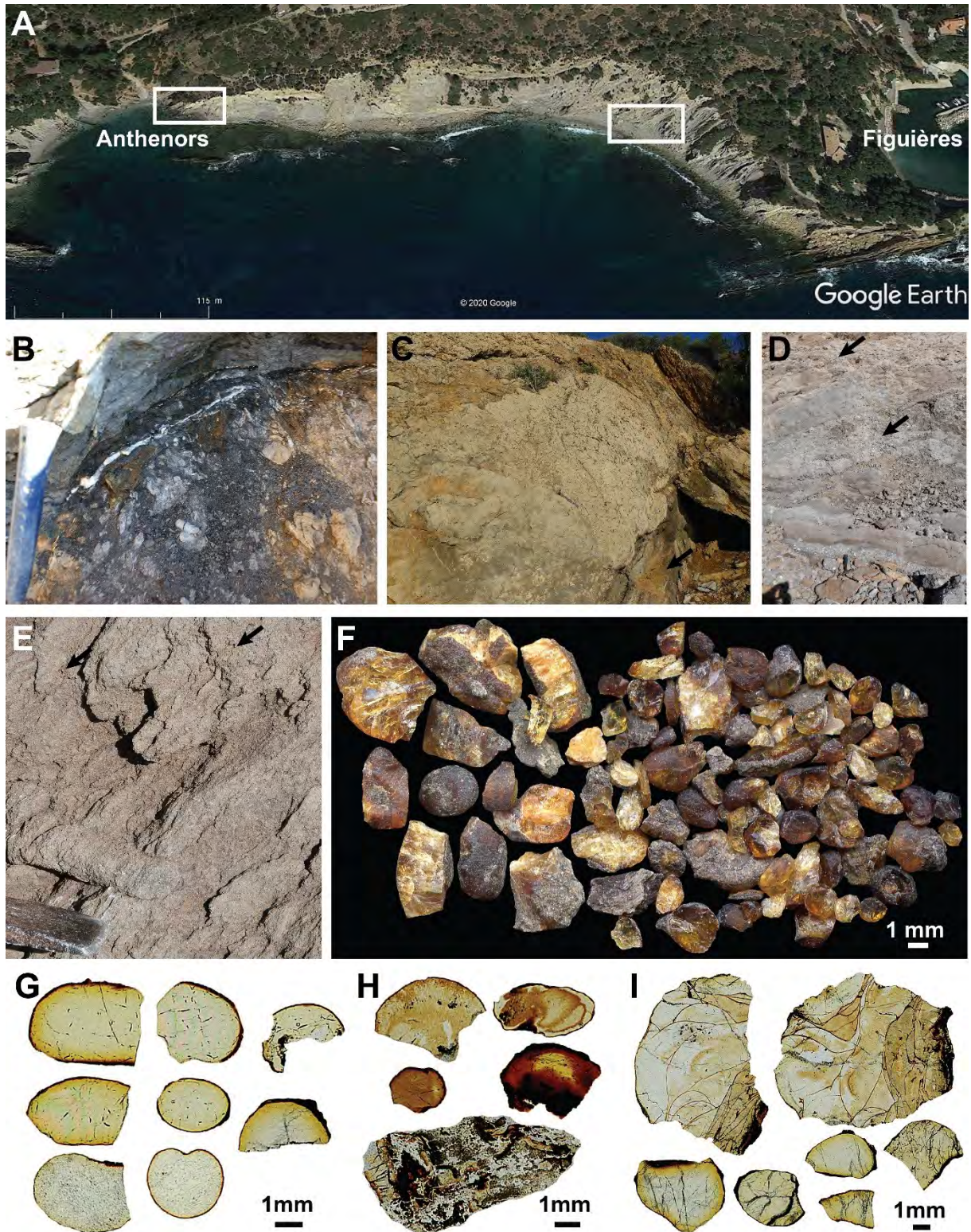
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Figure 11

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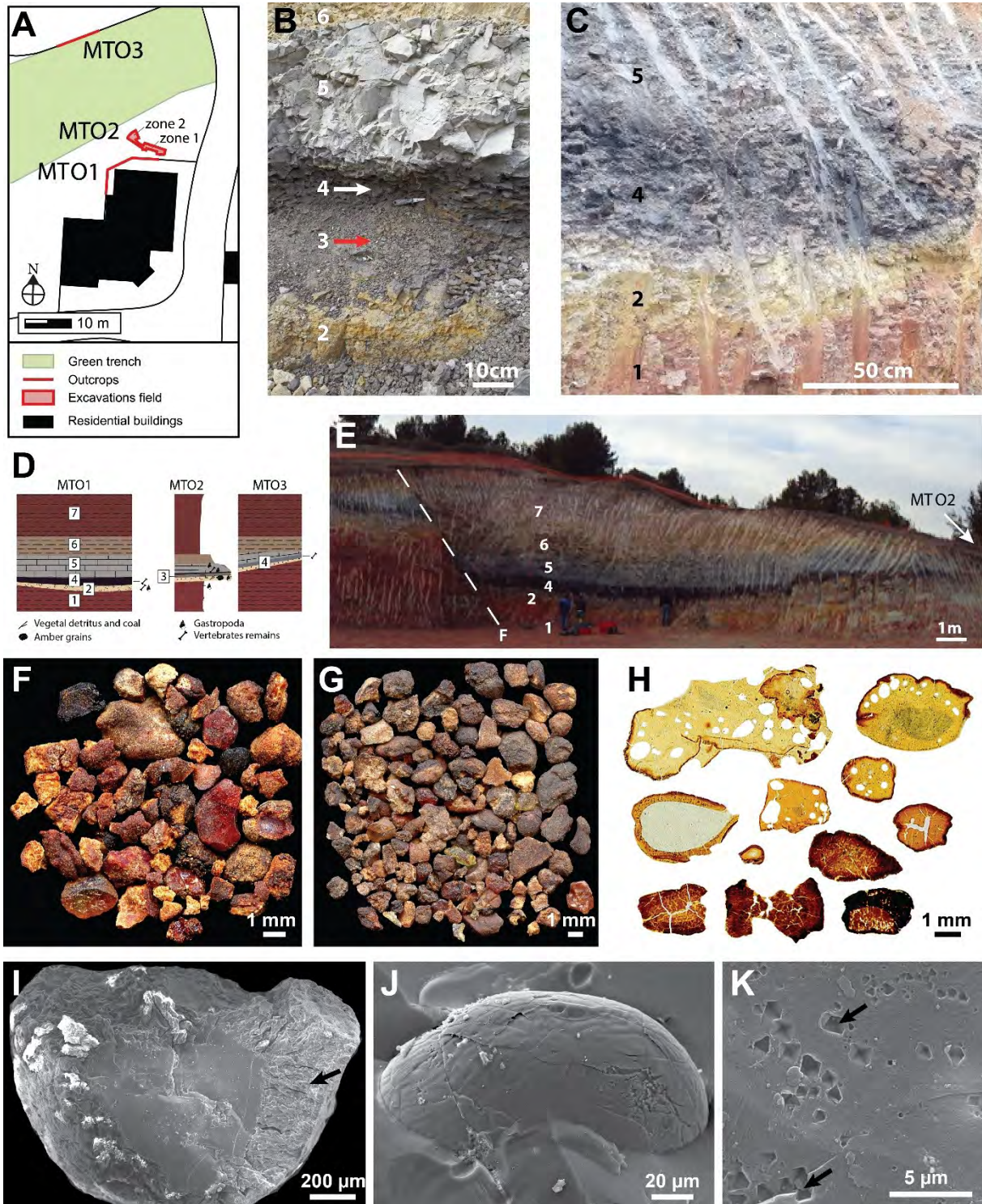
