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A new rich amber outcrop with palaeobiological inclusions in the Lower Cretaceous of Spain

Enrique Peñalver [a,*], Xavier Delclòs [b], Carmen Soriano [b]

[a] *Museo Geominero, Instituto Geológico y Minero de España, Ríos Rosas 23, E-28003 Madrid, Spain*

[b] *Departament d'Estratigrafia, Paleontologia i Geociències marines, Fac. Geologia, Martí i Franquès s/n, Universitat de Barcelona, E-08028 Barcelona, Spain*

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Abstract

A new amber outcrop has been found recently in a bed of lutite within the Escucha Formation near the village of Utrillas (Teruel Province), Spain. This new fossil site, which has been named San Just, contains an exceptional quantity of amber remains associated with fossilized wood and leaves of probable araucarian origin, and is dated as Early—Middle Albian (Early Cretaceous). The amber is physically and chemically similar to other Spanish Early Cretaceous ambers. Values of IRTF are also similar to other Early Cretaceous ambers, except for curve values of 800—400 cm^{-1} (in which bands are not visible) and the absence of exocyclic methylenic bands at 880 cm^{-1} and 1640 cm^{-1}. The latter is also a feature of Álava amber (Peñacerrada I and II exposures), and suggests a high degree of maturation. The San Just outcrop is the second in Teruel Province in which biological inclusions (mainly insects and chelicerates) have been found in amber. Insects are represented by hymenopterans (Scelionidae, Evaniidae: *Cretevania*, Stigmaphronidae), dipterans (Dolichopodidae: *Microphorites*, Ceratopogonidae), thysanopterans (Stenurothripidae), and coleopterans (Cucujidae). Chelicerates are represented by a mite and two small spiders. There are also plant remains (trichomes and a cluster of gymnosperm pollen grains) and some mycelia, with sporangia and branched hyphae. The relative abundance of highly transparent "stalactites" containing well-preserved arthropod remains, makes this new outcrop an exceptional resource for future research into the palaeoentomofauna and palaeoecology of forest ecosystems on the Iberian Plate during the Early Cretaceous.

Keywords: Amber; Arthropods; Biological inclusions; Early Cretaceous; Teruel Province; Spain

1. Introduction

There are few Cretaceous amber outcrops with fossil insects. Late Cretaceous exposures are known in New Jersey (USA), Manitoba and Alberta (Canada), Myanmar (Burma) and Taimyr and Nizhnyaya Agapa (Russia) (e.g., Borkent, 1995; Grimaldi, 1996, 2000; Zherikhin and Eskov, 1999; Grimaldi et al., 2000, 2002; Rasnitsyn and Quicke, 2002, Martínez-Delclòs et al., 2004; Grimaldi and Engel, 2005). Early Cretaceous amber sites are even more scarce, and commonly considered to be of greater scientific interest; these sites are located in Lebanon, Israel and Jordan (Azar, 2000; Poinar and Milki, 2001; Kaddumi, 2005), Charente-Maritime in France (Néraudeau et al., 2002; Perrichot, 2004, 2005), the Isle of Wight, southern England (Jarzembowski, 1999) and northeast Spain (Arbizu et al., 1999; Martínez-Delclòs et al., 1999; Alonso et al., 2000; Delclòs et al., 2005; Grimaldi and Engel, 2005). The Lebanese, French and Spanish sites are particularly interesting because of the abundance and diversity of the arthropod remains they contain.

Several compression deposits with abundant insects have been known from the Lower Cretaceous of Spain since the beginning of the 20th Century (Martínez-Delclòs, 1991; Peñalver et al., 1999). The nature of the record from amber deposits is substantially different. This generally comprises small forest-dwelling insects, which are not usually preserved as

* Corresponding author.
E-mail address: e.penalver@igme.es (E. Peñalver).

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compressions in sediments that accumulated in water (Martínez-Delclòs et al., 2004). As a result, the combined records provide a better indication of the true diversity of the entomofauna of the Iberian Plate during the Early Cretaceous than one or other alone, since both small and large terrestrial and aquatic forms are preserved. The Early Cretaceous was a period of wide diversification among insects, which took place in conjunction with the radiation of angiosperms and the extinction of numerous groups of plants.

In Teruel Province, Cretaceous amber has previously been found at the following localities: Linares de Mora, Portalrubio, Alpeñes, Pancrudo, Villel, Estercuel, Valle de Andorra, Foz-Calanda, Mora de Rubielos, Arroyo de la Pascueta (Rubielos de Mora), "Leonor" mine (Utrillas), Valdeconejos and Palomar de Arroyos (see Fig. 1 for the location of the last three). Recently, abundant amber has been found near the village of Utrillas (Fig. 1). This locality has been named San Just. The outcrop contains arthropods and plant remains, and is the second such locality in Teruel Province, along with amber from the Arroyo de la Pascueta site (Rubielos de Mora), which also contains biological inclusions (Peñalver and Martínez-Delclòs, 2002; Delclòs et al., 2005).

Given the importance of this new deposit, the first general description of its features is presented. It is also compared with the amber deposits from Álava (Late Aptian–Middle Albian), another important Spanish amber rich in biological inclusions. The San Just site, along with other Early Cretaceous continental deposits in Spain, has been proposed for inclusion in the UNESCO list of Geosites (García-Cortés et al., 2000). Owing to the vulnerability of the outcrop, the Spanish government needs to take special measures for its protection.

2. History

The occasional presence of amber in the Utrillas-Escucha area has been well documented since the mid 19th Century by discoveries resulting from mining activity. It is associated with lignites in the Escucha Formation, which were extracted extensively and used for fuel. Vilanova y Piera (1860) cited the village of Utrillas among the Spanish localities containing amber, and Vilanova y Piera (1870) wrote (p. 83) that "…apparently, a kind of fossil resin is found in Utrillas that imitates the succinum or yellow amber, and it appears in nodules or lumps, a common or characteristical appearance for this substance." Vilanova y Piera (1874) wrote more extensively about the Utrillas amber, suggesting that it could be used by jewellers to improve the socio-economic level of the Utrillas area. He reported kidney-shaped masses having an outer dirty-yellow colour that becomes more intense in the more compact and translucent inner part. In addition, he indicated that the small fragments obtained from these masses present colour homogeneity and great transparency and smoothness, as well as being very light and easy to work. A decade later, Cortázar (1885) indicated that this amber was being used for commercial purposes. Aside from these historical references to the Utrillas amber, the San Just outcrop has been mentioned in recent conference papers (Martínez-Delclòs and Peñalver, 1999; Martínez-Delclòs et al., 2000; Delclòs et al., 2003, 2005).

3. Geological setting

The main outcrops containing amber in the Utrillas-Escucha area, including San Just, are located along the northern margin of the Aliaga Subbasin, within the larger Maestrat Basin (Salas and Guimerà, 1997). The Maestrat Basin, together with other Mesozoic basins of the Iberian Range, is characterized by listric faults that developed during an important rift stage of the Late Oxfordian–Albian interval, linked to the opening of the northern part of the Atlantic Ocean (Salas et al., 2001). During the Early Cretaceous, sedimentation in the Iberian Basin (Iberian Range) was mainly dominated by limestone and marl that accumulated in shallow marine and freshwater environments. However, during the Early–Middle Albian, at the end of the rift stage, deltaic and estuarine systems developed (tide-influenced deltas), which evolved vertically into a deltaic system dominated by a fluvial environment with siliciclastic sedimentation, represented by the

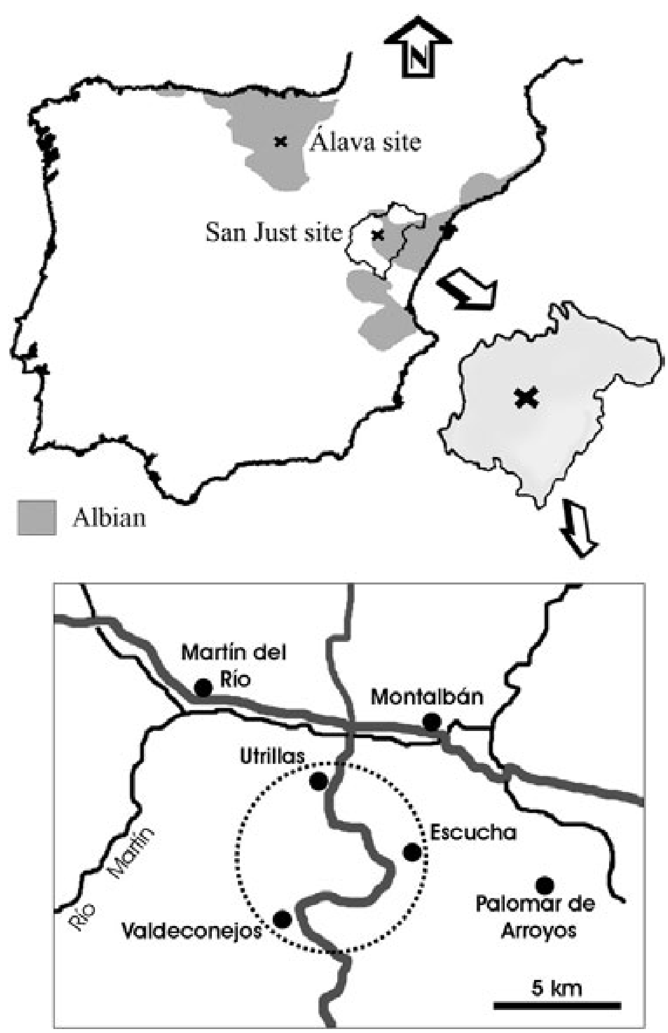


Fig. 1. Geographical location of the area of exploration and the San Just outcrop with insect-bearing Cretaceous amber.

