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New data on the age of the Lower Cretaceous amber outcrops of Lebanon

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Abstract

The "Grès du Liban" [Sandstone of Lebanon] is the basal lithostratigraphic unit for the Cretaceous series in Lebanon. In the upper part of these siliciclastic-dominated strata we identified three discrete intervals characterized by their richness in amber with biological inclusions, mostly insects. The middle and upper intervals previously attributed to an Early Aptian (= Bedoulian) age are nowadays ascribed to the Early and Late Barremian respectively; the lower interval is Early Barremian or possibly older. Besides that it is suggested that pieces of amber with inclusions from the middle and upper intervals could be reworked from the lower interval. In conclusion, the new dating of arthropod-bearing localities allows us to push back in time (at least to the Early Barremian) the first occurrences of all biological inclusions found therein.

Keywords: Lower Cretaceous; Barremian; "Grès du Liban"; Amber; Lebanon

1. Introduction

Amber is a fossil plant resin that has the property to preserve pristine details of any zoological, botanical, or phycological inclusions. Lebanon is renowned for its numerous amber localities (with more than 450 outcrops) spanning a large time window from the Kimmeridgian up to the Albian times. Most of the outcrops are Early Cretaceous in age and among them twenty-three (Fig. 1) enter the category of the oldest "intensively fossiliferous" sites (Azar, 2012). Early Cretaceous is a crucial period for the understanding of the coevolution between flowering plants and insects because it witnessed the radiation of angiosperms and the coeval rapid diversification of insects accompanied by the massive extinction of older groups (Jarzembowski and Ross, 1993). Azar et al. (2003) were the first to use fossil insects in amber to correlate discrete outcrops. However, they were not able to determine the exact geological age of these strata. Palynological dating was performed but it does not prove to be very successful with long-ranging taxa that are spanning the Late Jurassic and the Early Cretaceous (Azar et al., 2011). Fortunately, new paleontological and stratigraphic data (Maksoud et al., 2014; Granier et al., 2015) allowed us to give a more precise age to the Lebanese amber.

2. Geological context

The Lebanese Cretaceous strata begin with the "Grès du Liban" [Sandstone of Lebanon] (Granier et al., 2015), also called "Sandsteinformation des Libanon" [Sandstone Formation of Lebanon] (Fraas, 1878), "Grès lignitifère" [Sandstone with lignite] (Zumoffen, 1926) and "Grès de base" [basal Sandstone] (Dubertret, 1963, *inter alia*). The lower part of the "Grès du Liban", which is supposedly azoic but includes locally pisolitic layers, was ascribed to the Neocomian (i.e., Valanginian–Barremian) by Dubertret (1963). Its fossiliferous upper part was ascribed to the Lower Aptian by Dubertret (1963) and other workers. This upper part includes a thick

