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# Reassessment of amber-bearing deposits of Provence, southeastern France

Jean-Paul Saint Martin[1,*], Yves Dutour[2], Luc Ebbo[3], Camille Frau[4], Bruno Mazière[4], Didier Néraudeau[5], Simona Saint Martin[1], Thierry Tortosa[6], Eric Turini[2] and Xavier Valentin[7,8]

[1] UMR 7207 CR2P Centre de Recherche en Paléontologie – Paris, Muséum national d'Histoire naturelle, Sorbonne Université, CNRS, 8 rue Buffon, 75005 Paris, France
[2] Muséum d'Histoire Naturelle d'Aix-en-Provence, 7 allée des Robiniers, 13090 Aix-en-Provence, France
[3] Paléogalerie, Quartier le Mardaric, 04290 Salignac, France
[4] Groupement d'Intérêt Paléontologique, Science et Exposition, 60 bd Georges Richard, 83000 Toulon, France
[5] UMR 6118 CNRS Géosciences Rennes, Université Rennes-1, Campus de Beaulieu, bâtiment 15, 263, avenue du Général-Leclerc, 35042 Rennes Cedex, France
[6] Réserve Naturelle de la Sainte-Victoire, Hôtel du Département, 52 avenue Saint Just, 13256 Marseille Cedex 20, France
[7] UMR 7262 CNRS PALEVOPRIM, Université de Poitiers, 6 rue Michel-Brunet, 86073 Poitiers Cedex, France
[8] Palaios, Research Association, 15 rue de l'Aumônerie, 86300 Valdivienne, France

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**Abstract –** The presence of "geological" amber (or "succin" in old French monographs) has been reported for several centuries in the Mesozoic deposits of Provence, southeastern France. Diverse amber-bearing sites were inventoried by the authors but their location and stratigraphical context remain unclear for most of them. In the past decades, various data concerning chemistry, palaeontological content and comparison with archaeological discoveries improved our knowledge of the ambers of Provence, but only those of Cretaceous age. The present paper aims at providing a comprehensive description of all the presently known amber-bearing deposits of Provence, including the description of new sites. We highlight the great potential of Provence ambers and allow to consider a wider time range, from the Early Cretaceous to the Miocene.

**Keywords:** Amber / geology / Cretaceous / Oligocene / Miocene / Provence / southeastern France

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

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

## 1 Introduction

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

The first mentions and/or the description of geographical sites providing amber in France date back from the middle of the 18th century (Anonymous, 1742; Daubenton, 1751; Lavoisier, 1765; Papon, 1776). In these works, the presence of amber in Provence is reported with somewhat imprecise

*Corresponding author: jpsmart@mnhn.fr

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locations and with respect to the geological knowledge at this time.

In the 19th century, various treaties, dictionaries and encyclopedias also mentioned amber, often referred to as succin, in Provence (Buffon, 1802; Brongniart, 1807; Chaptal, 1807; de Drée, 1811; Amione, 1813; Patrin, 1819; Cuvier and Brongniart, 1822; Brongniart, 1823, 1827; Beudant, 1832; Gras, 1862; Meunier, 1885; Vasseur, 1894). The presence of amber is usually associated with mined lignite deposits. Rare works were fully devoted to amber (Graffenauer 1821; de Cessac, 1874) evoking, among others, some sites in Provence. Only the work of Bonnemère (1886) is focused on Provence. Other reports of amber are given through regional geological or stratigraphical studies (see below in the description of the deposits). An inventory of French amber occurrences was subsequently made by Lacroix (1910) in his treatise on mineralogy of France.

In the past decades, the Lacroix's treatise proves useful for scientists as exemplified by the growing body of studies on French ambers which appeared in the past decade. Several synthetic studies (Nel *et al.*, 2004; Perrichot *et al.*, 2007; Perrichot and Néraudeau, 2014) provided a review of the insect inclusions in the French Cretaceous, in which some sites of Provence are listed. Many authors have paid special attention to the Provence ambers. Several works aimed at analyzing the physico-chemical characteristics of those amber (Saskevitch and Popkova, 1978; Guiliano *et al.*, 2006; Onoratini *et al.*, 2009a, 2009b; Ragazzi *et al.*, 2009; Nohra *et al.*, 2015), and at clarifying the relationships between geological and archaeological ambers of Provence. Other studies have focused on macroinclusions (mainly arthropods: Nguyen Duy-Jacquemin and Azar, 2004; Perrichot *et al.*, 2006; Choufani *et al.*, 2013; Nel *et al.*, 2017), and microinclusions (Saint Martin *et al.*, 2012, 2013; Saint Martin and Saint Martin, 2018) or discuss the palaeobotany aspects (Gomez *et al.*, 2003). However, no comprehensive synthesis had been so far carried out on the many Provence amber-bearing sites.

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

## 2 Materials and sources

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

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

## 3 Cretaceous amber-bearing sites

### 3.1 Vaucluse

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

The Piolenc site has a long history of active lignite mining between the 17th and the 19th century (Expilly, 1768; Cuvier and Brongniart, 1822; Brongniart, 1823, 1829). The presence of amber and jet (jayet in french) was first reported by Expilly (1768). The lignitic sandy marls of Piolenc were described in detail by Gras (1862). This author considered these lignitic sandy marls as a particular distinctive stage of the Cretaceous, in correspondence to the Plan d'Aups lignitic marls (see Frau *et al.*, 2020, this volume), to the Upper Chalk of the Paris basin. Dumas (1876) and Frémy (1885) subsequently reassigned this formation to the Cenozoic but all of these authors overlooked the presence of amber in association with the lignite deposits. In the second part of the 20th century, the geological, sedimentological and palaeoenvironmental context of the Piolenc lignite formation were studied by several authors, and the palaeontological content was partially inventoried (Mennessier, 1949, 1950; Médus 1970; Triat and Médus, 1970; Desoignies, 1971; Triat, 1982; Malartre, 1994; Gomez *et al.*, 2003). A Santonian age for the Piolenc lignites was established thanks to the co-occurrence of radiolitid rudists (Mennessier, 1950).

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

The sedimentary series shows significant lateral facies changes (Figs. 3A–3C). At the base of the quarry, above yellowish sandstone exhibiting cross-bedded stratification, the presence of tiny beads or larger nodules of amber is easily observed in sandy levels (Figs. 3A, 3B, 4B and 4C) and in overhanging foliated sandy clays (Fig. 3D). Amber is also found at the base of a sandstone bed which can be clearly identified in the topography (unit d in Gomez *et al.*, 2003) and in the overlying levels (Fig. 4A), made of laminated sandy sediments (Fig. 3B). The last amber grain occurrence is found in the the root level (unit e in Gomez *et al.*, 2003) (Fig. 3E).