Escucha Formation. This formation is widespread in the Iberian and Coastal Catalonian ranges, and has a maximum thickness of 500 m in its type area.

In the Utrillas-Escucha area, the formation has traditionally been subdivided into three members that constitute a single stratigraphic unit of a depositional sequence (Querol, 1988). These are conformable and were named by Cervera et al. (1976) as the lower or Barriada, middle or Regachuelo, and upper or La Orden members. They are differentiated into two large sets of facies: lower deltaic plain (comprising sea-margin plain and a belt of salt marshes), and upper deltaic plain with flood and fluvial plains (Querol and Salas, 1988). Amber deposits have only been found in the upper part of the Barriada Member and in the El Regachuelo Member (in which they are more abundant), which consist of brackish and freshwater swamp deposits, respectively (Querol et al., 1992). The San Just amber has been found in grey–black claystones with abundant plant remains (Cheirolepidiaceae: *Frenelopsis* sp., and large pieces of carbonized wood), overlying the upper coal levels of the Escucha Formation (Fig. 2). The distribution and thickness of the coal levels have been controlled stratigraphically, palaeogeographically, sedimentologically and tectonically (Querol et al., 1992).

Palynological studies on the Escucha-Utrillas area have shown a predominance of spores of the Cyatheaceae/Dicksoniaceae and Schizaeaceae, which suggests warm to subtropical humid environments. The abundant occurrence of *Classopollis*-type pollen suggests the presence of warm dry areas where representatives of the Cheirolepidiaceae flourished (Solé de Porta et al., 1994). Díez et al. (2005) have recently identified some beds with fragmented rachises of the tree fern *Weichselia reticulata* (Stokes and Webb) in the same stratigraphic levels close to the village of Utrillas. Sender et al. (2005) found some plant-bearing levels in the Valle del Río Martín (northern margin of the Aliaga Subbasin) in the Regachuelo and (principally) La Orden members, which contain remains of ferns, Ginkgoales, Bennettitales, Caytoniales, Cycadales, conifers of the family Cheirolepidiaceae, and angiosperms, a floristic assemblage closely similar to the Potomac Group assemblages in the USA. The Escucha Formation is dated as Early–Middle Albian based on the palynological content of the different facies (Solé de Porta et al., 1994), and Early Albian based on the presence of the ammonite *Douvilleiceras monile* (Mamillatum Zone) (Martínez et al., 1994).

4. Amber characteristics

The San Just amber exhibits the typical characteristics of other Spanish Cretaceous ambers, such as the presence of lumps (Fig. 3A) with an alteration crust (Fig. 3B), a reddish colour in an unaltered, relatively opaque nucleus, and great fragility. In addition, it contains drop- and stalactite-shaped specimens (Fig. 3C–D), both lacking alteration crusts, similar to the Álava amber (Alonso et al., 2000). The alteration crust has been studied under both optical (Fig. 3B) and scanning electron microscopes, revealing an intricate group of branched, filamentous structures. These are most abundant in the outer part of the

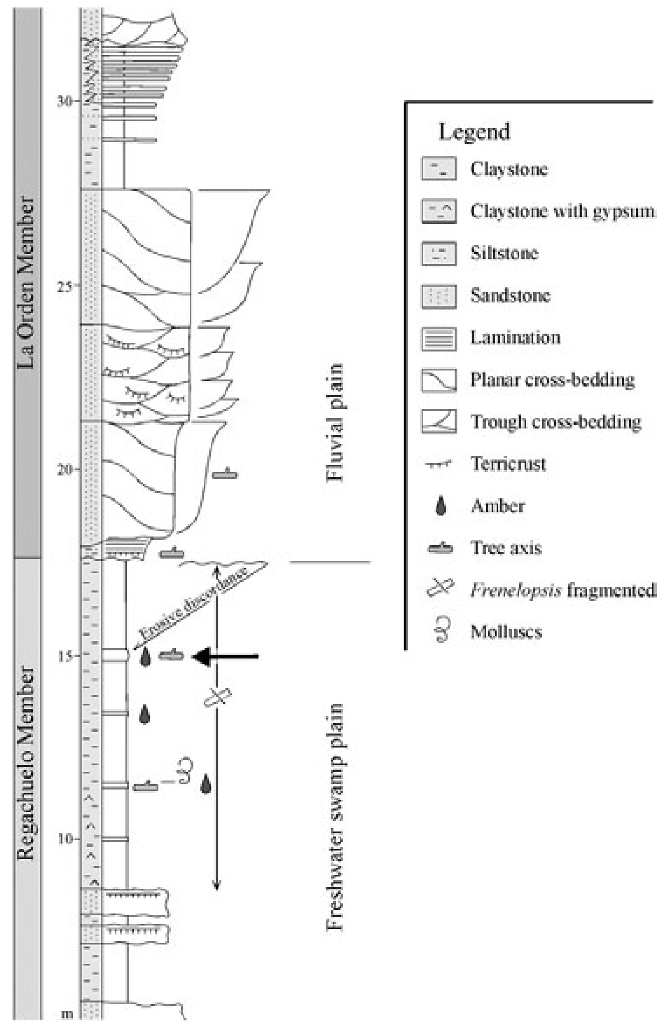
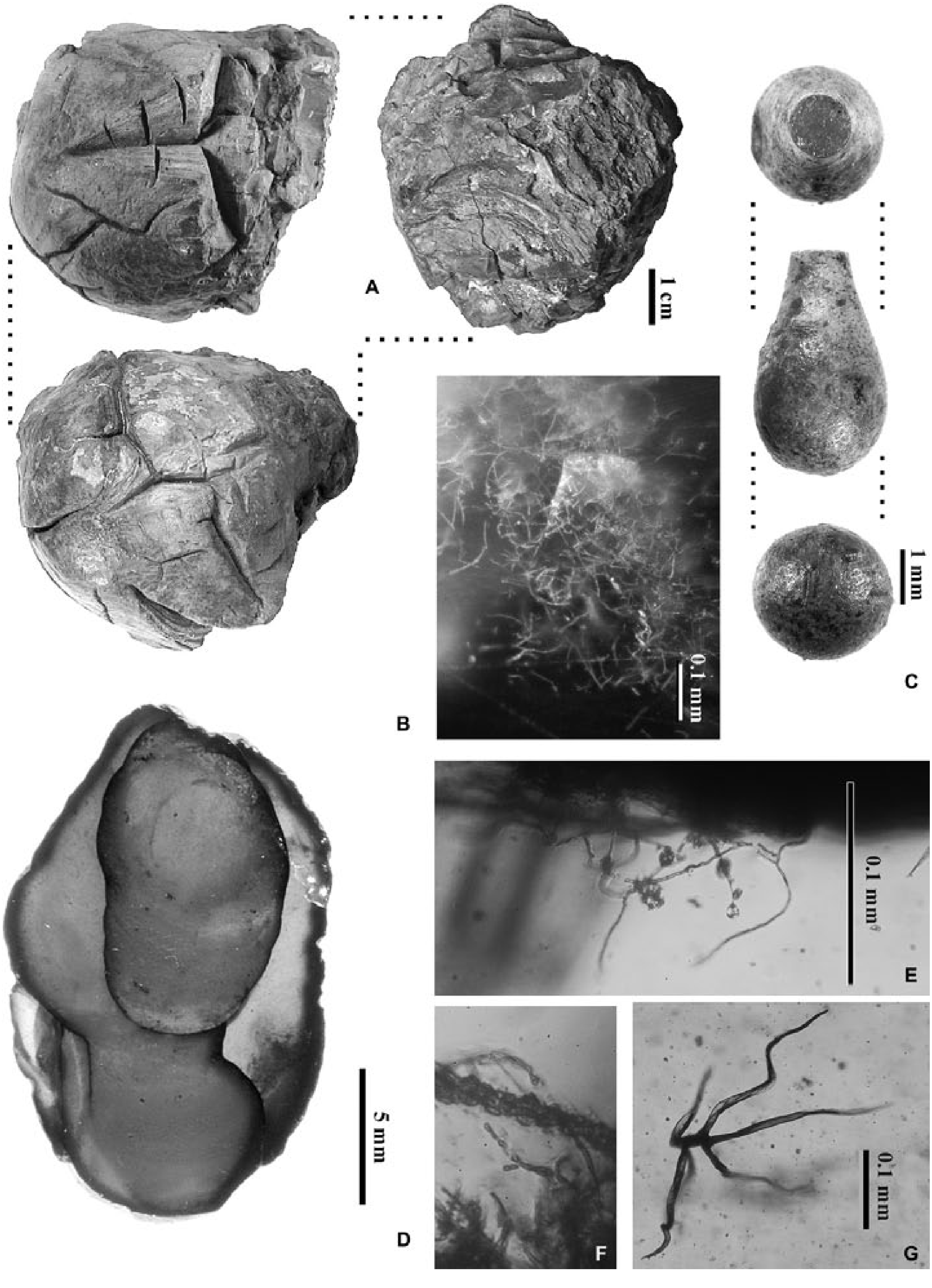