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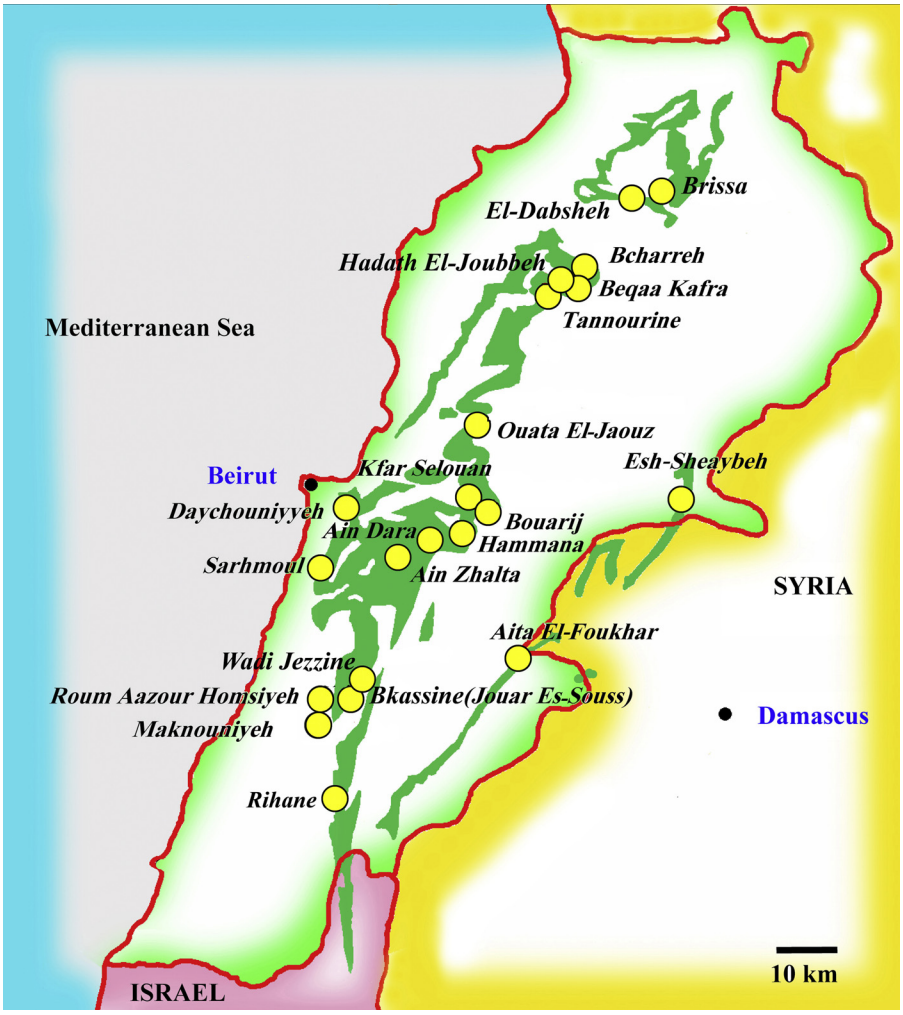

Fig. 1. Simplified map of Lebanon with locations of the Lower Cretaceous amber outcrops. Dark green areas indicate the distribution of the amber localities. Yellow circles indicate the outcrops with fossil inclusions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

marker bed consisting of oolitic limestones known as "Banc de Mrejatt" [Mrejatt Bed]. Considering our modern approach (Maksoud et al., 2014; Granier et al., 2015; Maksoud, 2015), Dubertret's lithostratigraphy can be regarded as facies-driven and his biostratigraphy as poorly constrained. Most authors were ascribing the amber outcrops we studied a Neocomian–Aptian (Zumoffen, 1926) or Neocomian–Early Aptian (Dubertret and Vautrin, 1937), or a Valanginian–Hauterivian age (Schlee and Dietrich, 2009), i.e., various ranges within the whole Early Cretaceous interval, except for the Albian and eventually the Late Aptian. The age of the overlying limestone unit, i.e., the "Falaise de Blanche" [Blanche Cliff] (Fig. 2), was also poorly constrained: Albian for Zumoffen (1926) or Late Aptian for Dubertret (Dubertret, 1934, 1955, 1963; Dubertret and Vautrin, 1937). A recent detailed holostratigraphic study led us to merge the whitish micritic limetsones of the "Falaise de Blanche" with the immediate underlying yellowish grainy limestones in a single lithostratigraphic Unconformity Bounded Unit (Maksoud et al., 2014). Because this unit can be biostratigraphically constrained by its micropaleontological contents (Fig. 3), it also equates with a regional stage, the "Jezzinian" (Maksoud et al., 2014), which is dated late Barremian–earliest Aptian (= early Bedoulian) age.

In Lebanon, the Lower Cretaceous fossiliferous amber outcrops are found in three intervals at the upper part of the "Grès du Liban" (Fig. 4):

- The **upper interval** is located between the Jezzinian above and the "Banc de Mrejatt" below. Outcrops belonging to this interval are those of the waterfall at Jezzine (South Lebanon), Hammana and Bouarij (Central Lebanon);
- The **middle interval** is located between the "Banc de Mrejatt" above and a pisolitic interval below. Outcrops belonging to this interval are those of Wadi Jezzine (South Lebanon), Ain Dara and Kfar Selouan (Central Lebanon);
- The **lower interval** falls below the pisolitic interval. Outcrops belonging to this interval are those of Rihane, Maknouniyeh, Roum-Aazour-Homsiyeh and Jouar Es-Souss in Bkassine (South Lebanon), and Ain Zhalta (Central Lebanon).