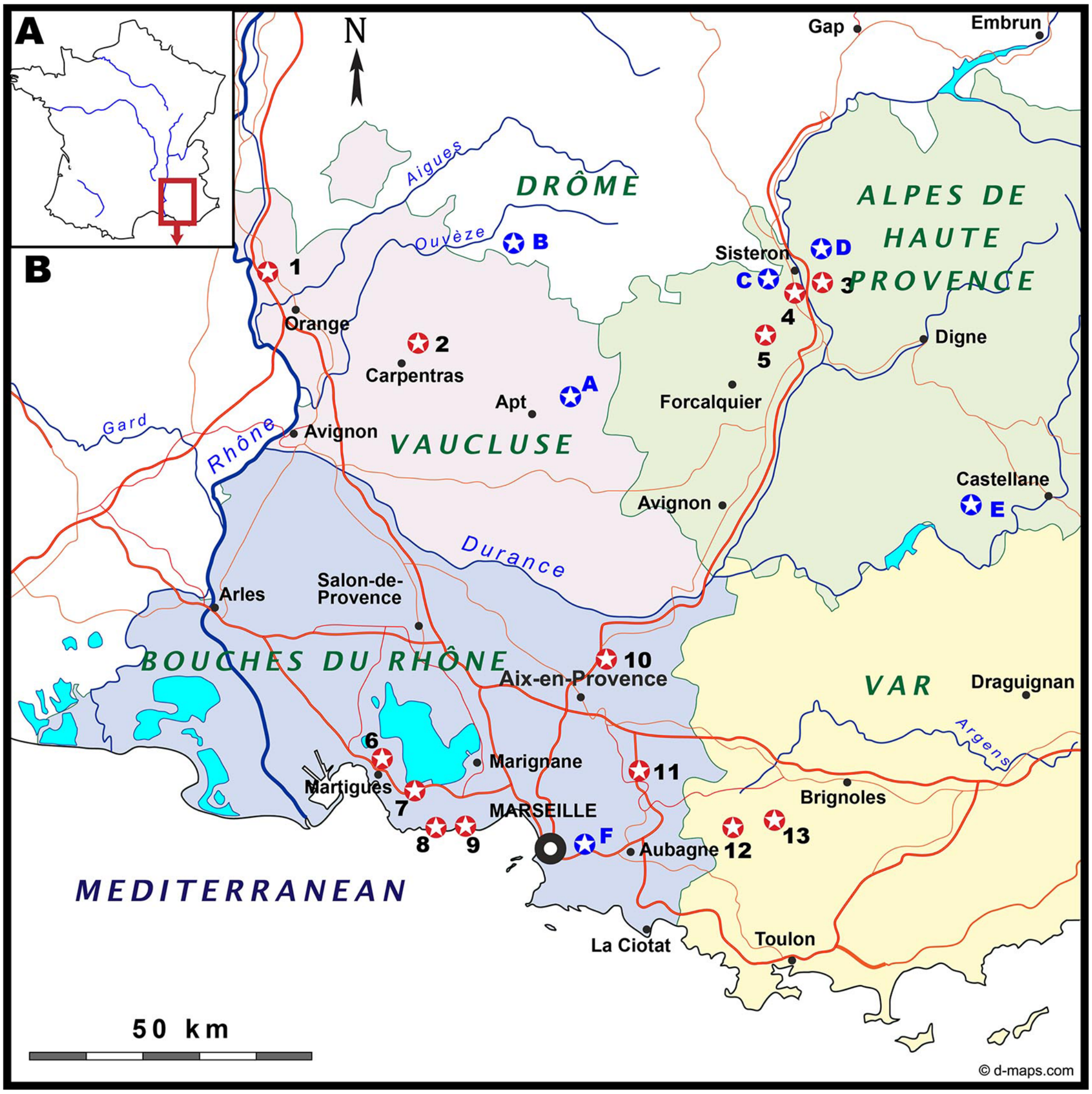


**Fig. 1.** Distribution map of amber-bearing sites in Provence. A: Situation in France of the concerned area; B: Verified amber sites: 1. Piolenc (Vaucluse); 2. Bédoin (Vaucluse); 3. Salignac (Alpes de Haute Provence); 4. Aubignosc (Alpes de Haute Provence); 5. Forcalquier sector (Alpes de Haute Provence);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

It should be noted that amber was also harvested at the top of the hill to the northwest on the so-called "Montée de Béziers" (Tab. 1, site 1b).

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

Despite its abundance, the Piolenc amber has provided very few arthropod inclusions, including two species of small dolichopodid flies (Nel *et al.*, 2017) and two new species of ceratopogonid midges (Choufani *et al.*, 2013). Furthermore, Saint Martin and Saint Martin (2018) showed that the Piolenc opaque grains are the result of extensive colonisation of the resin by sheathed bacteria assigned to the fossil species *Leptotrichites resinatus* Schmidt and Schäfer (2005).

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

Lignite deposits have long been mined at Bédoin and used as firewood for silkworm rooms, for cooking lime and plaster

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

| Amber-bearing sites Number in Figure 1b | Age | Location by Wgs 84 coordinate system | Status |
|---|---|---|---|
| 1. Piolenc | Santonian | | |
| 1a. Quartier Saint Louis quarry | | 44°11'08.8"N, 4°46'00.3"E | MNHN-PC |
| 1b. "Montée des Béziers" | | 44°11'02.1"N, 4°45'49.6"E | PC |
| 2. Bédoin | Late Albian | 44°07'36.1"N, 5°11'35.3"E | MNHN-PC |
| 3. Salignac | | | |
| 3a. Les Coignets | Upper Aptian | 44°10'40.0"N 5°59'17.9"E | MNHN-PC |
| 3b. Les Coulets | Upper Albian | 44°10'34.6"N 5°59'29.9"E | 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. Ensuès-la-Redonne | Santonian | | |
| 9a. Calanque des Anthénors | | 43°19'52.5"N, 5°12'13.2"E | MNHN-PC |
| 9b. Calanque des Figuières | | 43°19'50.1"N, 5°12'27.2"E | 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 | Santonian | | |
| 12a. La Brasque | | 43°19'24.9"N, 5°42'23.2"E | MNHN-PC |
| 12b. Dowtown | | 43°21'06.2"N, 5°51'15.8"E | PC |
| 13. Mazaugues | Santonian | | |
| 13a. Equireuil Quarry | | 43°21'39.6"N, 5°57'23.8"E | MNHN-PC |
| 13b. Glacières de Pivaut | | 43°21'12.5"N, 5°51'14.2"E | MNHN-PC |

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

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

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

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

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

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

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

Unfortunately we have no other indication on this amber regarding its exact location, its appearance and its abundance.

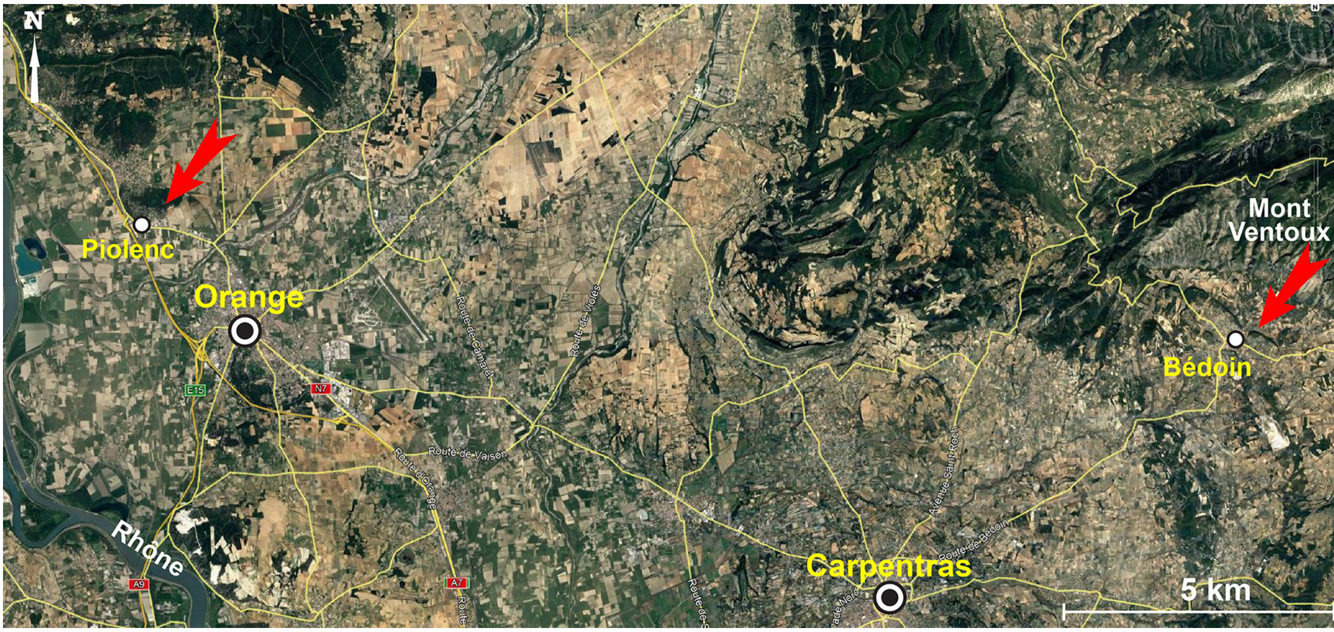


**Fig. 2.** Location of the two main amber-bearing sites in the Vaucluse department, Piolenc and Bédoin. © Google Earth 2020.

New field researches are thus required to confirm the presence of this amber and its habitus.

### 3.2 Drôme

Bréhéret (1997) reported south of the Eygaliers village (Fig. 1, site B), many woody debris and amber grains in glauconitic sandstones cropping out above Albian sediments. A basal Cenomanian age is tentatively assigned to these amber-bearing deposits. There is no indication of the appearance of this amber.

### 3.3 Alpes de Haute Provence

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

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

The only sample of Aptian age was taken north of Salignac near the Les Coignets locality (Fig. 1B, site 3a; Fig. 7; Tab. 1) in upper Aptian (Clansayesian) blue marl deposits. The amber grains are fairly opaque flattened orange ovoid nodules (Fig. 9A). Thin sections and polished sections made on this sample show a fairly concentric irregular structure reflecting successive resin flows (Fig. 9B). A central part is more translucent, reddish in colour. The periphery appears as an opaque yellow-orange crust.

Albian amber grains can be harvested at the Les Coulets locality in the hills and ravines oriented preferentially East-West and dipping south (Fig. 1B, site 3b, Fig. 7; Tab. 1). The area exhibiting *in situ* amber samples (Figs. 8A and 8B) is located between two index levels: 100 m above the "Paquier" black shale level marked by ammonite accumulations containing the lower Albian species *Leymeriella tardefurcata* (Orb. 1841) (Tribovillard and Gorin, 1991; Joly, 2008; Kennedy *et al.*, 2017) and 30 m below a sandstone limestone containing the ammonite *Idiohamites* which could mark the upper Albian (D. Bert, personal communication). According to the geological map at 1/50 000 of Sisteron, the harvesting sector is registered in the upper Albian (n6b) terranes and the boundary between the Albian and Cenomanian stages would be higher in the series, north near the Salignac village. Bréhéret (1997) noticed out the presence of driftwood in the Albian marls overlying the "Paquier" level. Amber nodules of pluricentrimetric size are scattered in foliated clayey sediments poor in fossils (Figs. 8C and 8D). Some smaller grains were harvested in a more calcareous level rich in bioturbations and containing belemnite rostra. The dominant colour of amber is orange-red when it is translucent (Fig. 8A). It can take a more yellowish tint and is therefore less translucent (Figs. 8D and