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Figure 12

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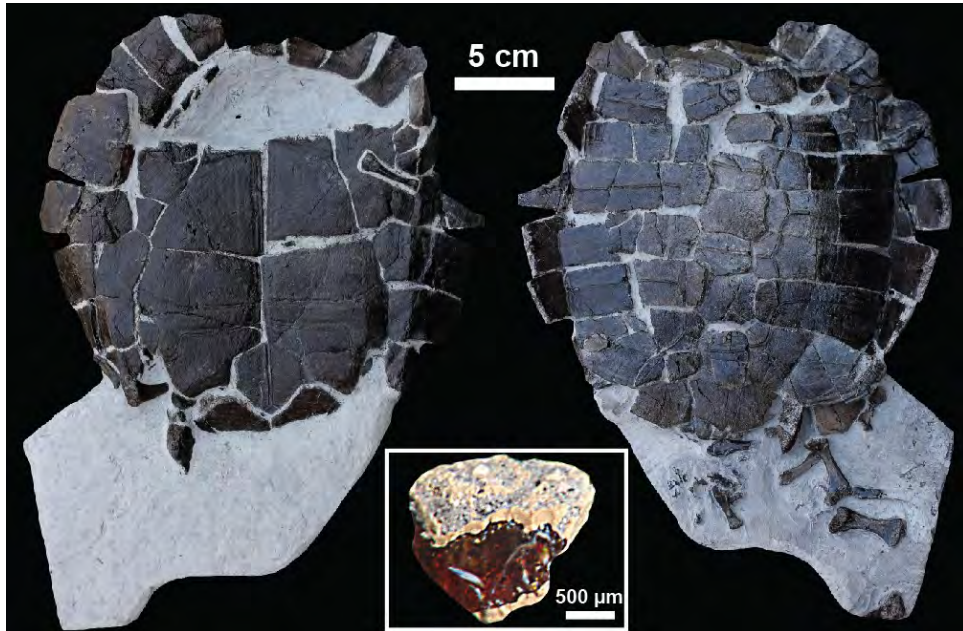
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Figure 13

