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Palaeoentomological (fossil insects) outcrops in Lebanon

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Abstract: With 35 Cretaceous outcrops yielding fossil insects, either in amber or as rock (marls, limestones, cinerite, or dysodile) impressions-compressions (adpressions), Lebanon has continuously contributed significantly to the advance of palaeoentomology and to our understanding of entomological evolution and palaeobiodiversity. Compared to its small surface area, this country can be considered among the richest of fossil insect outcrops. This is due to its geological history and mainly to its forest, fluvial - lacustrine tropical and proximal marine subtropical palaeoenvironments plus Peritethys equatorial and subequatorial palaeogeography during the Lower and "Middle" Cretaceous. Herein, an exhaustive review of all outcrops with insects is given. A list of all fossil insects described from Lebanon is provided.

Key-words:

- amber;
- Cretaceous;
- dysodile;
- fossil insects;
- adpression;
- palaeoenvironment;
- palaeobiodiversity

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Résumé : *Affleurements paléoentomologiques (insectes fossiles) au Liban.-* Avec 35 affleurements crétacés recelant des insectes fossiles, soit dans de l'ambre, soit sous forme d'impressions-compressions (adpressions) de roches (marnes, calcaires, cinérite ou dysodile), le Liban a depuis toujours significativement contribué aux progrès de la paléoentomologie et à l'amélioration de notre compréhension de l'évolution des insectes et de leur paléobiodiversité. En dépit de sa petite superficie, ce pays peut être considéré comme l'un des plus riches en gisements fossilifères ayant fourni des insectes. Ceci est dû principalement à son histoire géologique dans le cadre paléogéographique de la Périté-thys au cours du Crétacé inférieur et "moyen", *i.e.*, dans un domaine équatorial ou subéquatorial avec notamment des paléoenvironnements fluvio-lacustres à proximité de forêts tropicales ou des paléoenvironnements marins proximaux subtropicaux. Un examen exhaustif de tous les affleurements avec des insectes a été réalisé et une liste détaillée de tous les insectes fossiles du Liban est fournie.

Mots-clefs :

- ambre ;
- Crétacé ;
- dysodile ;
- insectes fossiles ;
- adpression ;
- paléoenvironnement ;
- paléobiodiversité

1. Introduction

Insects are the most diverse group of animals on the planet and as such are present in a wider variety of habitats than most other complex organisms (Grimaldi & Engel, 2005).

Palaeoentomology (a branch of entomology that deals with fossil insects and related terrestrial arthropods) started in its present scientific and taxonomic form in the late eighteenth century, shortly after the foundation of modern taxonomy with the 10th edition of Linnaeus' "*Systema Naturae*", when some papers commencing with one by Blochs (1776) on the curiosities of insects entombed in fossil resins were published. It is however noteworthy to state that before this, fossil insects were mentioned several times, *viz*. in Aristotle's "*Zoologia*", in Marcus Valerius Martialis' "*Epigrammaton libri*", in Plinius Secundus' "*Naturalis Historia*", in Sir Francis Bacon's "*The historie of life and death…*", in famous Emmanuel Kant's quotes, and especially in Nathanael Sendelius' "*Historia succinorum…*" on amber and its inclusions and many others (Szwedo, 2011).

The beginning of the nineteenth century (with the growing interest in geological sciences and prehistoric life) witnessed the first attempts to study and describe insects from sedimentary rocks (D. Azar *et al.*, 2018). This discipline then developed during the nineteenth and beginning of the twentieth centuries, slowly but constantly, and resulted in some major works and reviews (*e.g.*, Handlirsch, 1906-1908).

At the beginning of the twenty-first century, with the growing interest in fossil insects and globalisation, several serious multidisciplinary and collaborative scientific teams have been formed in many countries resulting in a noticeable increase in the number of annually published works during the past two decades, form dozens to hundreds.

Palaeoentomology is nowadays developing significantly and exponentially. This discipline is undergoing an intellectual radiation with the discovery of new rock and amber outcrops with fossil insects of different geological ages and in various parts of the world (D. Azar *et al.*, 2018). It is noteworthy to state that since its beginning, palaeoentomology covered not only descriptive aspects of terrestrial arthropods (including Insecta, Chelicerata, Myriapoda, *etc.*) but also reconstructions of ancient environments, ecology, evolution and phylogenies.

Herein we present an exhaustive review of all the 35 outcrops yielding fossil insects in Lebanon, either as rock adpressions or amber inclusions (Fig. 1) and we provide an updated list of hitherto described Lebanese fossil insects.