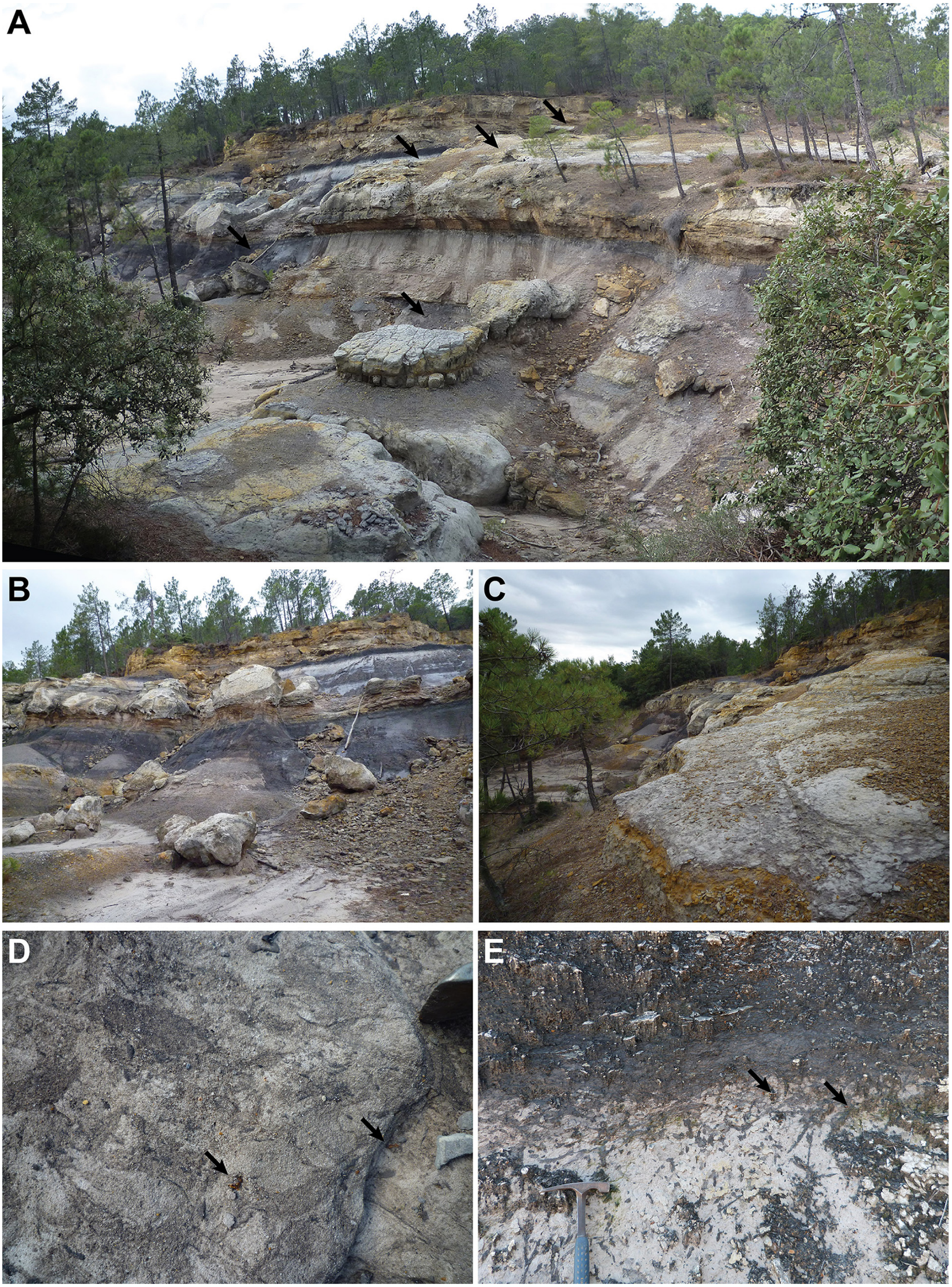


**Fig. 3.** Piolenc site. A: view of the outcrops at the quarry level showing the different amber harvesting points (arrows); B: view of the lower part of the section with the reference level (level E of Gomez *et al.*, 2003); C: side view of the section; D: occurrence of amber grains in the lower woody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

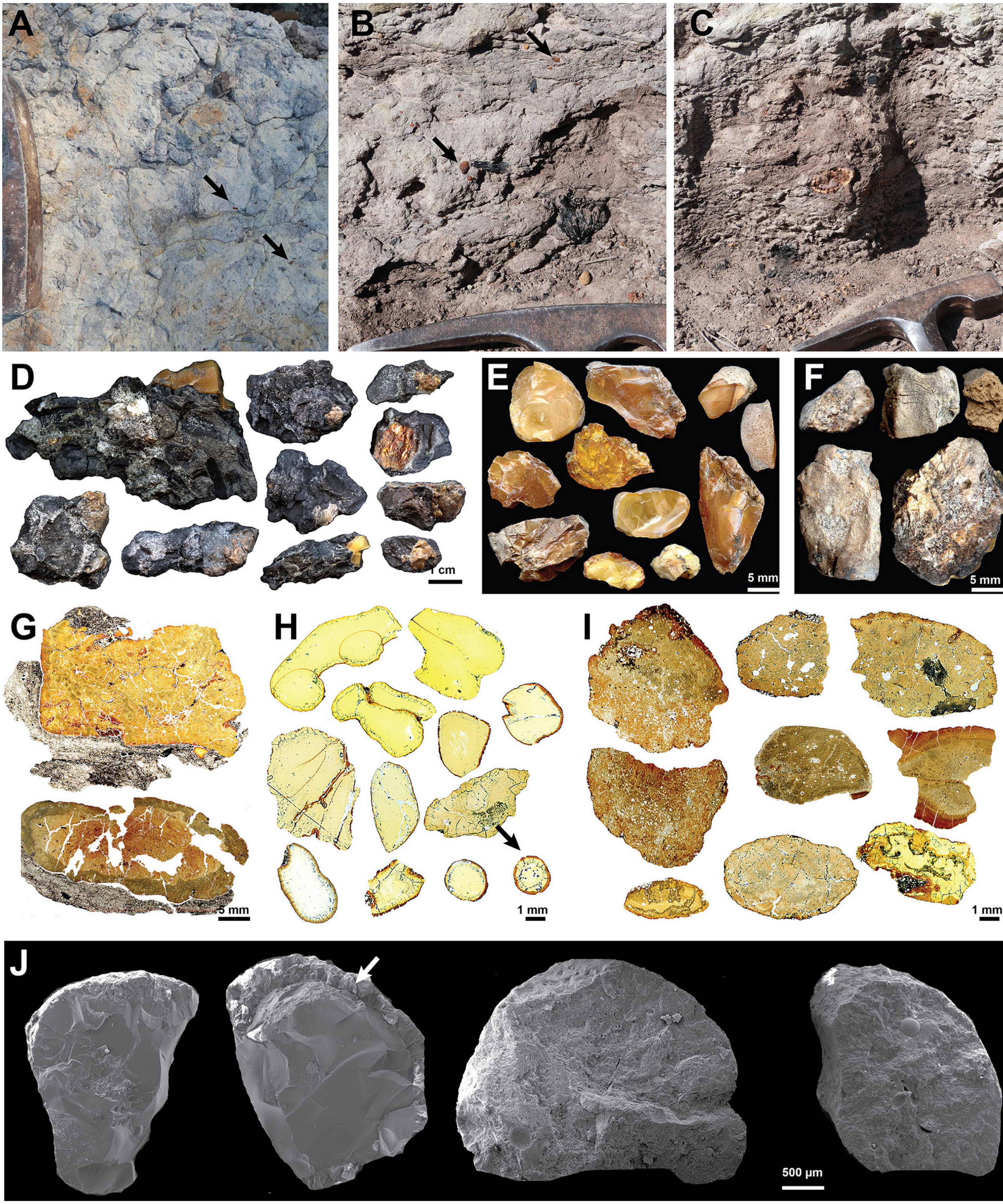


**Fig. 4.** Piolenc site. A: amber grains in a sandstone level; B: nodule and grain of amber (arrows) in sandy marls; C: opaque orange amber nodule in more or less flaky sandy marl. D: grains of amber in a gangue made up of woody fragments; E: Appearance of translucent amber grains; F: completely opaque earthy-looking amber grains; G: thin sections of amber nodules showing the gangue rich in vegetable organic matter; H: thin sections of translucent amber grains in the form of drops with their characteristic red envelope; I: thin sections of opaque amber grains showing the invasion of the grain by impurities; J: views of amber grains in SEM with a translucent appearance (two copies on the left) with possibly a visible crust (arrow) or opaque (two copies on the right). (MNHN collection).