The "Banc de Mrejatt" and the pisolitic interval are not present all over Lebanon but only in a tectonic compartment

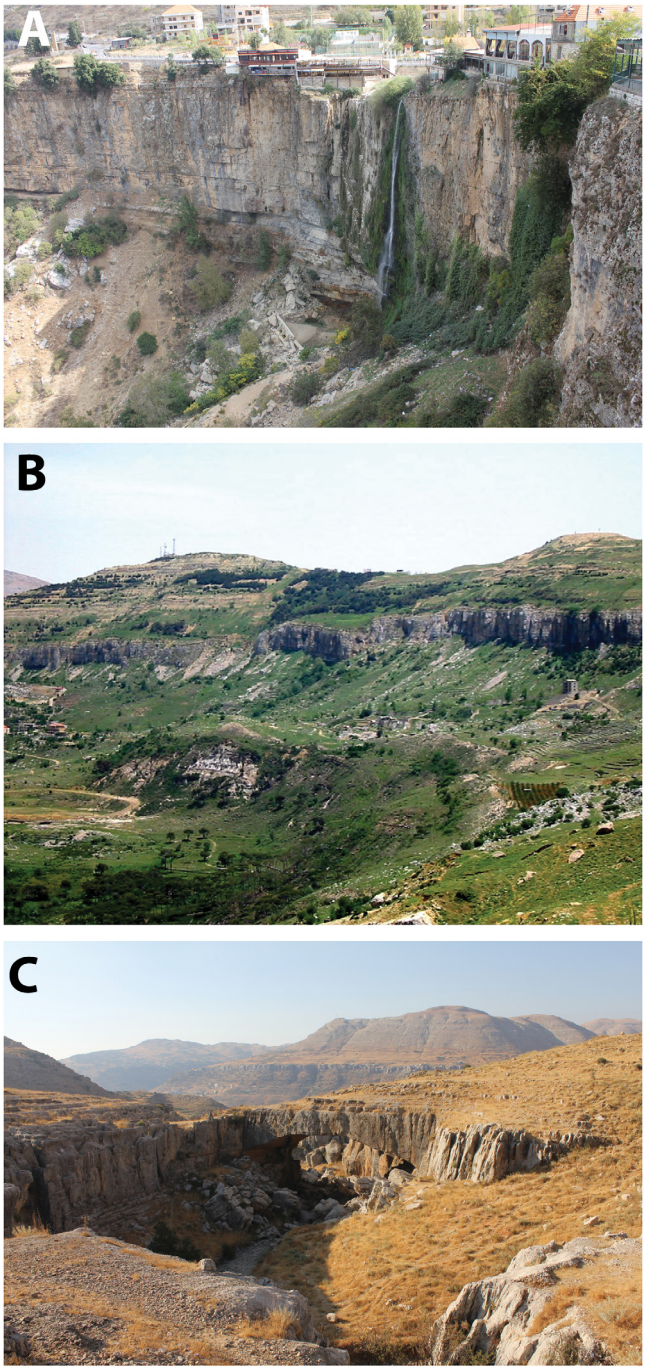

Fig. 2. Blanche or Jezzine Cliff, a distinctive geomorphological unit; (A) in Jezzine; (B) in Hammana; (C) in Kfardebiane, forming the Faqra natural bridge.

limited respectively westward and eastward by the Roum and the Yammouneh faults of Central and Southern Lebanon. As a consequence we miss marker beds outside this area, in Aita El-Foukhar, Esh-Sheaybeh (East Lebanon), Daychouniyyeh, Sarhmoul, Ain Zhalta, Ouata El-Jaouz (Central Lebanon), Bcharreh, Tannourine, Hadath El-Joubbeh, Beqaa Kafra, El-Dabsheh and Brissa (North Lebanon).

3. Paleoenvironment of amber deposits

The fossiliferous amber deposits appear in the form of dark shales with lignite and fossil plant debris in the three intervals of the uppermost part of the "Grès du Liban". There deposits are interpreted as corresponding to siliciclastic coastal and estuarine palaeoenvironments based on the occurrence of bioturbation, echinids (e.g., *Heteraster oblongus* (Brongniart, 1821)) and bivalves in the transgressive marine layers and that of amber and lignite in the regressive layers. The entomofaunal association of the amber inclusions indicates a dense and dark amber-producing forest with warm tropical climate, which is also corroborated by the palynological data (Azar et al., 2011).