Fig. 2. Stratigraphic log of the San Just section indicating the level rich in amber (arrow). The amber-bearing strata are within the Escucha Formation, which is divided into lower or Barriada, middle or Regachuelo, and upper or La Orden members.

crust, and become more isolated and less abundant at the boundary with the unaltered amber, in a manner identical to that observed in the ambers of Asturias (Corchón-Rodríguez et al., in press), Arroyo de la Pascueta (Teruel Province) and La Hoya (Castellón Province). This suggests that they are not biological inclusions but a type of degradation or alteration feature of the amber. They have been interpreted by some authors as fossil fungal structures, green algae or fossilized bacteria (see Poinar, 1992; Poinar et al., 1993; Schönborn et al., 1999). During the last three years, this type of structure has been studied in detail by three different research groups. Ascaso et al. (2003, 2005) interpreted it as fossilized fungal mycelium. Breton and Tostain (2005) have described it as a new genus and species of a fossil cyanobacterium, *Palaeocolteronema cenomanensis* of the family Capsosiraceae. Schmidt and Schäfer (2005) described it as *Leptotrichites resinatus*, a new genus and species of sheathed bacteria. These studies have emphasized the general morphology of the structure but have not explained how the microorganisms came to be included in the resin or its peculiar distribution in the amber masses. If the


A
1 cm
B
0.1 mm
C
1 mm
D
5 mm
E
0.1 mm
F
G
0.1 mm

structure is truly attributable to a fossil microorganism it is necessary to carry out a taphonomic study.

A specimen of particular taphonomic importance is shown in Fig. 3A. It is a rounded amber mass of $55 \times 53 \times 52$ mm, with a flat area exhibiting marks that correspond to the bark of a tree on which the resin mass would have accumulated. The rest of the surface is a hemisphere with clear evidence of oxidation (i.e., an opaque, external layer clear brown in colour), which is very smooth with the exception of some clusters of cracks. These cracks are deep and star-shaped, with fluted surfaces in their interior (especially visible in the upper left part of Fig. 3A). This is an example of the formation of globular or kidney-shaped masses by thick resin, as can be observed on the trunks and branches of living trees of the genera *Prunus* and *Pinus*. In this specimen, the growth of the kidney-shaped mass was caused by the input of resin into its interior, not by repeated flows of fluid resin that would have covered it with concentric layers; these are not evident here. In the interior there are no draining layers but instead a very homogenous mass of amber. The marked cracks in the surface of the globular mass are evidence of interior growth; the dried external surface was cracked by the increase in volume of the mass, a process followed by successive stages of drying and internal expansion that led to the formation of secondary and tertiary cracks on the internal surfaces of the original cracks.

The input of resin directly into the interior determined that the external surface of this type of mass remained sticky only during the first stage of its formation, limiting the number of arthropods or plant remains that could become trapped in it. In these masses, biological inclusions can only occur in the outer part, which is usually altered, forming a crust. It is likely that the formation of an alteration crust would have destroyed the specimens present in the outer part. This could explain the lack of biological inclusions in most of the Cretaceous globular or kidney-shaped amber masses and as well as in the Early Eocene amber of Oise (France) with inclusions of insect larvae (Nel pers. comm., 2006). On the other hand, the stalactitic masses and drops indicate the presence of fluid resin, in which biological inclusions are commonly found. The production of both thick and fluid resin could have occurred on the same tree, depending on factors such as the part of the tree in which exudation took place, the reasons for the emission, or the ambient temperature. Martínez-Delclòs et al. (2004) discussed the circumstances of resin production in the past, and on their implications for the insect fossil record (see also Henwood, 1993).

5. Infrared spectroscopy analysis

Infrared spectroscopy analysis (transmittance) of an amber specimen from the San Just outcrop was carried out in the Molecular Spectrometry Unit at the University of Barcelona with an IM120 spectrometer IR BOMEM connected to a SpectraTech IRPlan microscope that uses a diamond cell. Three analyses were conducted on: (1) samples from the altered crust; (2) unaltered amber in the inner part; (3) the boundary between the two parts.

Kosmowska-Ceranowicz (1999) presented an infrared spectrum of an Utrillas amber sample, which is generally very similar to the San Just amber. Neither of the spectra shows pronounced bands in the range of 800–400 cm^{-1} (Fig. 4), unlike most Spanish Cretaceous amber spectra. In addition, they do not show pronounced bands at 475 cm^{-1} and 540 cm^{-1}, unlike the amber from Álava and Santander (see Kosmowska-Ceranowicz, 1999). These bands are only present in some of the spectra of the Álava ambers (see Alonso et al., 2000). The first band is absent from acid resins and the second is characteristic of hydrocarbon resins. The San Just amber shows an intense band C-H at 1458 cm^{-1} and one intense carbonyl band at 1724 cm^{-1}, both typical of amber spectra. It also shows a band at 856 cm^{-1}, which is similarly pronounced in samples of Álava amber (see Alonso et al., 2000). Another important characteristic of the San Just amber spectrum is the absence of exocyclic methylenic bands at 880 cm^{-1} and 1640 cm^{-1}, as in the Álava amber. These indicate a high degree of maturation, including the effects of the diagenetic process, which is consistent with their Cretaceous age (Alonso et al., 2000).

6. Biological inclusions and origin of the amber

Some "stalactitic" masses containing plant and arthropod inclusions, as well as other amber fragments, were found during a palaeontological investigation of the Utrillas area in 2003. The biological inclusions were prepared for appropriate conservation and study according to the methods and protocol outlined in Corral et al. (1999). The specimens have been deposited in the collection of the "Fundación Conjunto Paleontológico de Teruel" (File 12/05).

Plant remains (sensu lato) found in the San Just amber include fungal hyphae, "stellate-hairs" or trichomes, and pollen grains, all of which are present in the same "stalactite". Fungal hyphae (some reaching almost 0.5 mm in length) are branched and septate, and in an isolated portion of an arthropod cuticle (Fig. 5A). Two additional mycelia are present on both sides of the thorax of a dolichopodid fly (Figs. 3E, F, 5B, C, 6D). One of these mycelia has hyphae that are up to 0.1 mm in length, and several sporangia that are up to 9 μm in diameter (Fig. 5B). The other exhibits a large number of abundantly septate hyphae (Fig. 5C). The mycelia in the dolichopodid fly seem to correspond to mitosporic fungi or to the

Fig. 3. Some morphologies of the San Just amber, details of degradation and remains of a plant. A, lump of amber (CPT-950) that shows the marks of tree bark (upper right), two phases during which the external surface has cracked owing to drying and an increase in volume by the flow of resin into the interior of the globular lump. B, detail of the characteristic filamentous degradation of Spanish Cretaceous amber that has been misinterpreted by several authors as preserved microorganisms. C, distal part of a dripping process (CPT-951), originating from resin with a low viscosity, which shows the globular morphology prior to the formation of a drop. D, cross section of a stalactite (CPT-972) that shows several layers from different instances of resin outflow. E, fungal hyphae with sporangia that grew on the thorax of a fly of the genus *Microphorites* (family Dolichopodidae) (CPT-963) (see Figs. 5B, 6D, 7). F, septal hyphae branching from one of the mycelia on the same specimen of *Microphorites*. G, "stellate-hair" (trichome) (CPT-958), of a plant, possibly originating from a fern or conifer.