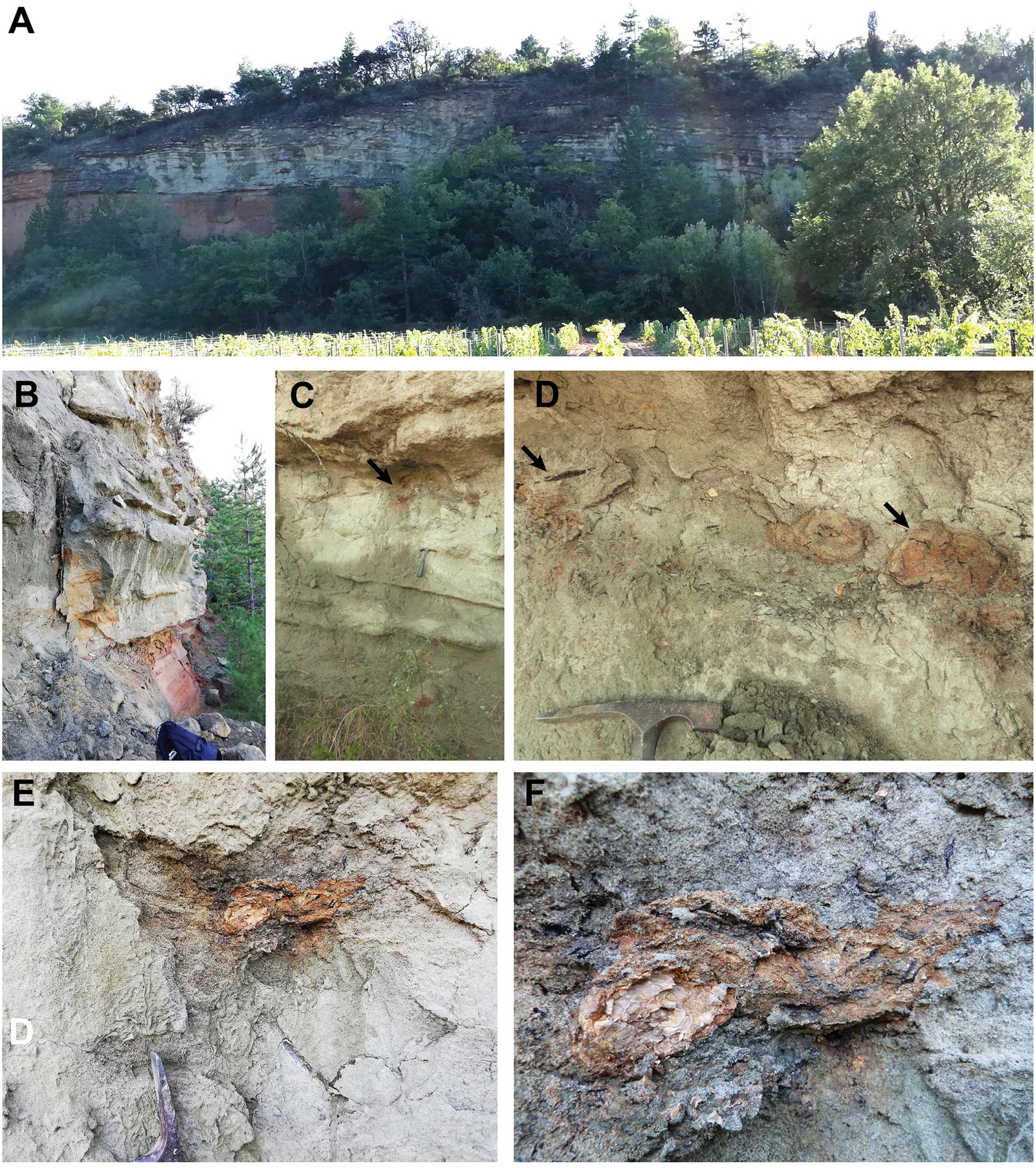


**Fig. 5.** Bédoin site. A: view of the cliffs showing the sandstone series ocrified towards the base with the situation of the amber level (arrow); B: view of the outcrops showing the ocher sandstones overlain by the amber level (arrow); C: detail of the cliff and situation of sampled amber nodules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

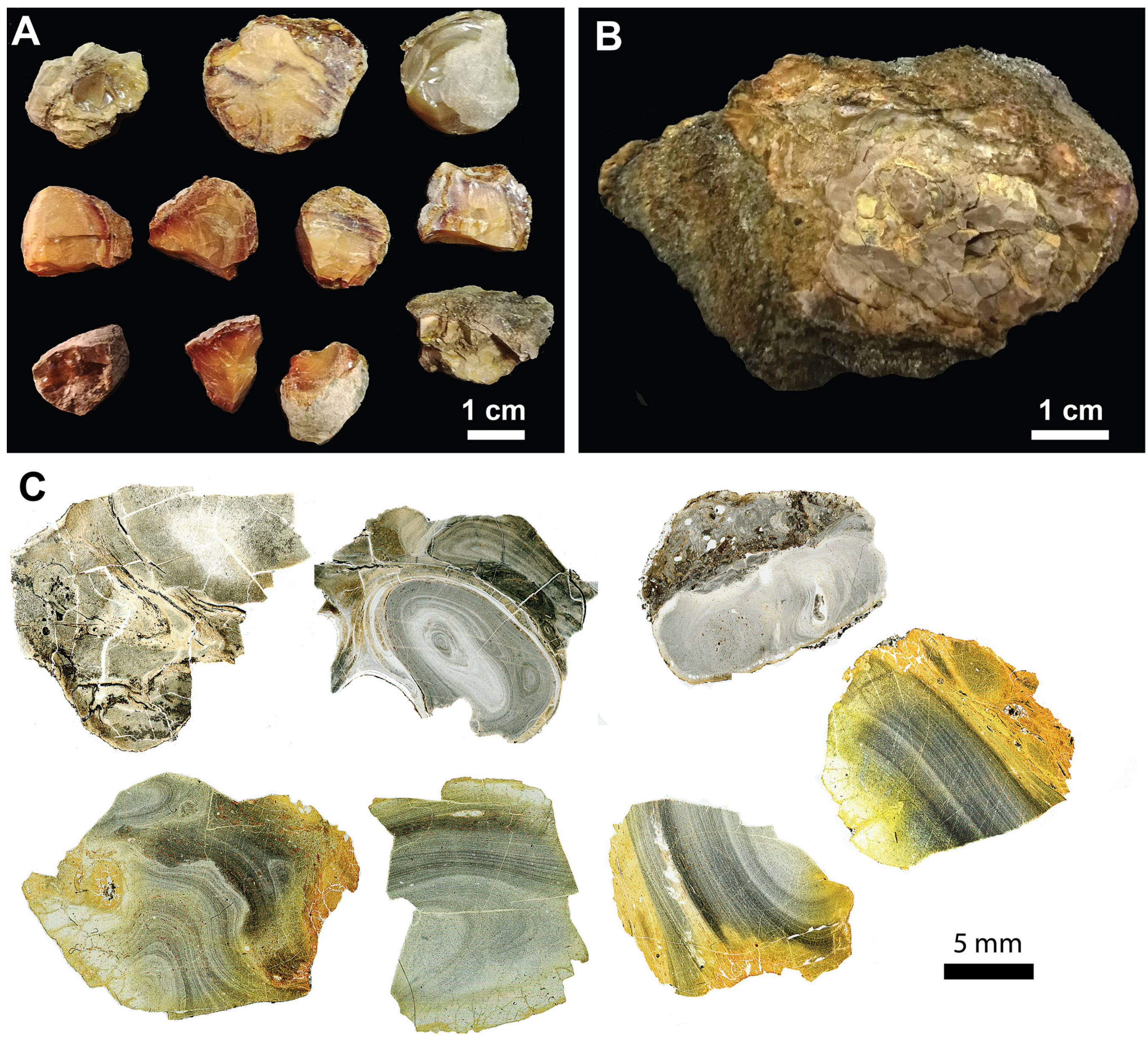


**Fig. 6.** Bédoin site. A: Appearance of harvested amber, from reddish to opaque translucents grains; B: Opaque nodule; C: thin sections showing the arrangement of the various resin flows underlined by blackish impurities in section. (MNHN collection).

8F). The thin sections reveal the successive flows marked by impurities (Fig. 8E). Macro-inclusions are rare despite the relative large size of amber pieces. Arthropod inclusions previously described in this amber include a specimen of *Phryssonotus* belonging to the Synxenidae (bristly millipedes) (Nguyen Duy-Jacquemin and Azar, 2004) and the Heteroptera *Ebboa areolata*, belonging to the Ebboidae (Perrichot *et al.*, 2006). Microinclusions are not uncommon and yield colonies of the sheathed bacterium *Leptotrichites resinatus* characterizing the opaque parts of the amber pieces (Saint Martin and Saint Martin, 2018).

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

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

The presence of amber from around the Lure Moutain region is known from old monographs (Darluc, 1784; Patrin, 1819; Brongniart, 1823, 1827; Beudant, 1832; de Cessac, 1874; Lacroix, 1910; Desailly, 1930). Darluc (1784) cited the Ongles village as an amber-bearing site. However, more extensive