4. Discussion

A list of the macro- and micro- fossils found in the upper part of the "Grès du Liban" and in the Jezzinian is presented in Fig. 3. With respect to the Jezzinian, this regional stage spans the uppermost Barremian–lowermost Aptian (= lower Bedoulian) transition (Maksoud et al., 2014; Maksoud, 2015). Considering the former "Grès du Liban", we commonly refer to two key subunits:

- The first and higher subunit, i.e., the "Banc de Mrejatt", consists mainly of oolitic limestones. It includes one biostratigraphically significant benthic foraminifer: *Eopalorbitolina transiens* (Cherchi and Schroeder, 1999) (Fig. 3), which is a zonal marker of the Lower to Upper Barremian transition according to Schroeder et al. (2010). Accordingly the "Banc de Mrejatt" is correlated to the transgression of sequence Ba3 of Clavel et al. (2007) and ascribed a late Early Barremian age (Fig. 3);
- The second and lower subunit, i.e., the pisolitic interval or "calcaires à pisolithes" of Heybroek (1942), consists of lacustrine shales and marls, locally with pisolites ranging in size from a hazel nut to an orange. Charophyte remains (thalli, utricles, and gyrogonites) are commonly found in this interval (Grambast and Lorch, 1968; Granier et al., 2015). For instance, from Ain Dara, Falougha and Homsiyeh, Granier et al. (2015) list: *Ascidiella reticulata* Grambast and Lorch, 1968, *Atopochara trivolvis* var. *triquetra* Grambast, 1968, *Clavator ampullaceus* (Grambast and Lorch, 1968), *C. delteus* (Grambast and Lorch, 1968), *Sphaerochara asema* (Grambast and Lorch, 1968), as well as *Charaxis martin-closasi* Granier et al., 2015, and *Munieria parvula* (Carozzi, 1946), but also rare calcareous algae, *Salpingoporella* (*Hensonella*) *dinarica* (Radoičić, 1959), and benthic foraminifers, *Choffatella* gr. *decipiens* Schlumberger, 1905. According to Martín-Closas (personal communication), the charophyte association should refer to the *Cruciata-Paucibracteatus* biozone of Martín-Closas et al. (2009) that spans the Late Barremian–Early Aptian interval. However, due to its topographic location, this interval is older than the "Banc de Mrejatt" and should be considered at least Early Barremian in age.