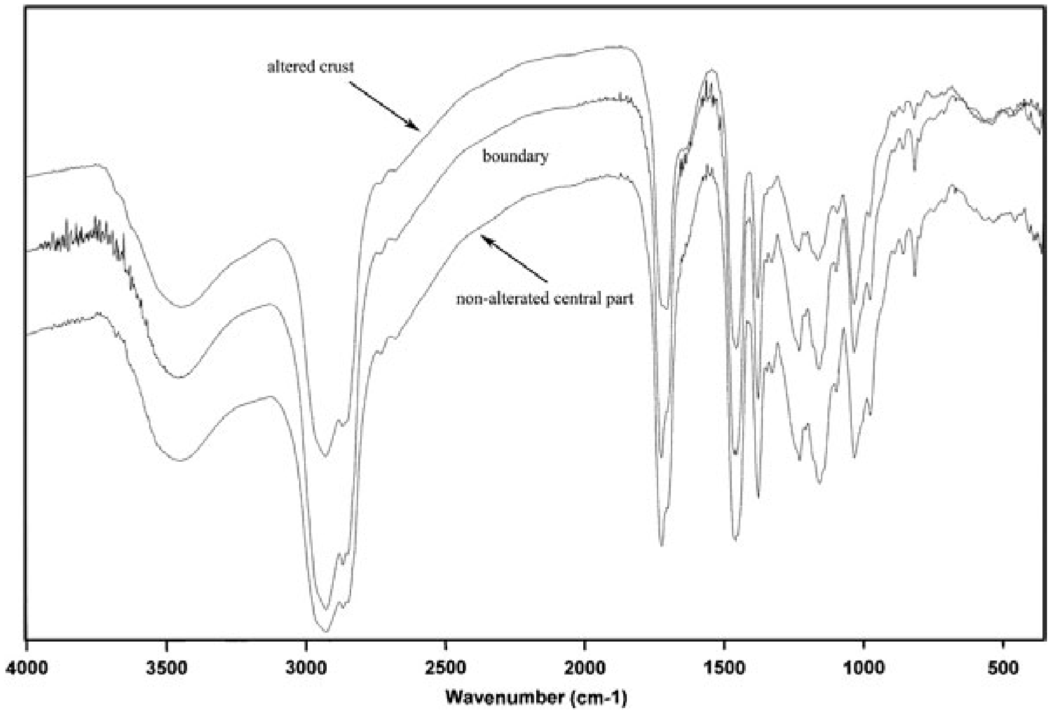


Fig. 4. Infrared spectra (IRTF) of the San Just amber; analysis of the external layer of degradation, the unaltered central part, and the boundary between the two parts of the same lump. Resolution 4 cm^{-1}.

zygomycetes group (Atienza pers. comm., 2005). These hyphae would have developed in the dead fly before it became included in the resin, but we cannot rule out the possibility that their growth took place within the resin itself. Other hyphal groups have been detected on the elytra of a beetle specimen (Cucujidae). True fungal hyphae have been reported in Late Cretaceous amber from Mississippi (Waggoner, 1994), which have morphological characteristics different from those found in the San Just amber, and in Late Cretaceous amber from Schliersee (Germany), according Schmidt et al. (2001).

In addition, there are nine preserved specimens of ''stellate-hairs'' or trichomes (Fig. 3G), which are similar to those found in Tertiary Baltic amber and Late and Early Cretaceous ambers from New Jersey and Lebanon, respectively. The trichomes found at San Just are smaller and contain fewer filamentous expansions (2–6) than those in the Baltic amber, which have been related to the formation of new buds or flowers in oaks (Weitschat and Wichard, 2002). For this reason, it has been suggested that the resin-producing forests contained oak trees. Poinar (1992) indicated that five main types of trichomes have been identified in Baltic amber and that all can be found in extant species of Fagaceae. The trichomes in the Cretaceous amber of San Just and elsewhere, however, do not indicate the presence of this family, since it did not exist then. It is likely, as today (Gifford and Foster, 1987; Hall and Burke, 1974; Jones, 1998), that these ''stellate-hairs'' belonged to ferns or conifers. They apparently prevent the drying of new buds or block excessive sunlight in some present-day coniferous trees, and control the availability of water on the surface of fern leaves. Finally, about 80 small (diameter ca. 30 μm), smooth, inaperturate pollen grains (CPT-959) attributed to the genus *Inaperturopollenites* (Barrón pers. comm., 2006), have been found on an oxidation drying surface.

So far, insect remains in the San Just amber comprise 24 specimens from four orders: Hymenoptera, Diptera, Thysanoptera and Coleoptera. A small insect coprolite, 0.12 × 0.03 mm, with a tubular form has also been found. Hymenopterans are the most abundant group and include the families Scelionidae, Evaniidae and Stigmaphronidae, all small, parasitoid wasps (Fig. 6A, B). Scelionidae is the most abundant group (eight specimens found so far), with several morphotypes detected, some robust and others more delicate, as has been observed in the Álava amber (Martínez-Delclòs and Peñalver, 1998; Alonso et al., 2000). Specimens of Evaniidae (CPT-957 and 960) are practically complete, and belong to the genus *Cretevania* Rasnitsyn, 1975, which was the only genus in the family Cretevaniidae until the description of *Procretevania* Zhang and Zhang, 2000 (Basibuyuk et al., 2002). An additional Spanish specimen of *Cretevania* has been found in the Arroyo de la Pascueta amber of Rubielos de Mora (Peñalver and Martínez-Delclòs, 2002). In contrast, this genus has not been found in the Álava amber. Most of the small number of *Cretevania* specimens found in Siberian, Mongolian and English outcrops are incomplete. So far, the genus contains five valid species (Rasnitsyn et al., 1998; Deans, 2005). A specimen of the extinct family Stigmaphronidae (Fig. 6A), within the superfamily Ceraphronoidea, is virtually complete, lacking only a part of the right antenna. It is a small wasp with reduced wing venation and highly developed hind legs with thick femora and wide, triangular tibiae ending in thick spines. Other specimens of Stigmaphronidae have been found in Cretaceous ambers from Siberia, New