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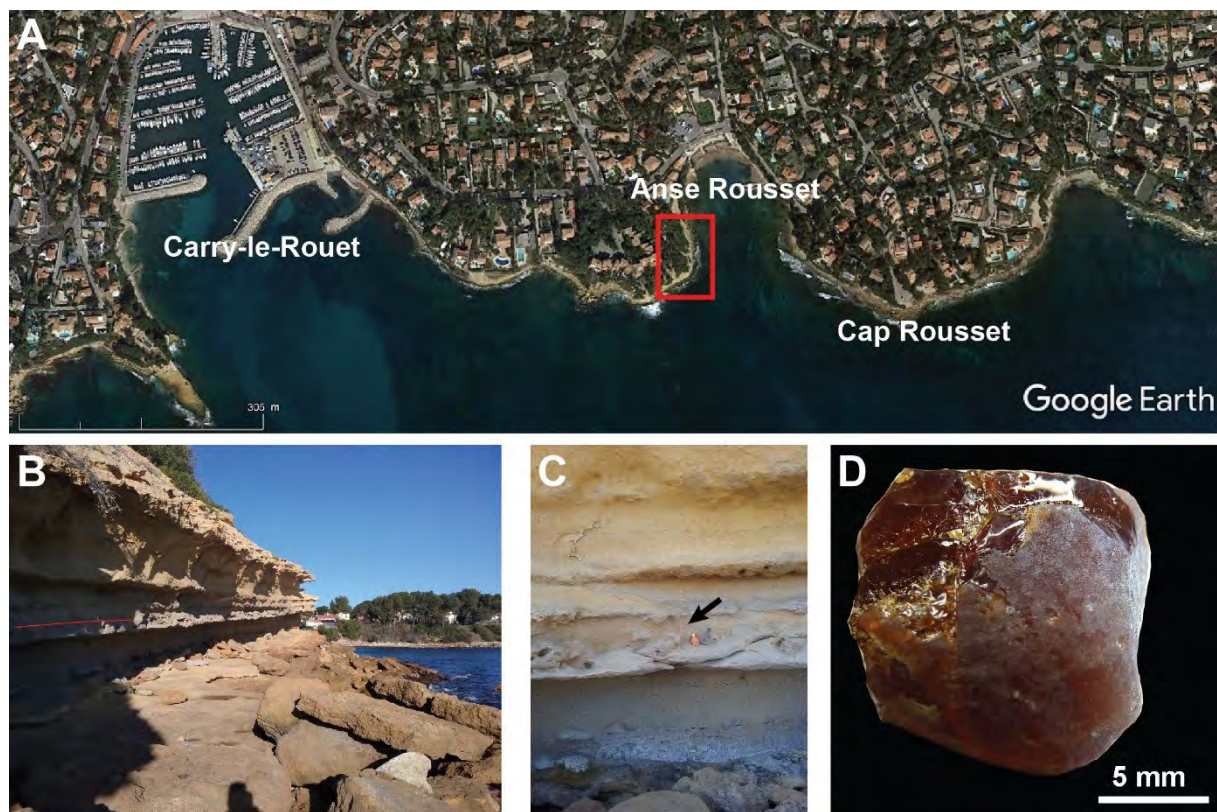
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Figure 14

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