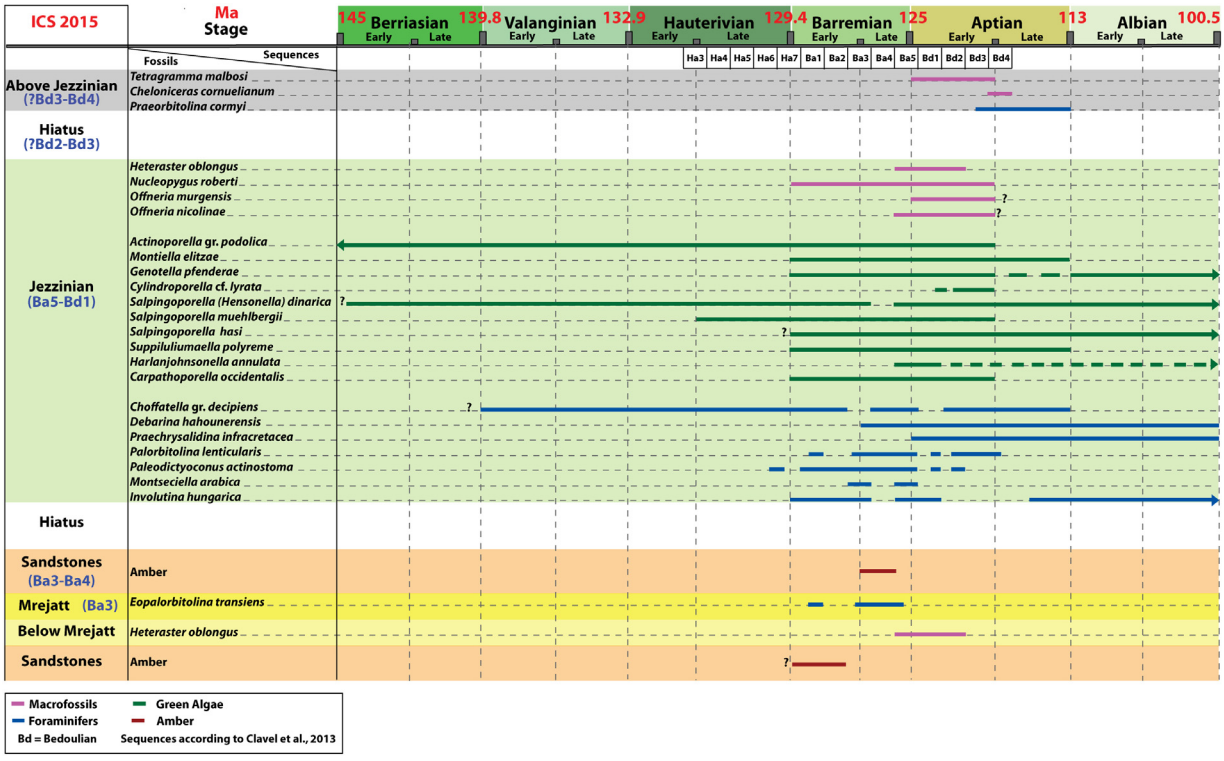

Fig. 3. List of macro- and micro- fossils of the Jezzinian unit and its underlaying strata (Clavel et al., 2013).

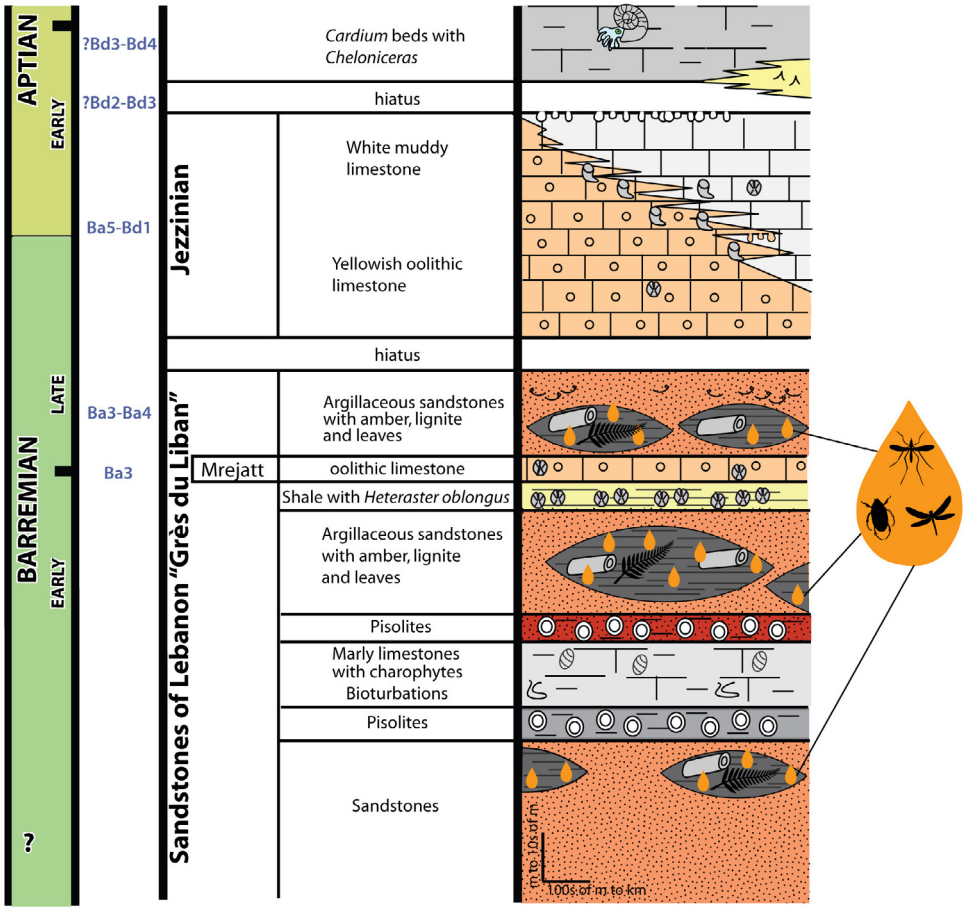

Fig. 4. Simplified stratigraphic section showing the different intervals where the fossiliferous amber crops out in the Lower Cretaceous sandstones of Lebanon.