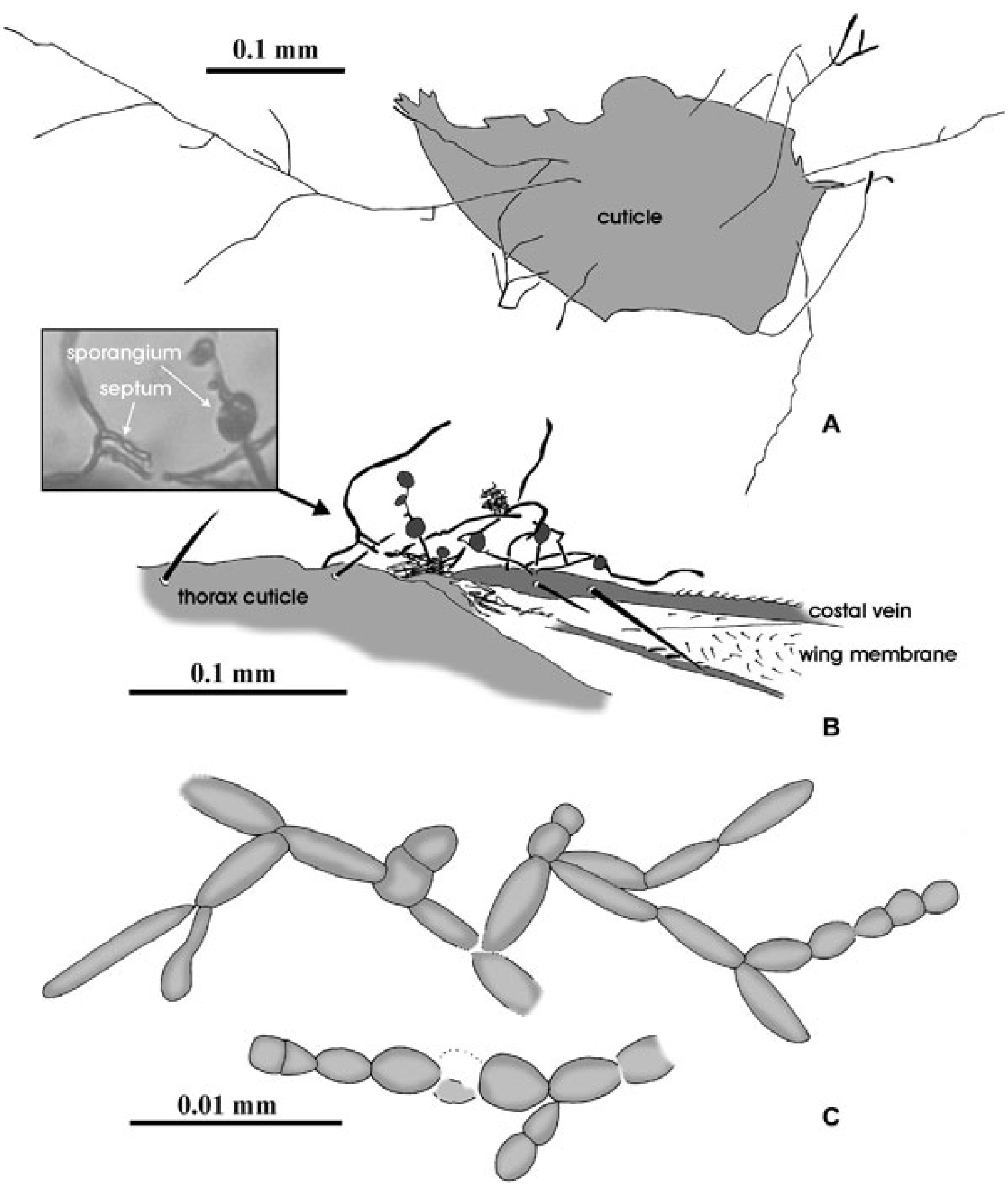


Fig. 5. Fungal hyphae. A, fungal hyphae that grew on a small, isolated fragment of the cuticle of an arthropod. B, fungal hyphae with sporangia that grew on the thorax of a fly of the genus *Microphorites* (family Dolichopodidae) (see Figs. 3E, 6F). C, septal hyphae of one of the mycelia on the same specimen of *Microphorites* (see Figs. 3F, 6D).

Jersey, Canada, Myanmar, Lebanon (Grimaldi et al., 2002) and northern Spain (Álava amber) (Martínez-Delclòs et al., 1999, 2000).

Dipterans in the San Just amber belong to the families Ceratopogonidae, of the suborder Nematocera, and Dolichopodidae, of the suborder Brachycera (Fig. 6C, D). The ceratopogonid specimen (Fig. 6C), possibly a female, shows characteristics of the proboscis, palps, eyes, antennae and wings that differentiate it from the other three species previously identified in Álava amber (Szadziewski and Arillo, 1998, 2003): *Protoculicoides skalskii*, *Archiaustroconops alavensis* and *Leptoconops zherikhini*. *Austroconops* has also been recorded from the Álava amber (Szadziewski and Arillo, 2003). The specimen from the family Dolichopodidae (''Microphorinae'') belongs in *Microphorites* Hennig, 1971 and is a female (Figs. 6D, 7). This genus contains four species that have been found in Early Cretaceous amber from Lebanon and France (Nel et al., 2004). Therefore, the *Microphorites* specimen is the most important find to date at San Just, given the scarcity of specimens referable to this genus in the fossil record. Specimens of brachycerans that probably belong in the subfamily ''Microphorinae'' have been recorded from the Álava amber (Alonso et al., 2000).

The one representative of Thysanoptera found at San Just belongs to the family Stenurothripidae. It is a complete specimen, 0.64 mm long, that has elongate wings covered with dense, fine hairs (Figs. 6E, 7). There are several other specimens of thysanopterans in Álava amber (Alonso et al., 2000),

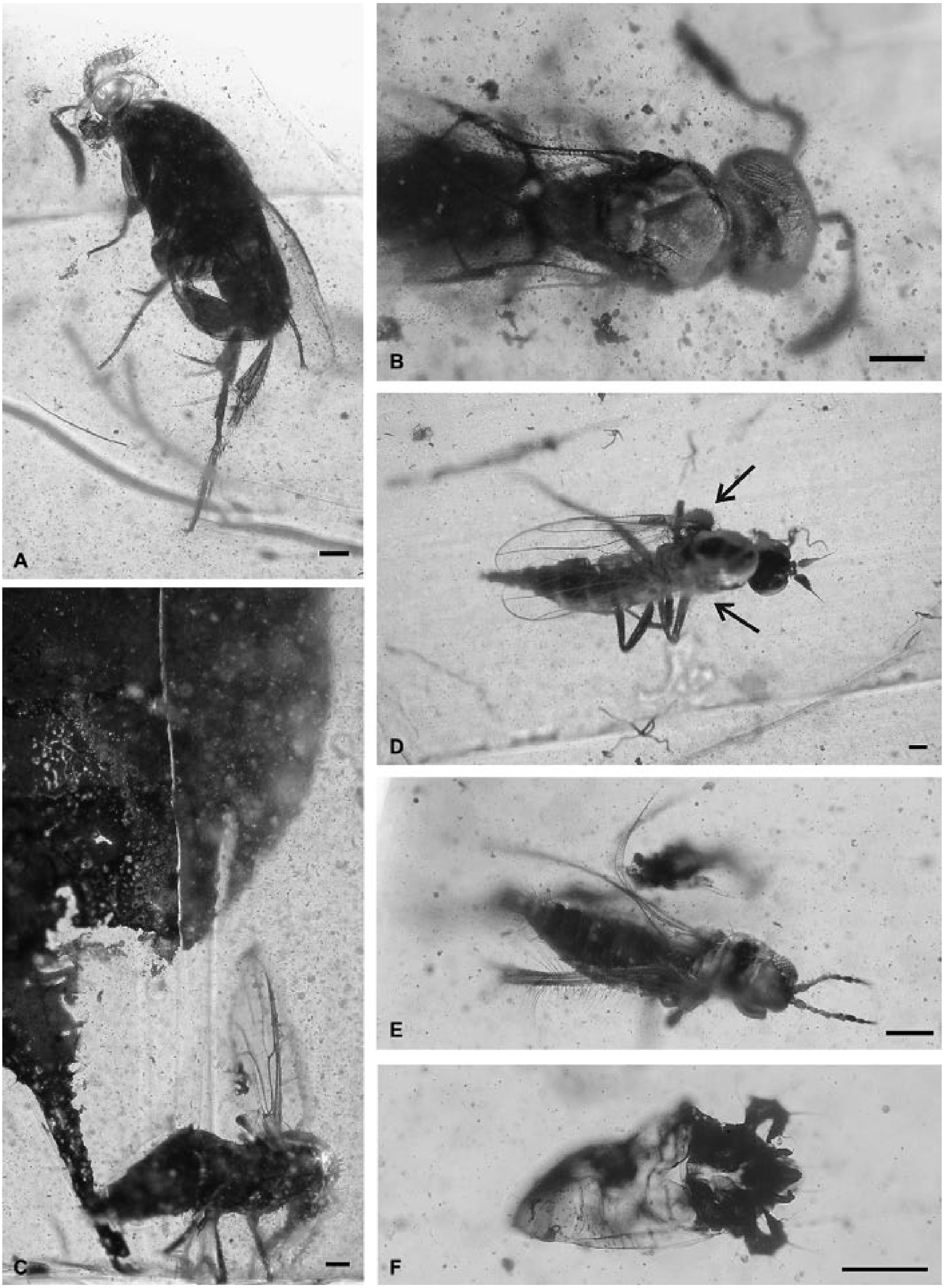


Fig. 6. Assorted arthropods, mainly insects, in the San Just amber. A, Hymenoptera: Stigmaphronidae (CPT-961), lateral view. B, Hymenoptera: Scelionidae (CPT-969), dorsal view. C, Diptera: Ceratopogonidae (CPT-970), lateral view. D, Diptera: Dolichopodidae: *Microphorites* sp. (CPT-963), dorsal view (the arrows indicate the two fungal hyphae that grew on the thorax; upper arrow, see Figs. 3F, 5C; lower arrow, see Figs. 3E, 5B). E, Thysanoptera: Stenurothripidae (CPT-971), dorsal view (see Fig. 7). F, nymphal mite of the order Oribatida (CPT-964), ventral view. Scale bars represent 0.1 mm.

possibly also referable to the Stenurothripidae. The Thysanoptera originated in the early Mesozoic or late Palaeozoic; there are a few very well-preserved specimens from the Upper Triassic of Virginia and Kazakhstan (Grimaldi et al., 2004). By the Early Cretaceous, true thrips became much more abundant as compressions and biological inclusions (Grimaldi et al., 2004), although compared to other orders of insects the fossil record of the Thysanoptera is very limited.