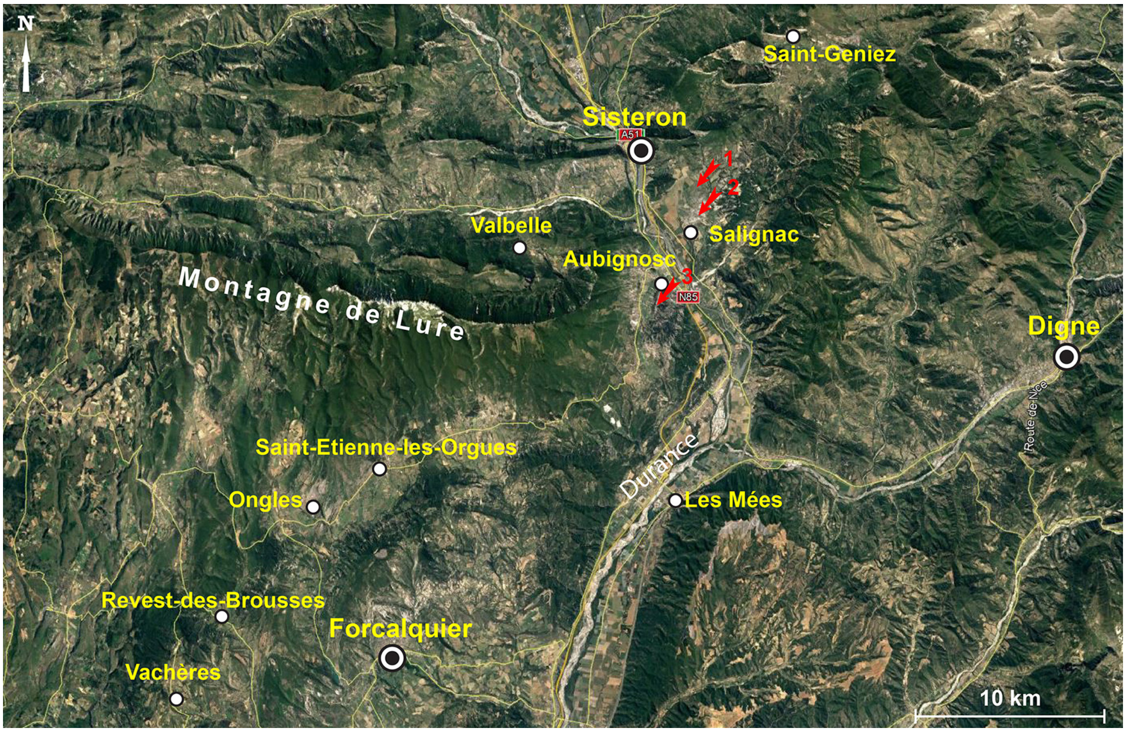


**Fig. 7.** Situation of the outcrops and sites described in the Sisteron and Montagne de Lure areas, with location of the samples (red arrows): 1. Salignac, Les Coignets (upper Aptian); 2. Salignac, Les Coulets (upper Albian); 3. Aubignosc (upper Albian). © Google Earth 2020.

information on the amber from around the Lure Moutain (Fig. 7) is provided by recent work of Onoratini *et al.* (2009a, b). These authors have proposed a synthetic lithostratigraphic framework inwhich the different amber sites are reported. However, the precise geographical locations of the samples are not given.

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

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

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

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

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

The presence of amber in northwest Blieux is only known from Bréhéret (1997) who reported black horizons with driftwood and amber interspersed in Albian dark marly sediments. We do not know the characteristics of this amber.

### 3.3.4 Sites of uncertain age and location

Two amber sites are mentioned by Papon (1776) at Tour de Beuvons, today Valbelle (Fig. 1, site C; Fig. 7) and by Darluc (1784) at Saint-Geniez-de-Dromont, a village located northeast of Sisteron (Fig. 1, site D; Fig. 7). These records have been then

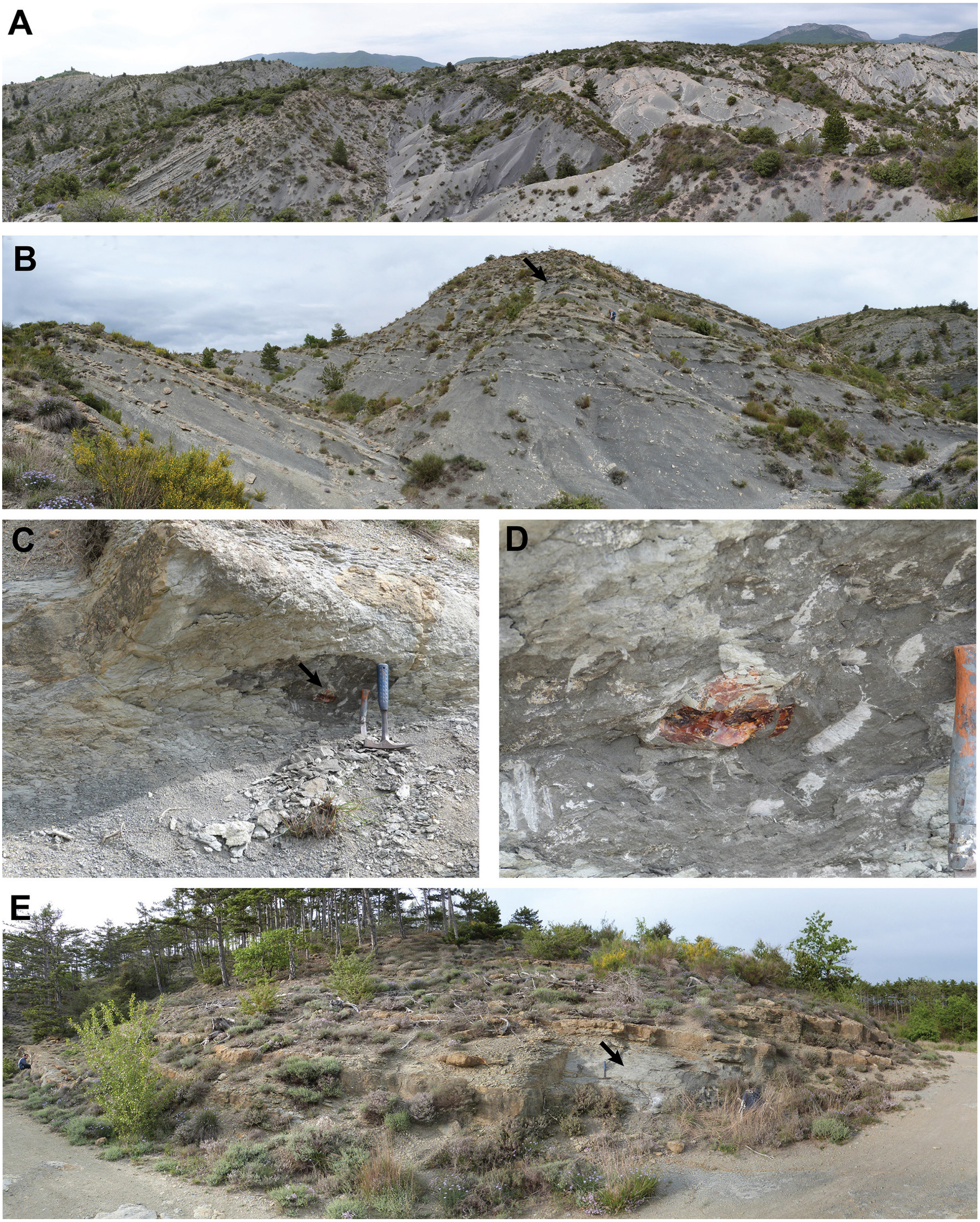


**Fig. 8.** Albian sites of the Sisteron area. A–D: Salignac. A: succession of Albian sediments and zone of presence of amber *in situ*; B: situation of a sampled amber nodule (arrow) within a marl-limestone succession; C: amber nodule (arrow) in a marly sediment; D: detail of the amber nodule showing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

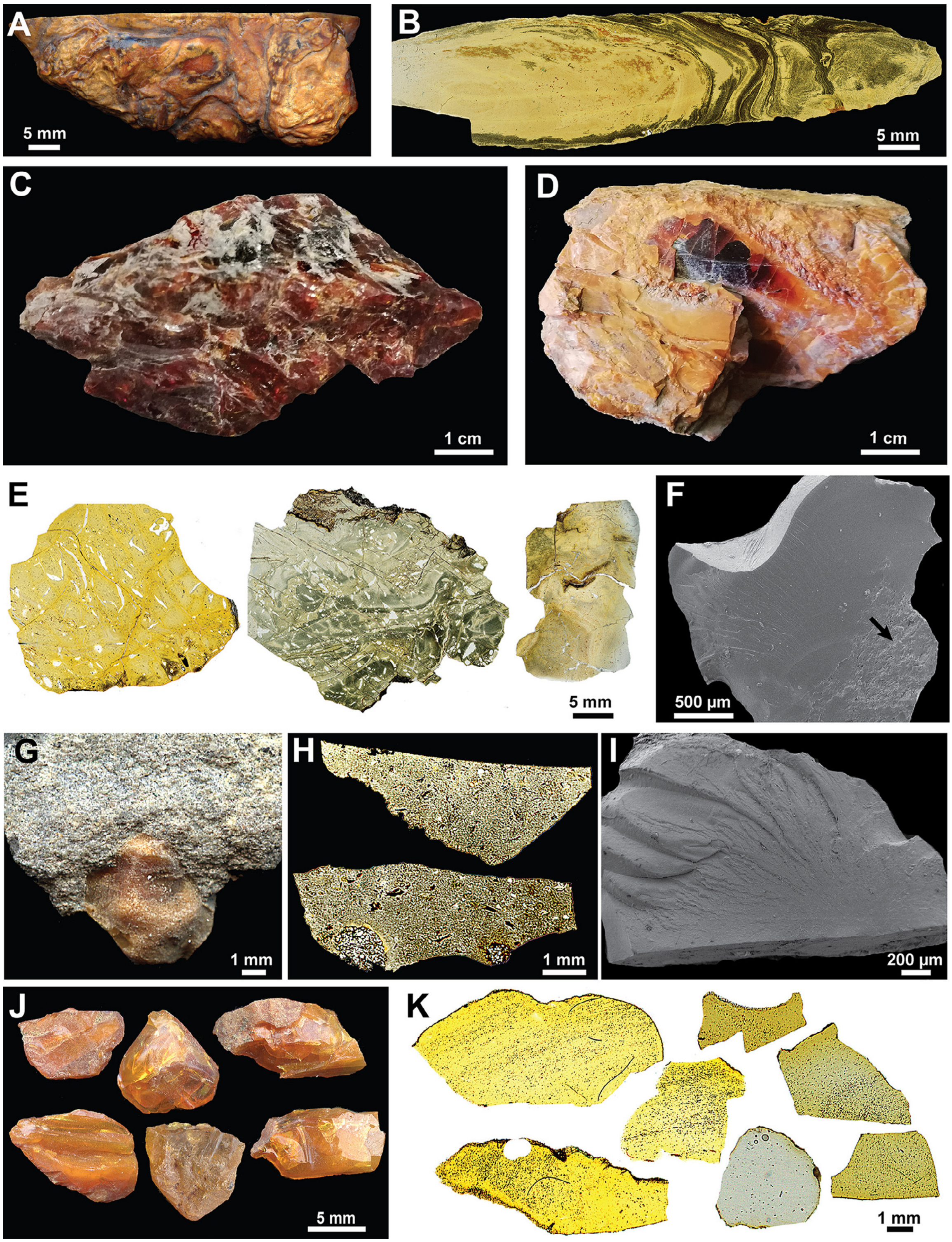


**Fig. 9.** Amber from the Sisteron-Montagne de Lure region. A–B: Aptian from Salignac. C–F: Albian from Salignac. G–I: Albian from Aubignosc. J–K: Cenomanian of Saint Etienne-les-Orgues. A: nodule with an opaque orange exterior appearance showing the various resin flows which compose it; B: thin section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


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

cited by Kilian (1889) and Lacroix (1910) without further details regarding their precise location and geological context. New field work is thus required to confirm the presence of amber there.