Table 1
List of shared entomological taxa between the fossiliferous amber outcrops. ED = El-Dabsheh; BC = Bcharreh; TA = Tannourine; BO = Bouarij; HA = Hammana; SA = Sarhmoul; JE = Jouar Es-Souss (Jezzine); HR = Roum-Aazour-Homsiyeh; KF = Kfar Selouan; AN = Ain Dara; SH = Esh-Sheabeh; BR = Brissa; WJ = Wadi Jezzine; RI = Rihane; BK = Beqaa Kafra; DA = Dayshouniyyeh; + = presence; ? = not yet found or not verified.

Order	Family	Taxa	ED	BC	TA	BO	HA	SA	JE	HR	KF	AN	SH	BR	WJ	RI	BK	DA
Coleoptera	Staphylinidae	*Libanoeuaesthetus pentatarsus* Lefèbvre et al.	?	?	?	?	+	?	?	?	?	+	?	?	?	?	?	?
Hemiptera	Enicocephalidae	*Enicocephalinus acragrimaldii* Azar et al.	+	+	?	+	+	?	+	?	+	+	+	?	?	?	?	?
Diptera	Psychodidae	*Libanophlebotomus lutfallahi* Azar et al.	?	+	?	?	+	?	+	?	?	?	?	?	?	?	?	?
		Eophlebotomus gezei Azar et al.	?	?	?	+	+	?	?	+	?	?	?	?	?	?	?	?
		Paleopsychoda jacquelinea Azar et al.	?	?	?	+	+	?	+	?	?	?	+	+	+	?	?	?
	Empididae	*Phaetempis lebanensis* Grimaldi and Cumming	?	+	?	?	?	?	+	?	?	?	?	?	?	?	?	?
	Chimeromiidae	*Chimeromyia intriguea* Grimaldi and Cumming	?	+	?	?	?	?	+	?	?	?	?	?	?	?	?	?
	Ceratopogonidae	*Archiaustroconops ceratoformis* Szadziewski	?	+	?	+	+	+	+	?	+	+	?	?	?	?	+	?
		Archiaustroconops szadziewskii Borkent	?	+	?	?	+	?	+	?	?	?	?	?	?	?	?	?
		Archiaustroconops cretaceous Szadziewski	?	?	?	?	+	?	+	?	?	?	?	?	?	?	?	?
		Archiaustroconops hamus Borkent	?	+	?	?	?	?	+	?	?	?	?	?	?	?	+	?
		Archiaustroconops megaspinus Borkent	?	+	?	?	+	?	?	?	?	?	?	?	?	?	?	?
		Austroconops gondwanicus Szadziewski	?	+	+	?	?	?	+	?	?	?	?	?	?	?	?	?
		Austroconops fossilis Szadziewski	?	+	?	?	?	?	+	?	?	?	?	?	?	?	?	?
		Protoculicoides punctus Borkent	+	+	?	+	?	?	?	?	?	?	?	?	?	?	?	+
	Archizelmiridae	*Zelmiarcha lebanensis* Grimaldi et al.	+	?	+	?	+	?	?	?	?	+	?	?	?	?	?	?
	Chironomidae	*Libanochlites neocomicus* Brundin	+	?	+	+	+	+	+	?	?	+	?	+	+	?	?	?
		Haematotanypus libanicus Azar, Veltz and Nel	?	?	?	?	?	?	+	+	?	?	?	?	?	?	?	?
Neuroptera	Rhachiberothidae	*Raptorapax terribilissima* Petrolevičius, Azar and Nel	?	?	?	+	?	?	?	?	?	?	?	+	?	?	?	?
Mantodea	*Incertae sedis*	*Burmantis lebanensis* Grimaldi	?	+	?	?	?	?	?	?	?	?	?	?	?	+	?	?