Coleoptera are represented in the San Just amber by a small (length 1.6 mm), elongate, parallel-sided, strongly dorsoventrally flattened specimen, with scale-like setae on the elytra. This specimen (CPT-965) belongs in the family Cucujidae (superfamily Cucujoidea). Adults of extant species of this family are usually found under the bark of dead trees, under logs and among decaying plant matter.

Arachnids from San Just include one mite and two spiders. The mite (Fig. 6F) corresponds to a nymph of the order Oribatida (= Cryptostigmata) (Arillo pers. comm., 2005); this order is also present in the Álava amber, in which the species *Archaeorchestes minguezae* and *Eupterotegaeus bitranslamellatus* (Arillo and Subías, 2000, 2002) have been identified. Another chelicerate order present in the latter amber is Actinotrichida (Alonso et al., 2000). Mites are common in Cretaceous ambers, being more abundant in Burmese amber (Grimaldi et al., 2002), followed by the recently discovered Archingeay deposits in France (Perrichot, 2004).

The two araneoids found at San Just (CPT-955 and 956) have been examined by Dr. David Penney, but their familial affinities have been impossible to determine owing to their poor state of preservation. Aside from the San Just specimens, the only other spider remains in Spanish amber are from Álava (Alonso et al., 2000; Penney, 2006) and the El Caleyu outcrops in Asturias (Arbizu et al., 1999), the latter providing only one poorly preserved specimen that cannot be precisely identified.

Most of the specimens discussed here come from two ‘‘stalactitic’’ masses of amber and can thus be considered syninclusions (sensu Koteja, 1996). The hymenopteran specimens of the Scelionidae, the ceratopogonid dipteran and the thysanopteran were found as syninclusions in a partially transparent amber stalactite with abundant concentric oxidation-drying layers. Another set of syninclusions, in a yellowish transparent amber ‘‘stalactite’’, 18.0×7.5 mm, without oxidation-drying layers, is represented by the specimen of *Cretevania*, the stigmaphronid wasp, the *Microphorites* fly, the coleopteran, a pair of legs from an undetermined insect, the mite, the ‘‘stellate-hairs’’ and the pollen grains. Some of the arthropods in this set are trapped within a spider’s web, most probably an orb web, which is the oldest in the fossil record (Peñalver et al., 2006).

The abundance of biological inclusions in the amber of San Just makes it among the richest of the Early Cretaceous amber deposits in the Teruel-Castellón area (the others being Arroyo de la Pascueta and La Hoya), and their preservation is better

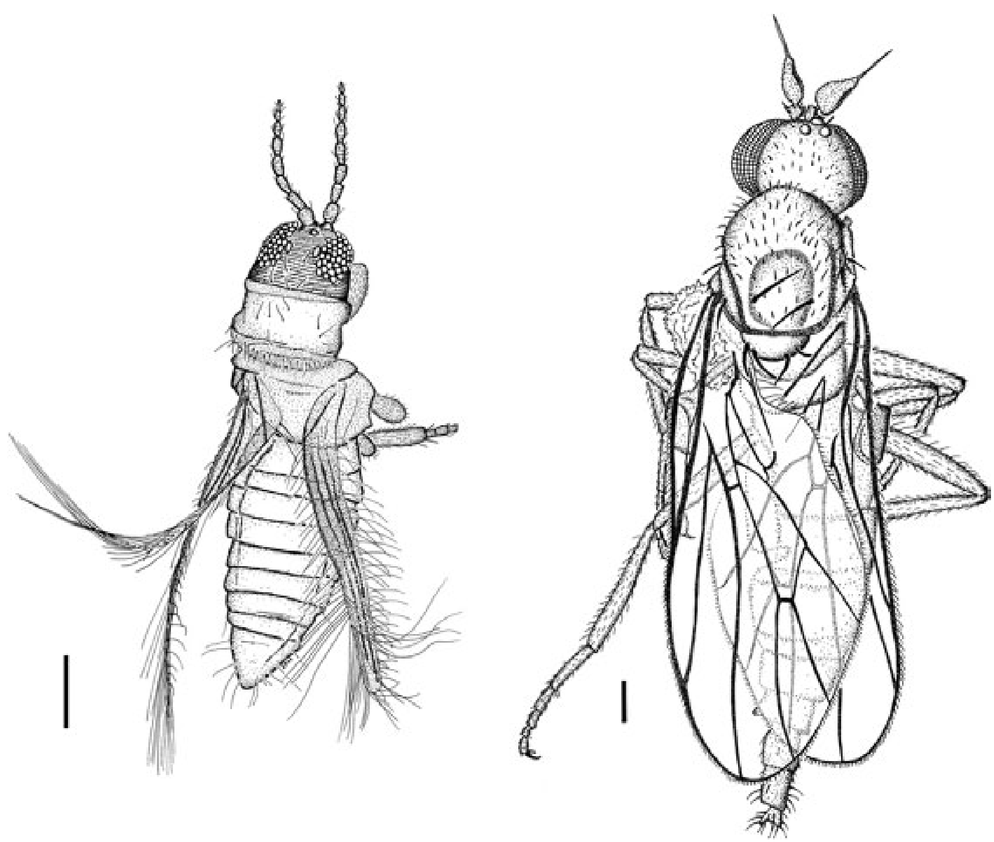


Fig. 7. Camera lucida drawings of a specimen of the family Stenurothripidae (Thysanoptera) (CPT-971): dorsal view (left), and a female specimen of *Microphorites* (CPT-963), dorsal view (right). Scale bars represent 0.1 mm.

than elsewhere. The few amber masses were found without the need for excavation, yet they have yielded 15 arthropod specimens. It is likely that future investigations will provide even more material, allowing extensive studies on the entomofauna.

Determining the type of tree that produced this amber is problematic, since no study has yet been performed on the amber fragments containing wood. It probably has the same origins as the Álava amber, the molecular composition of which suggests a coniferalean, probably araucariacean origin (Alonso et al., 2000), as for Baltic amber. The absence of key organic compounds indicates that the Álava amber does not have podocarpacean, burseracean, cupressacean, dipterocarpacean or caesalpinacean origins. Although the set of compounds detected differs from that of Baltic amber, both have certain common sub-products, suggesting that they have similar origins. Perhaps the observed differences are mainly because the Álava amber is more mature. The araucariacean origin of the Álava amber is supported by the high number of associated pollen grains related to the Araucariaceae (Alonso et al., 2000; Barrón et al., 2001) found in it.

7. Conclusions

In spite of historical references to the presence of Cretaceous amber in the Utrillas area that date back to 1860, amber from this locality has never hitherto been studied systematically and had apparently never previously yielded specimens with biological inclusions. The San Just exposure near the village of Utrillas has yielded ‘‘stalactitic’’ amber masses with well-preserved fossil inclusions. A study of these masses and their features, including an IRTF analysis, has confirmed a Cretaceous age, and that they are similar to ambers found in outcrops at Peñacerrada (Álava), El Caleyu, Arroyo de la Pascueta and La Hoya. Even though only a preliminary investigation has been carried out, the specimens found in a few pieces of amber indicate a high diversity of arthropod remains. So far, four orders of insects have been found. Other fossils found include a mite, spiders and several plant remains. This record is similar to that for other Early Cretaceous ambers from Spain and France, but shows some significant differences from the Álava amber (e.g. the presence of *Cretevania*, a rare parasitoid wasp). The discoveries of a thysanopteran of the family Stenurothripidae and a dolichopodid dipteran referable to the genus *Microphorites* constitute the most important palaeoentomological records from this amber to date.

The study of a large globular mass with drying cracks and marks left by the bark of the resin-producing tree provides new data and interpretations that help to explain the origin and relative abundance of kidney-shaped amber masses in Spanish Early Cretaceous outcrops. These masses seem to have been formed by the release of very thick resin onto the outer part of the trunks. They would have dried quickly, but would have kept growing by the flow of resin into their interior; hence, they had a sticky external surface only during a short initial period. This is in contrast to the ‘‘stalactitic’’ masses that have grown from successive external resin flows.