## 3.4 Bouches du Rhône

### 3.4.1 Santonian

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

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

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

The Ensuès amber (Fig. 1B, site 9) has also been evoked by various works (Perrichot *et al.*, 2007; Onoratini *et al.*, 2009a, b; Ragazzi *et al.*, 2009), but has never been published in a comprehensive description. The detailed lithostratigraphic succession of the investigation sector is moreover very difficult to define due to the strong deformations which affect the series at the heart of a syncline whose axis is parallel to the coast (Guieu *et al.*, 1996). The Santonian sediments outcrop along the coast between the localities of La Redonne and Calanque de Méjean. There, sands, marls and sandstones rest on the Méjean Coniacian sandstones rich in crinoid fragments (Guieu *et al.*, 1996; Philip and Gari, 2005). Amber grains were harvested by S.S.M., J.P.S.M. and X.V. more precisely between the “Calanque des Anthénors” and the “Calanque des Figuières” in two accessible places (Fig. 11A). In the “Calanque des Anthénors” area (Tab. 1, site 9a), the Santonian is represented at its base by heavily burrowed sandstones (Fig. 11C). The series continues with nodular sandstones and soft sandstones with lignite debris and amber grains (Figs. 11B and 11E). This first amber bearing level is overlain by cross-bedded sandstone, bioclastic sandstone, dark gray soft sandstone, and then by laminated marly sandstones (Fig. 11C) also containing lignite debris, rare oysters and amber grains. The rest of the outcropping series consists of alternating sandstone and masses of debris flows containing strongly disarticulated rudist constructions (Fig. 11D). East of the “Calanque des Figuières” (Fig. 11A; Tab. 1, site 9b), the series are characterized by rudist buildups. According to Philip (1970) and Philip and Gari (2005), the rudist association is characteristic of a Santonian age. A lens with lignite debris yields numerous amber pieces (Fig. 11B) and contains remains of the brackish gastropod *Campylostylus galloprovincialis* (Matheron, 1843). The amber corresponds to orange-yellow translucent to reddish-brown opaque tiny grains (Fig. 11F). The thin sections reveal three types of grains: fairly translucent with a fine reddish envelope (Fig. 11G), opaque (Fig. 11H) and crystalline ones marked by intense fracturing (Fig. 11I).

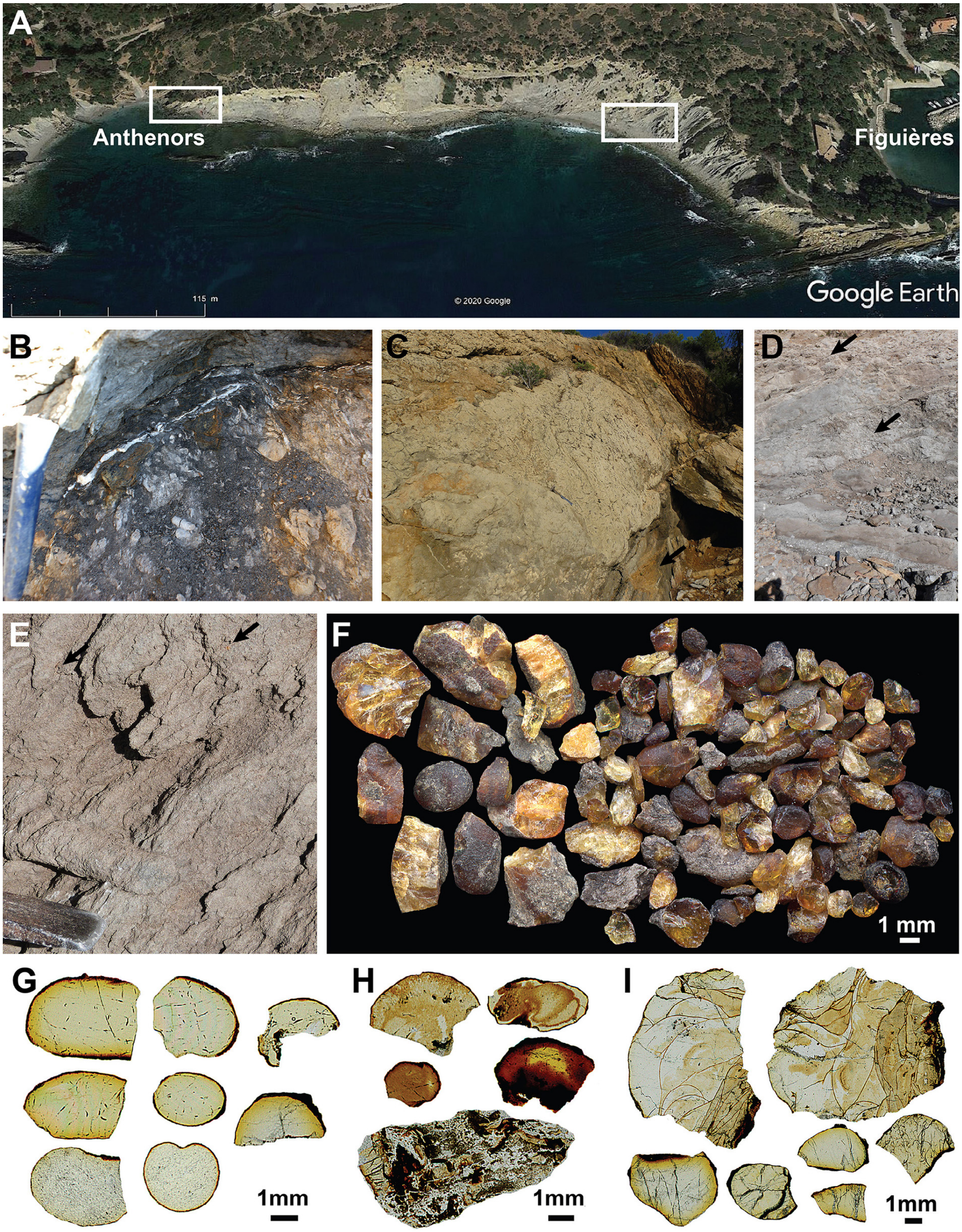


**Fig. 11.** Santonian amber from Ensuès-la-Redonne. A: Situation of the sampling areas (white squares), © Google Earth 2020.; B: Lens rich in liginite debris and amber grains east of Anse des Figuières; C: contact between the burrowed bioclastic sandstone limestone and the flaky sandy marls that yielded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

Another potential amber-bearing spot occurrence is reported by Matheron (1839, 1843) near the Allauch locality, east of Marseille (Fig. 1, site F). In terranes equivalent to those of Piolenc, Martigues-La Mède and Sainte Baume (Var) today considered Santonian in age, a few layers would contain lignite debris and amber grains ("succin" *in litt*.). Exploration in this area has so far failed to locate the amber site.

### 3.4.2 Upper Campanian

The Martigues-Terres d'Ocre locality (MTO) is situated 2.5 km northwest from the city centre of Martigues (Fig. 10, locality 1). The locality, consisting in a lenticular fluviolacustrine deposits, was studied thanks to two outcrops and excavation sites in three different sectors following building construction works in a new residential area (MTO1-3; Fig. 12A). Each sector presents the same general sedimentological succession with some slight differences in layers thickness, depending on the presence/absence of an additional marly horizon and on the position in the deposit structure (Fig. 12D; Tortosa, 2014). The series begin with red marls (Level 1), then overlain by a lenticular deposit of sandstone including some vertebrate macroremains (Level 2). In MTO2, this Level 2 becomes a very thin yellow sandy marls horizon (Fig. 12D). It corresponds to an alluvial fan constituting a deltaic structure penetrating into a lacustrine environment. The alluvial material takes its origin from the ancient southern Pyreneo-Provençal mountain chain (Anglada *et al.*, 1979). This horizon is overlain by massive black marls (Level 4), rich in vertebrate macroremains (Figs. 12B, 12D and 12E). In MTO2, there is an intercalation of thin grey marl layers between the Levels 2 and 4 (Figs. 12B and 12D). This Level 3 is rich in fossil plant detritus (see below in text). It is followed by the Level 4 which is rich in vertebrate macroremains. Its base is a grey marl horizon with some very thin discontinued yellowish layers. The top is a dark grey horizon including some little greenish sandy lenses. This layer ends with a thin shelly horizon and continues with the Level 5. In MTO3, the Level 4 becomes greyish hard marls, less rich in vertebrate remains, exhibiting hardgrounds in some spots (Figs. 12C and 12D). The series continues with Level 5 which is a thick compact layer of grey calcareous marls. The Levels 3–5 are indicative of lacustrine environment with a limited fluviatile input. The following Levels 6 and 7 are respectively orange marls and red marls. This series is located in 400 m-thick red marls represented here by Levels 1 and 7 and conglomerates formation corresponding to the local "Begudian facies" (Babinot and Durand, 1980). Those facies are dated to the base of upper Campanian (Cojan and Moreau, 2006; Gradstein *et al.*, 2020).