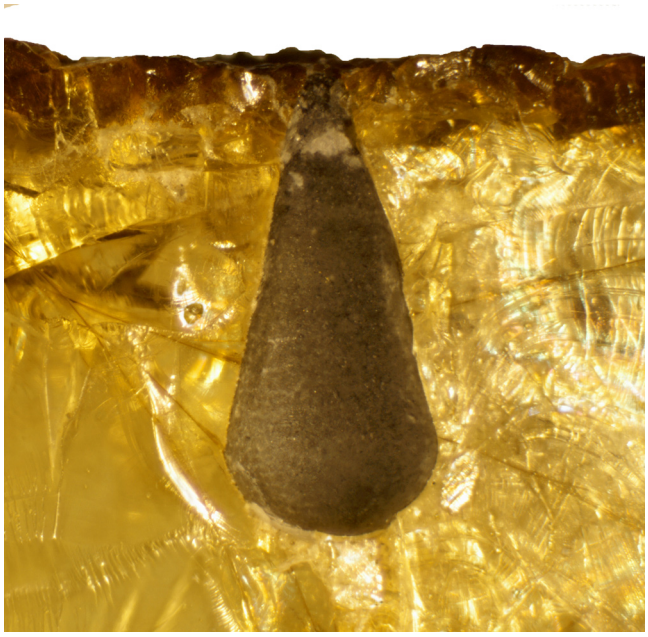

Fig. 5. Amber with shipworm boring, from Chambouk (North of Lebanon). Such borings occur as well in different fossiliferous amber from different outcrops like Hammana, Ain Dara, Kfar Selouan, Bouarij and many others.

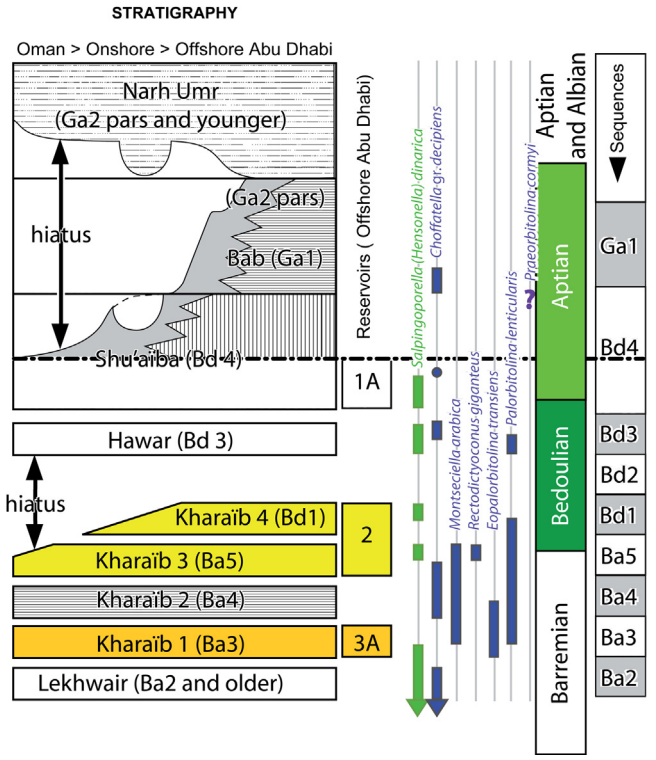

Fig. 6. Stratigraphic log of Abu Dhabi with the Southern and Northern Tethyan correlations (modified from Granier and Busnardo, 2013) and the stratigraphic distribution of some microfossils. The yellow highlighted zone represents the Jezzinian correlating with the Kharaib 3 and Kharaib 4, and equating with the Ba5 and Bd1 of Clavel et al. (2007). The orange highlighted zone represents the "Banc de Mrejatt" correlating with the Kharaib 1, and equating with the Ba3 of Clavel et al. (2007). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