The relative abundance of highly transparent ‘‘stalactitic’’ masses that commonly contain well-preserved arthropod inclusions make this new deposit an exceptional outcrop for future investigations into the Early Cretaceous entomofauna of the Iberian Plate. Detailed comparison of their fossil record with that of existing examples from the Álava amber will be of particular interest. Therefore, San Just is the most important amber-bearing deposit for the study of Cretaceous fossil insects in the eastern Iberian Peninsula, surpassing other similar deposits in the region in terms of abundance, variety and the state of preservation.

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References

Alonso, J., Arillo, A., Barrón, E., Corral, J.C., Grimalt, J., López, J.F., López, R., Martínez-Delclòs, X., Ortuño, V.M., Peñalver, E., Trincão, P.R., 2000. A new fossil resin with biological inclusions in Lower Cretaceous deposits from Álava (northern Spain, Basque-Cantabrian Basin). Journal of Paleontology 74, 158–178.

Arbizu, M., Bernárdez, E., Peñalver, E., Prieto, M.A., 1999. El ámbar de Asturias (España). Estudios del Museo de Ciencias Naturales de Álava 14 (Special Publication 2), 245–254.

Arillo, A., Subías, L.S., 2000. A new fossil oribatid mite, *Archaeorchestes minguezae* gen. nov., sp. nov. from the Spanish Lower Cretaceous amber. Description of a new family, Archaeorchestidae (Acariformes, Oribatida, Zetorchestoidea). Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg 84, 231–236.

Arillo, A., Subías, L.S., 2002. Second fossil oribatid mite from the Spanish Lower Cretaceous amber. *Eupterotegaeus bitranslamellatus* n. sp. (Acariformes, Oribatida, Cepheidae). Acarologia 42, 403–406.

Ascaso, C., Wierzchos, J., Corral, C., López del Valle, R., Alonso, J., 2003. New applications of light and electron microscopic techniques for the study of microbiological inclusions in amber. Journal of Paleontology 77, 1182–1192.

Ascaso, C., Wierzchos, J., Speranza, M., Gutiérrez, J.C., Martín-González, A., De Los Ríos, A., Alonso, J., 2005. Fossil protist and fungi in amber and rock substrates. Micropaleontology 51, 59–72.

Azar, D., 2000. Les Ambres Mésozoïques du Liban. Unpublished PhD thesis, Universite Paris XI, Orsay, 164 pp.

Barrón, E., Comas-Rengifo, J., Elorza, L., 2001. Contribuciones al estudio palinológico del Cretácico Inferior de la Cuenca Vasco-Cantábrica: los afloramientos ambarígenos de Peñacerrada (España). Coloquios de Paleontología 52, 135–156.

Basibuyuk, H.H., Rasnitsyn, A.P., Fitton, M.G., Quicke, D.L.J., 2002. The limits of the family Evaniidae (Insecta: Hymenoptera) and a new genus from Lebanese amber. Insect Systematics and Evolution 33, 23–34.

Borkent, A., 1995. Biting Midges in the Cretaceous Amber of North America (Diptera: Ceratopogonidae). Backhuys Publishers, Leiden, 237 pp.

Breton, G., Tostain, F., 2005. Les microorganismes de l'ambre cénomanien d'Écommoy (Sarthe, France). Comptes Rendus Palevol 4, 31–46.

Cervera, A., Pardo, G., Villena, J., 1976. Algunas precisiones litoestratigráficas sobre la Formación ''lignitos de Escucha''. Tecniterrae 3 (14), 25–33.

Corchón-Rodríguez, M.S., Mateos-Cachorro, A., Álvarez-Fernández, E., Delclòs, X., Peñalver, E., van der Made, J. Ressources complémentaires et mobilité dans le Magdalénien Cantabrique (14000–13000 BP). Nouvelles donnes sur cétacées, phoques, mollusques, ambre et jais de la Grotte de Las Caldas (Asturies, Nord de l'Espagne). L'Anthropologie, Elsevier, Amsterdam, in press.

Corral, J.C., López del Valle, R., Alonso, J., 1999. El ámbar cretácico de Álava (Cuenca Vasco-Cantábrica, norte de España). Su colecta y preparación. Estudios del Museo de Ciencias Naturales de Álava 14 (Special Publication 2), 7–21.

Cortázar, D., 1885. Bosquejo físico-geológico y minero de la provincia de Teruel. Boletín de la Comisión del Mapa Geológico de España 12, 263–607.

Deans, A.R., 2005. Annotated catalog of the world's ensign species (Hymenoptera: Evaniidae). Contributions of the American Entomological Institute 34 (1), 164.

Delclòs, X., Arillo, A., Ortuño, V.M., Peñalver, E., Soriano, C., 2003. Asociaciones de hexápodos (Arthropoda) del Cretácico Inferior de la Península Ibérica. XIX Jornadas de la Sociedad Española de Paleontología, Morella, pp. 70–71.

Delclòs, X., Peñalver, E., Arillo, A., Ortuño, V.M., López del Valle, R., Soriano, C., 2005. Spanish Mesozoic amber localities. Abstracts, 2nd World Congress on Amber and its Inclusions, Pretoria, p. 43.

Díez, J.B., Sender, L.M., Villanueva-Amadoz, U., Ferrer, J., Rubio, C., 2005. New data regarding *Weichselia reticulata*: soral clusters and the spore developmental process. Review of Palaeobotany and Palynology 135, 99–107.

García-Cortés, A., Rábano, I., Locutura, J., Bellido, F., Fernández-Gianotti, J., Martín-Serrano, A., Quesada, C., Barnolas, A., Durán, J.J., 2000. Contextos geológicos españoles de relevancia internacional: establecimiento, descripción y justificación según la metodología del proyecto Global Geosites de la IUGS. Boletín Geológico y Minero 111 (6), 5–38.

Gifford, E.M., Foster, A.S., 1987. Morphology and Evolution of Vascular Plants, Third Edition. W.H. Freeman and Co., New York, 626 pp.

Grimaldi, D.A., 1996. Amber: Window to the Past. Harry N. Abrahams, Inc. and American Museum of Natural History, New York, 215 pp.

Grimaldi, D.A. (Ed.), 2000. Studies on Fossils in Amber, with Particular Reference to the Cretaceous of New Jersey. Backhuys Publishers, Leiden, 498 pp.

Grimaldi, D.A., Engel, M.S., 2005. Evolution of the Insects. Cambridge University Press, New York, 755 pp.

Grimaldi, D.A., Engel, M.S., Nascimbene, P.C., 2002. Fossiliferous Cretaceous amber from Myanmar (Burma): its rediscovery, biotic diversity, and paleontological significance. American Museum Novitates 3361, 1–71.

Grimaldi, D.A., Shedrinsky, A., Wampler, P., 2000. A remarkable deposit of fossiliferous amber from the Upper Cretaceous (Turonian) of New Jersey. In: Grimaldi, D.A. (Ed.), Studies on Fossils in Amber, with Particular Reference to the Cretaceous of New Jersey. Backhuys Publishers Leiden, pp. 1–76.

Grimaldi, D.A., Shmakov, A., Fraser, N., 2004. Mesozoic thrips and early evolution of the order Thysanoptera (Insecta). Journal of Paleontology 78, 941–952.

Hall, D.M., Burke, W., 1974. Wettability of leaves of a selection of New Zealand plants. New Zealand Journal of Botany 12, 283–298.

Henwood, A., 1993. Recent plant resins and the taphonomy of organisms in amber: a review. Modern Geology 19, 35–59.

Jarzembowski, E.A., 1999. British amber: a little-known resource. Estudios del Museo de Ciencias Naturales de Álava 14 (Special Publication 2), 133–140.

Jones, D.L., 1998. Encyclopaedia of Ferns. An Introduction to Ferns, their Structure, Biology, Economic Importance, Cultivation and Propagation. Timber Press, Portland, Oregon, 433 pp.

Kaddumi, H.F., 2005. Amber of Jordan: the Oldest Prehistoric Insects in Fossilized Resin. Published by the author, Amman, 168 pp.

Kosmowska-Ceranowicz, B., 1999. Succinite and some other fossil resins in Poland and Europe (deposits, finds, features and differences in IRS). Estudios del Museo de Ciencias Naturales de Álava 14 (Special Publication 2), 73–117.

Koteja, J., 1996. Syninclusions. Inclusion-Wrostek 22, 10–12.

Martínez, R., Grauges, A., Salas, R., 1994. Distribución de los amonites del Cretácico inferior de la Cordillera Costera Catalana e Ibérica Oriental. Cuadernos de Geología Ibérica 18, 337–354.

Martínez-Delclòs, X., 1991. Insectos Hemimetábolos del Cretácico Inferior de España. Sistemática y Tafonomía. Unpublished PhD thesis, University of Barcelona, 784 pp.