Beside of the stratigraphical repositionning based on local continental facies, the only available biomarkers are gastropods which were collected in Levels 2 to 5. The collected palaeomalacofauna is a mix of terrestrial and freshwaters species represented by internal molds. They include in Level 2 *Melania* cf. *colloti*, *Palaeostoa cureti*, *Physa galloprovincialis*, *Physa michaudii*, *Physa patula*, *Proalbinaria* (= *Clausilia*) *matheroni*, *Rognacia abbreviata, Viviparus beaumontianus* and various undeterminated species. Above Level 2, the fauna is poorly preserved and we were only able to determine the species *Palaeocyclophorus galloprovincialis* in Level 5. The palaeomalacofauna presents a taxa usually found in the Valdo-Fuvelian facies (upper Santonian-lower Campanian), *Melania* cf. *colloti*, whereas the others are known from upper Campanian to Maastrichtian (Begudo-Rognacian facies) such as *Palaeocyclophorus galloprovincialis, Palaeostoa cureti, Physa galloprovincialis, Physa michaudii, Physa patula, Proalbinaria matheroni, Rognacia abbreviata* (Fabre-Taxy, 1951, 1959). It is interesting to note the absence of common "Rognacian" taxa such as *Bauxia, Lychnus* and *Pyrgulifera* which are usually abundant in Rognacian facies. The MTO locality offers a palaeomalacofauna composition reminiscent of another observed in the upper Campanian (Begudian facies) of Pourrières-La Neuve in the Var department (Garcia *et al.*, 2000). Indeed, both localities have specimens much reduced in size compared to their original descriptions. The most of the specimens have not been identified because of their fragmentary nature. Moreover, it is currently difficult to distinguish juveniles, dwarves or new small species since they do not correspond to any published taxa to date. Following these stratigraphical and palaeontological observations, we confirm the position of MTO locality in the upper Campanian but restricted to its lower part (~c33).

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

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

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

## 3.5 Var

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

The only mentions of the presence of amber in the Var department were given during the 19th century works of

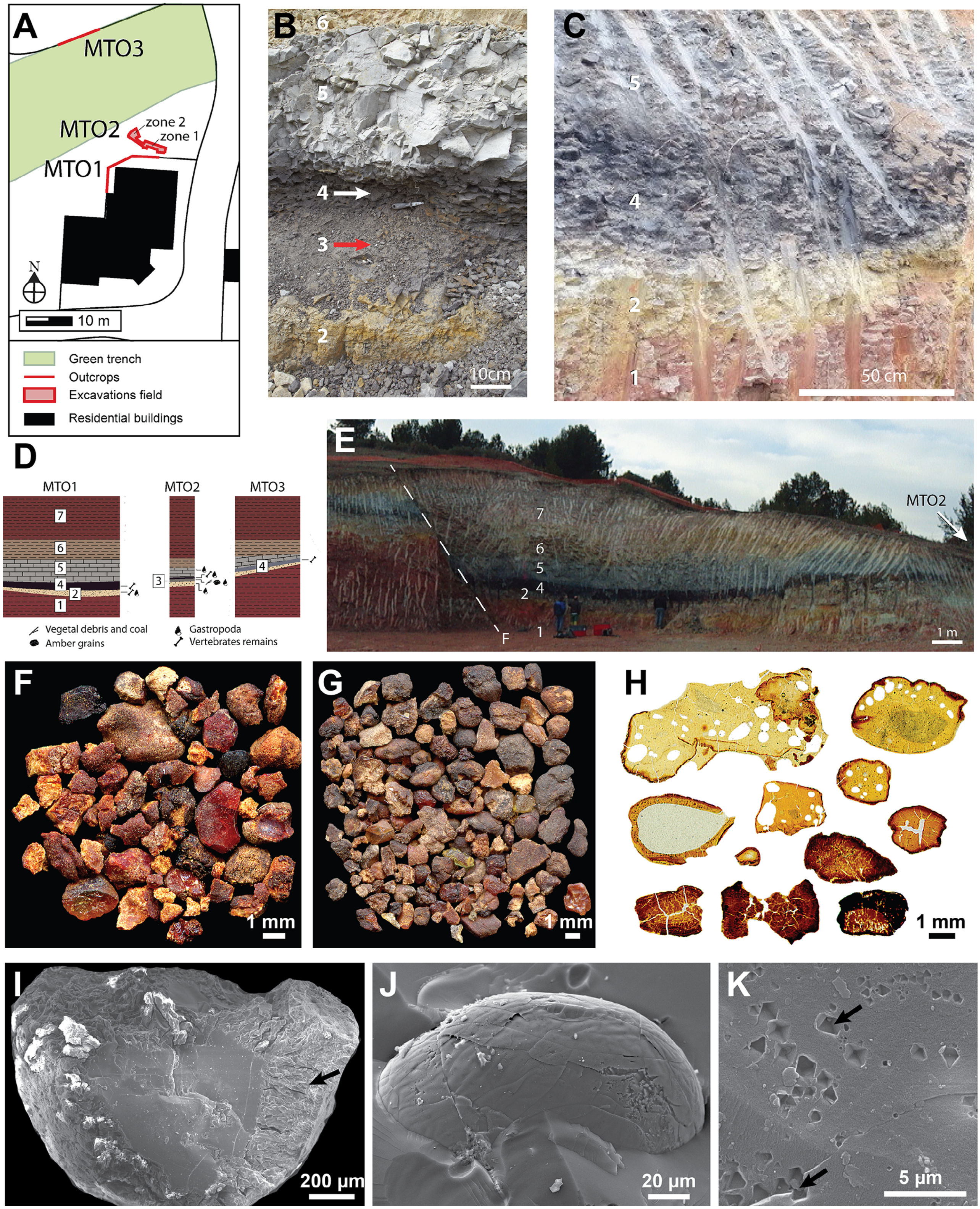


**Fig. 12.** Amber from Martigues-Terres d'Ocre locality (MTO1-3). A: plan of the locality with the three sites; B: excavations of the zone 2 in MTO2 site (white arrow: level rich in macro-remains of vertebrates, red arrow: level rich in amber grains); C: outcrop in MTO3 site; D: logs of the three sites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

Coquand (1860, 1864) and Collot (1890) at the Plan d'Aups village. Onoratini *et al.* (2009a) confirmed the presence of amber there by the record of a single grain at Plan d'Aups. Subsequently, Saint Martin and Saint Martin (2018) found new amber spot occurrence eastward (Glacières de Pivaut; Tab. 1, site 13b). New field investigations have led to the discovery of new sites at Plan d'Aups (Tab. 1, sites 12a,b) as well as at Mazaugues (Tab. 1, site 13a), in two different stratigraphic levels. More data on these sites, and their palaeoenvironmental context can be found in Frau *et al.* (2020, this volume).

## 4 Cenozoic amber sites

### 4.1 Oligocene amber from Venelles

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

A millimeter-sized grain of amber was extracted from the matrix of an undetermined turtle shell (Fig. 13). The grain has a thick opaque beige crust of around 200 μm around a more translucent centre with a dominant red hue. No inclusion could be highlighted in the translucent part.

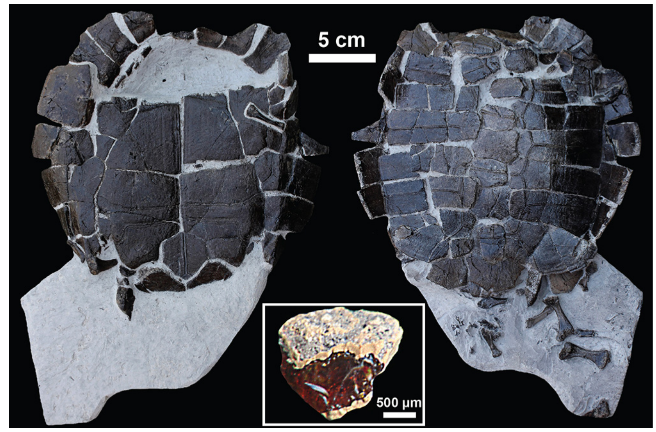


**Fig. 13.** Oligocene amber from Venelles (white box) and views of the turtle in the matrix of which an amber grain was found (MHNA collection).

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

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

The harvested amber grain is quite translucent, orange-red in colour. Its globular shape is approximately 1.6 cm in size (Fig. 14D). Examination does not reveal any inclusion.

## 5 Discussion-Perspectives

### 5.1 Stratigraphical range

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

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

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

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

The case of the uppermost Cretaceous amber from Martigues is interesting from a palaeogeographical point of view, with the evolution of the region towards continental environments beginning in the Santonian-Campanian times, but also the relationship between amber and the resin producing forest, and the vertebrate populations (*e.g.* dinosaurs). It is indeed one of the remarkable sites where the remains of dinosaurs and amber grains are found together (*e.g.* Néraudeau *et al.*, 2003, 2005, 2009 for France or

McKellar *et al.*, 2019 and Cockx *et al.*, 2020 for Canada) especially at the end of the Cretaceous, shortly before the K/Pg event, which heightens its interest.