All three fossiliferous amber-bearing intervals cited above are very rich in biological inclusions, mostly terrestrial arthropod remains (Azar, 1997, 2012; Azar et al., 2010). Nevertheless, their entomofauna associations are very similar (Table 1), which suggests they bear the very close ages, if not the same age (Azar et al., 2003; Azar, 2012; Veltz et al., 2013). Because it is commonly assumed that insects — with sometimes more than two generations per year — have a rapid rate of evolution, the entomofaunal similarity of these three intervals could implicate that the age of the amber should be the same, i.e., that of the older/lower interval. As a matter of fact, the amber pebbles found in the upper and middle intervals are rounded and commonly bored by shipworms (Fig. 5), suggesting that the resin was already hardened when deposited because it usually takes quite a long time for resin to be transformed into copal and then into amber. Therefore, these pebbles have possibly been reworked from the lower interval. In addition, palynomorphs related to the biorecord Superret-Nobarg, which is equivalent to *Stellatopollis doylei* Ibrahim, 2002, were found as inclusion in the amber (of Hammana) though this taxon does not exist in the palynological assemblage of the embedding sediments (Azar et al., 2011). This fact too could point to a possible reworking of amber in younger sediments. These interpretations would support those of Veltz et al. (2013), who stated that the amber deposits found in the facies attributed to the so-called "Abeih Formation" (our middle and higher intervals), have been most likely reworked from older deposits (op. cit., p. 18: "all the deposits have nearly the same age, some of the amber material was redeposited in different condition in consequence to the flooding system").

5. Correlation

Maksoud et al. (2014) and Maksoud (2015) applied a micropalaeontological approach based on calcareous microfossils (foraminifers and calcareous algae). These typically Southern Tethysian assemblages contribute to high-resolution, holostratigraphic correlations with the Persian Gulf area, on the eastern part of the Arabian Plate. Accordingly, the Jezzinian and "Banc de Mrejatt" correlate with the Kharaibian Regional Stage (also known as reservoir units in the oil industry): the Jezzinian falls within the Kharaib 3 and 4 whereas "Banc de Mrejatt" matches the Kharaib 1 (Fig. 6). Because the Kharaibian is correlated with Northern Tethysian Urgonian stratigraphic units (Granier and Busnardo, 2013; Granier et al., 2013, 2014), the Jezzinian and "Banc de Mrejatt" can in turn be correlated with these units and therefrom to the international standard scale for the Cretaceous. The Jezzinian corresponds to a rather short interval spanning the sequences Ba5-Bd1 of Clavel et al. (2007) (Figs. 3, 4), encompassing the standard Barremian–Aptian (Bedoulian) stage boundary, whereas "Banc de Mrejatt" equates to the sequence Ba3 of Clavel et al. (2007). Therefore amber-bearing sediments of the higher interval, those between the Jezzinian and "Banc de Mrejatt" (e.g., the outcrops beneath the waterfall of Jezzine, and those of Hammana and Bouarij), are

equivalent to the sequences Ba3-Ba4 of Clavel et al. (2007). They are ascribed a Late Barremian age. Amber-bearing sediments of the intervals immediately below "Banc de Mrejatt", i.e., the middle and lower intervals, are not higher in the succession than the sequence Ba2 of Clavel et al. (2007); they are not younger than the Early Barremian.

6. Conclusion

The upper part of the "Grès du Liban", which is rich in amber with biological inclusions, can be subdivided into three discrete intervals. The upper interval is located between the lower Jezzinian unconformity and the "Banc de Mrejatt", and dated Late Barremian; the middle interval is located between "Banc de Mrejatt" and a pisolitic interval, and dated Early Barremian; the lower amber level is located below the pisolitic interval and dated Early Barremian or (?) older. The entomofauna associations of the amber-bearing deposits above and below the "Banc de Mrejatt" are very similar, suggesting the amber-inclusions and the amber itself have the same age although the amber-bearing deposits can obviously not be given the same age. It is suggested that the amber of the two higher intervals, i.e., the upper and middle intervals, is reworked from the lower interval. Accordingly, the age of the amber from the "Grès du Liban" could be Early Barremian or even older in age. Forthcoming investigations on the "Grès du Liban" will probably help determine their age and support our hypothesis regarding the origin and age of the amber pieces.To be delete after Query reply ------ Clavel et al. (2013)

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