Martínez-Delclòs, X., Arillo, A., Ortuño, V.M., Peñalver, E., 1999. El ámbar del Cretácico Inferior de Peñacerrada (Álava, España). Temas Geológico-Mineros. Instituto Tecnológico Geominero de España 26, 13–17.

Martínez-Delclòs, X., Arillo, A., Ortuño, V.M., Peñalver, E., 2000. Paleoentomological inclusions in the Spanish Lower Cretaceous amber. Abstracts, I International Meeting on Paleoarthropodology, Ribeirão Preto, pp. 18–19.

Martínez-Delclòs, X., Briggs, D.E.G., Peñalver, E., 2004. Taphonomy of insects in carbonates and amber. Palaeogeography, Palaeoclimatology, Palaeoecology 203, 19–64.

Martínez-Delclòs, X., Peñalver, E., 1998. The fossil Scelionidae (Insecta: Hymenoptera) from the Lower Cretaceous amber of Álava (Spain). Abstracts, World Congress on Amber Inclusions, Vitoria-Gasteiz, p. 163.

Martínez-Delclòs, X., Peñalver, E., 1999. Insect assemblages in the Mesozoic record of the Iberian Peninsula. Abstracts, VII International Symposium on Mesozoic Terrestrial Ecosystems, Buenos Aires, pp. 42–43.

Nel, A., Perrichot, V., Daugeron, Ch., Néraudeau, D., 2004. A new *Microphorites* in the Lower Cretaceous amber of the southwest of France (Diptera: Dolichopodidae, ''Microphorinae''). Annales de la Société Entomologique de France (Nouvelle Série) 40, 23–29.

Néraudeau, D., Perrichot, V., Dejax, J., Masure, E., Nel, A., Philippe, M., Moreau, P., Guillocheau, F., Guyot, T., 2002. Un nouveau gisement à ambre insectifère et à végétaux (Albien terminal probable): Archingeay (Charente-Maritime, France). Geobios 35, 233–240.

Penney, D., 2006. The oldest lagonomegopid spider, a new species in Lower Cretaceous amber from Álava, Spain. Geologica Acta 4, 377–382.

Peñalver, E., Grimaldi, D.A., Delclòs, X., 2006. Early Cretaceous spider web with its prey. Science 312, 1761.

Peñalver, E., Martínez-Delclòs, X., Arillo, A., 1999. Yacimientos con insectos fósiles en España. Revista Española de Paleontología 14, 231–245.

Peñalver, E., Martínez-Delclòs, X., 2002. Importancia patrimonial de Arroyo de la Pascueta, un yacimiento de ámbar cretácico con insectos fósiles en Rubielos de Mora. In: Meléndez, G., Peñalver, E. (Coordinators.), El Patrimonio Paleontológico de Teruel. Instituto de Estudios Turolenses, Teruel, pp. 201–208.

Perrichot, V., 2004. Early Cretaceous amber from south-western France: insight into the Mesozoic litter fauna. Geologica Acta 2, 9–22.

Perrichot, V., 2005. Environnements paraliques à amber et à végétaux du Crétacé Nord-Aquitain (Charentes, Sud-Ouest de la France). Mémoires des Géosciences, Rennes 118, 1–213.

Poinar, G.O., 1992. Life in Amber. Stanford University Press, Stanford, 350 pp.

Poinar, G.O., Milki, R., 2001. Lebanese Amber. The Oldest Insect Ecosystem in Fossilized Resin. Oregon State University Press, Portland, 96 pp.

Poinar, G.O., Waggoner, B.M., Bauer, U.-Ch., 1993. Terrestrial soft-bodied protists and other microorganisms in Triassic amber. Science 259, 222–224.

Querol, X., 1988. Estudio geológico de la Formación Escucha en la Cuenca del Maestrazgo, Cordillera Ibérica Oriental. Unpublished Tesis de licenciatura, University of Barcelona, 261 pp.

Querol, X., Salas, R., 1988. El sistema deposicional deltaico del Albiense medio en la cuenca del Maestrazgo. Cordillera Ibérica Oriental. Extended abstracts, II Congreso Geológico de España, Granada, Sección de Estratigrafía-Sedimentología, pp. 173–176.

Querol, X., Salas, R., Pardo, G., Ardevol, L., 1992. Albian coal-bearing deposits of the Iberian Range in northeastern Spain. In: McCabe, P.J., Parrish, J.T. (Eds.), Controls on the Distribution and Quality of Cretaceous Coals. Geological Society of America, Special Paper 267, 193–208.

Rasnitsyn, A.P., Jarzembowski, E.A., Ross, A.J., 1998. Wasps (Insecta: Vespida = Hymenoptera) from the Purbeck and Wealden (Lower Cretaceous) of southern England and their biostratigraphical and palaeoenvironmental significance. Cretaceous Research 19, 329–391.

Rasnitsyn, A.P., Quicke, D.L.J. (Eds.), 2002. History of Insects. Kluwer Academic Publishers, Dordrecht, 517 pp.

Salas, R., Guimerà, J., 1997. Estructura y estratigrafía secuencial de la cuenca del Maestrazgo durante la etapa de rift Jurásica superior–Cretácica inferior (Cordillera Ibérica Oriental). Boletín Geológico y Minero 108, 393–402.

Salas, R., Guimerà, J., Mas, R., Martín-Closas, C., Meléndez, A., Alonso, A., 2001. Evolution of the Mesozoic Central Iberian Rift System and its Cainozoic inversion (Iberian Chain). In: Ziegler, P.A., Cavazza, W., Robertson, A.H.F., Crasquin-Soleau, S. (Eds.), Peri-Tethys Memoir 6: Peri-Tethyan Rift/Wrench Basins and Passive Margins. Mémoires du Muséum National d'Histoire Naturelle, Paris 186, 145–185.

Schmidt, A.R., von Eynatten, H., Wagreich, M., 2001. The Mesozoic amber of Schliersee (southern Germany) is Cretaceous in age. Cretaceous Research 22, 423–428.

Schmidt, A.R., Schäfer, U., 2005. *Leptotrichites resinatus* new genus and species: a fossil sheathed bacterium in alpine Cretaceous amber. Journal of Paleontology 79, 175–184.

Schönborn, W., Dörfelt, H., Foissner, W., Krienitz, L., Schäfer, U., 1999. A fossilized microcenosis in Triassic amber. Journal of Eukaryotic Microbiology 46, 571–584.

Sender, L.M., Díez, J.B., Ferrer, J., Pons, D., Rubio, C., 2005. Preliminary data on a new Albian flora from the Valle del Río Martín, Teruel, Spain. Cretaceous Research 26, 898–905.

Solé de Porta, N., Querol, X., Cabanes, R., Salas, R., 1994. Nuevas aportaciones a la palinología y paleoclimatología de la Formación Escucha (Albiense inferior-medio) en las Cubetas de Utrillas y Oliete, Cordillera Ibérica Oriental. Cuadernos de Geología Ibérica 18, 203–215.

Szadziewski, R., Arillo, A., 1998. Biting midges (Diptera: Ceratopogonidae) from the Lower Cretaceous amber from Álava, Spain. Polish Journal of Entomology 67, 291–298.

Szadziewski, R., Arillo, A., 2003. The oldest fossil record of the extant subgenus *Leptoconops (Leptoconops)* (Diptera: Ceratopogonidae). Acta Zoologica Cracoviensia 46 (Supplement, Fossil Insects), 271–275.

Vilanova y Piera, J., 1860. Manual de Geología Aplicada a la Agricultura y a las Artes Industriales. Imprenta Nacional, Madrid 1, 384.

Vilanova y Piera, J., 1870. Ensayo de una Descripción Geognóstica de la Provincia de Teruel en sus Relaciones con la Agricultura de la Misma. Junta General de Estadística, Madrid, 312 pp.

Vilanova y Piera, J., 1874. Observaciones sobre la teruelita de Teruel y el azabache y el ámbar de Utrillas. Actas de la Sociedad Española de Historia Natural 3, 58–60.

Waggoner, B.M., 1994. Fossil microorganisms from Upper Cretaceous amber of Mississippi. Review of Palaeobotany and Palynology 80, 75–84.

Weitschat, W., Wichard, W., 2002. Atlas of Plants and Animals in Baltic Amber. Verlag Dr., Friedrich Pfeil, München, 256 pp.

Zherikhin, V.V., Eskov, K. Yu., 1999. Mesozoic and Lower Tertiary resins in former USSR. Estudios del Museo de Ciencias Naturales de Álava 14 (Special Publication 2), 119–131.