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

The most recent amber of Provence is those from the Aquitanian of Carry-le-Rouet, with an magnetostratigraphical age estimated at −22.30 million years by Demory *et al.* (2011). Until now the younger amber known in France seemed to be that reported in Allinges (department of Haute Savoie) and named *allingite* by Aweng (1894). In fact, several works report the presence of amber supposed to come from the Lower Miocene "molasse" in the Voirons Massif south of Allinges (Lacroix, 1910; Galippe, 1920; Saskevitch and Popkova, 1978). The problem is that the exact age of the sediments is not clearly defined. A reexamination of the geological situation (Tercier, 1928) rather suggests an Eocene to Oligocene age more recently confirmed (Jan Du Chêne *et al.*, 1975; Ospina-Ostios *et al.*, 2013; Ragusa, 2015). If this should prove correct, the Carry-le-Rouet amber constitutes the younger occurrence in France.

### 5.2 Characteristics, botanical origin and amber depositional environments

Amber chemistry has been a domain of investigations for a very long time and various methods have been used. Provence amber has thus been subject of various works devoted to chemical features of amber as well for archaeological or historical reasons as with the objective of determining the botanical origin of the amber. All the studies document a difference between the Provence ambers and the Baltic ones, which has made it possible to definitively reject the hypothesis of the use of local amber in the archaeological interest in Provence and to favour the Baltic source (Buddhue, 1938; Beck and Liu, 1976; Onoratini *et al.*, 2009a). The first study by Beck and Liu (1976) on amber from the Montagne de Lure concludes that it is close to the Cenomanian amber from Gard department. On the basis of various Fourier transform infrared spectroscopy analyzes (IRTF) concerning the oxygen function, the exomethylene group or carbonyl groups, Onoratini *et al.* (2009a, 2009b) highlighted the separation into two groups of amber also corresponding to two stratigraphic age groups: the Albo-Cenomanian ambers from the "Montagne de Lure" and the Santonian ambers from various sites (Piolenc, Martigues-La Mède, Ensues, Belcodène, Plan d'Aups). Another study using the techniques of Infrared Spectroscopy, Solid-State CPMAS 13C NMR Spectroscopy and Thermochemolysis – GC-MS on different ambers from France (Nohra *et al.*, 2015) also leads to distinguish the Salignac samples those from Santonian (here Piolenc and Belcodène). Finally, the thermal analysis of Cretaceous amber from France (Ragazzi *et al.*, 2009) leads to a similar result separating the Salignac amber (associated with a site in the west of France) from all of the Santonian ambers from Provence (Piolenc, Ensuès, and Belcodène). This distinction is also related to the appearance of amber. Thus, the Albo-Cenomanian ambers are mainly large nodules with a dominant yellow to red colour while the Santonian amber is represented by grains of smaller size, often preserved in the form of drops of original resin, from translucent to fully opaque. This differentiation seems to result from two factors which can possibly combine. The first cause would be related to the conditions of geological evolution of the sediments containing the amber (temperature, pressure, tectonics). The age of the amber could thus explain a differential maturation: the oldest ambers would show greater maturity. According to Onoratini *et al.* (2009a), slight differences observed between amber of the same age, as is the case for the Santonian amber, would be due to the fact that the amber of deposits from the coastal environment were blocked in their maturation by the return of marine conditions (Martigues-La Mède, Ensuès, Belcodène) while others remained in continental environments (Piolenc) experienced a greater maturation. However, it should be noted that in Piolenc there is also a marine intercalation within the lignite series. The nature of the plants producing the resin is also one of the causes of the differences observed. This is a very often discussed subject which aims to determine the botanical origin of the resin from which amber originates (see synthesis in Seyfullah *et al.*, 2018). With regard to Provence, the replacement during the Cretaceous period of forests dominated by gymnosperms (especially Araucariaceae and Cheirolepidiaceae) by forests with more abundant angiosperms (Philippe *et al.*, 2008) could have resulted in a different nature of the trees producing resin. The amber from Santonian deposits would then have another botanical origin than the Albo-Cenomanian ambers, involving so angiosperm trees (Onoratini *et al.*, 2009a; Ragazzi *et al.*, 2009). However, according to Nohra *et al.* (2015) the Santonian amber is rather the result of resins from other gymnosperms, as the Cupressaceae, even if the only conifers identified at Piolenc are Araucariaceae (Gomez *et al.*, 2003). Cupressaceae are thus more often invoked in the production of resin from the Late Cretaceous (Seyfullah *et al.*, 2018). The problem is that direct evidence is generally lacking to support these claims. Besides chemistry analyses of amber, the nature of the associated plant remains in the deposits can constitute another indication. Unfortunately, few deposits, in particular for the Albo-Cenomanian sites, have delivered exploitable botanical associations, except at Piolenc (Gomez *et al.*, 2003) and in the Sainte-Baume Massif where Santonian remains of *Frenelopsis* are reported (gymnosperms Cheirolepidiaceae) (Frau *et al.*, 2020, this volume and references therein). The problem of the resin origins arises all the more for the new deposits presented in this work. Thus, the upper Campanian amber from Martigues has characteristics that distinguish it from other Cretaceous ambers. The fluidity of the slightly heated grains could sign a low degree of maturity and/or be related to another botanical source. Oligocene amber from Venelles cannot provide any information, since the vertebrate deposit did not deliver identifiable plant remains. Finally, the Miocene amber from Carry-le-Rouet is included in a series of sedimentary layers which contain numerous very small lignite debris which have never been identified. For lower and mid Miocene amber deposits in the world, the involvement of angiosperm is quite often highlighted, in particular the Fabaceae (Antoine *et al.*, 2006; Calvillo-Canadell *et al.*, 2010; Penney, 2010;

Solórzano Kraemer, 2010; Seyfullah *et al.*, 2018). This could be the case with Carry-le-Rouet amber, and chemical analyses would provide valuable information.

The part of the processes involved in the genesis of amber deposits is difficult to determine precisely and the comparison between deposits of different origin and age remains delicate (Knight *et al.*, 2010 and discussion in Saint Martin *et al.*, 2013). Depending on the deposits, these differences must take into account the necessary distinction between the sedimentary deposit environment and the resin formation environment, that is to say the modes of transport, burial and taphonomy. Schematically, three main types of depositional environments characterize the Provence amber sites: 1) open marine to distal environments; 2) coastal, lagoon or estuarine environments; 3) continental environments. In the first category ranks the Aptian and Albo-Cenomanian sites; the deposit medium can be rather deep and distal, as is probably the case for the Salignac amber. The abundance of amber harvested from very ancient times therefore implies a very active secretion of resin, subsequently floated and deposited in the seabed, which cannot be directly illustrated. In relation, it should be noted that driftwood is known in several Albian basins in south-eastern France (Cotillon and Lemoigne, 1971). The second category concerns ambers of various ages such as the Albian amber from Bédoin, the Santonian ambers (Gomez *et al.*, 2003; Guiliano *et al.*, 2006; Saint Martin *et al.*, 2012, 2013; Frau *et al.*, 2020, this volume) or the Aquitanian amber from Carry-le-Rouet (for similar depositional environment of Lower Miocene, see Serrano-Sánchez *et al.*, 2015) which can be framed respectively for the latest in the evolution of carbonate to rudist platforms or coastal environments with coral reef development. The third type of depositional environment consists on continental deposits of a lake and river character such as that of the upper Campanian of Martigues. The wide range of ages from the Aptian to the Miocene of the ambers produced in Provence thus reflects a complex geological history having undergone the same tectono-sedimentary evolution with the setting up of the Durancian uplift and the compression tectonics which influenced the sedimentary structure and the evolution of landscapes till the mid-Cretaceous times (Guyonnet-Benaize *et al.*, 2010; Onoratini *et al.*, 2009a, b). For more recent periods, it is the Oligocene-Miocene rifting on the margin of the Gulf of Lion which constitutes the tectono-sedimentary framework conditioning the landscapes where amber was formed (Oudet *et al.*, 2010).

### 5.3 Future orientations

Provence amber represents a potential for perfecting knowledge of the evolution of environments, climatic conditions and resin-producing trees in a given region. To exploit this potential, it would be important to unify by integrated studies the data resulting from field observations, physico-chemical characterization of amber, and macro-inclusions and microinclusions content. Thus studies in inorganic chemistry have demonstrated a difference in composition between the periphery and the core of the grains, this due to the development in some cases of a crust due to colonization by microorganisms (Aquilina *et al.*, 2013). The appearance of amber is in fact largely determined by the colonization of the initial resin by microorganisms (see Frau *et al.*, 2020, this volume; Néraudeau *et al.*, this volume; Valentin *et al.*, this volume). An adaptation of the characterization techniques of amber according to these organic parameters conditioning the real nature of the amber found would undoubtedly be desirable. In addition, the recent discovery of several amber deposits of various ages shows the possibility of extending investigations in the field, especially for the presence of amber reported in the literature but not verified since. This is all the truer for a period rich in lignite observed locally between the Santonian and the Maastrichtian in the Basin de l'Arc, which would offer the possibility to continuously follow the development of resin production at a key moment in the Upper Cretaceous.

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