2. Historical background

Lebanon officially joined "the club" of the countries with fossil insect localities in 1888, when Hermann Julius Kolbe (b.1855-d.1939) (Fig. 2.A) described the trace of an insect larva (to which he gave a scientific name, *Curculionites senonicus* Kolbe, 1888: 136, Pl. XI, fig. 8; herein: Fig. 2.B) in silicified wood from the late Santonian lithographic limestone of Sahel Alma. Anton Handlirsch (b.1865-d.1935) later (1906-1908, p. 665) changed the name of the insect that is supposed to make this trace to *Curculidium senonicum*. The outcrop of Sahel Alma is world famous for its fossil fishes (Davis, 1887). The oldest written evidence of this site dates back to the fourth century AD when Eusebius of Caesarea (*circa* b.263-d.339) (often called Eusebius Pamphili), the bishop of Caesarea Palaestina, evoked these mysterious stones found in Lebanon and considered them as the witnesses of Noah's deluge. The most famous mention of this site probably appears in the writings of Jean de Joinville (b.1224-d.1317) -one of the great chroniclers of Medieval France- who tells how a fossil fish was presented to King Louis IX ("Saint Louis") (b.1214-d.1270) during one of his crusades to the Middle East.

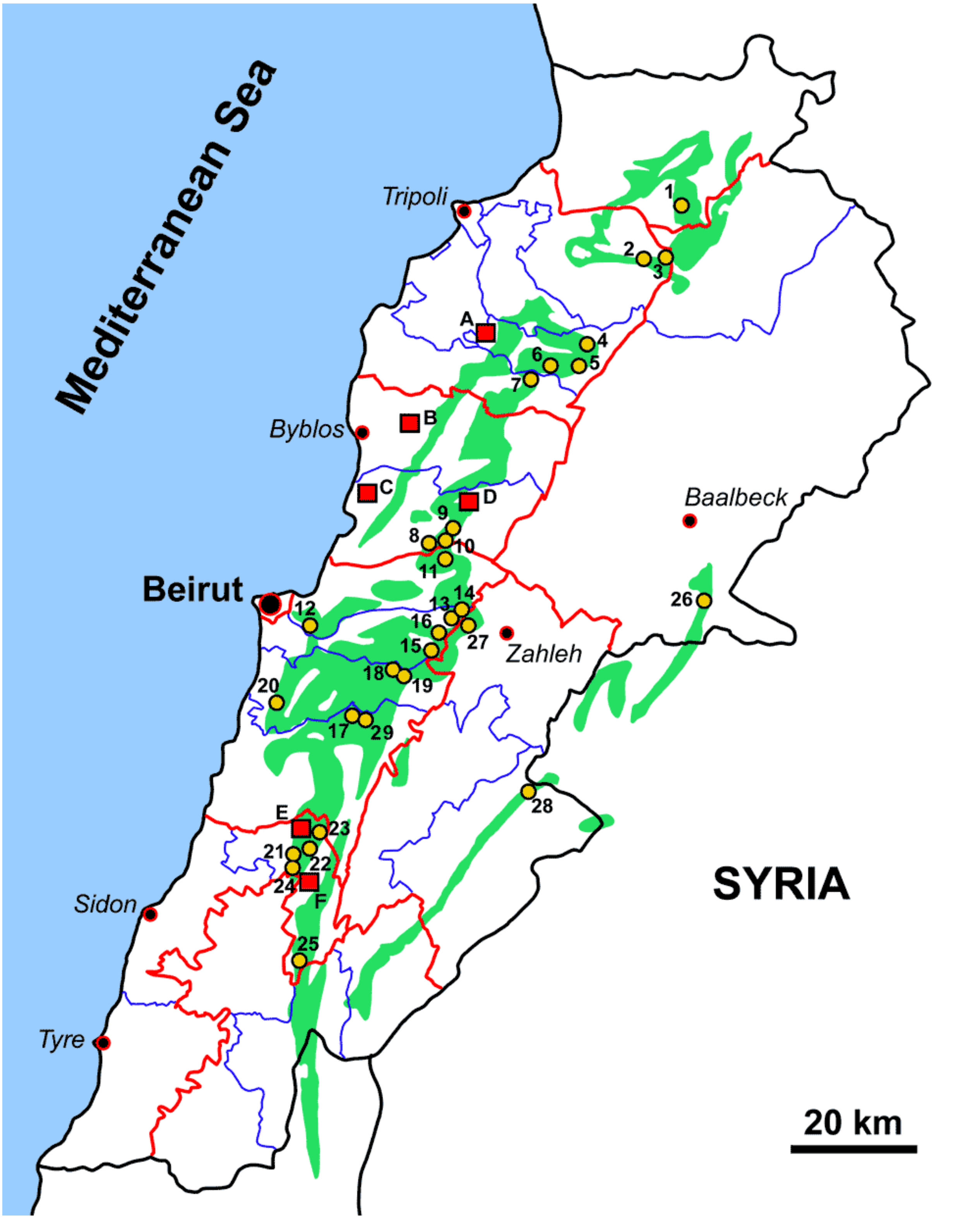


Figure 1: Location map of Lebanese outcrops with fossil insects. Green areas indicate the distribution of the amber localities. Yellow circular spots indicate the locations of Lower Cretaceous amber outcrops with insect inclusions. Red squares indicate the locations of the outcrops with fossil insects preserved as compression-impression. Amber outcrops with insects: **(1)** Mechmech (Ain El-Khyar); **(2)** Nimrin (El-Dabsheh); **(3)** Brissa; **(4)** near Bcharreh; **(5)** Beqaa Kafra; **(6)** Hadath El-Joubbeh; **(7)** Tannourine; **(8)** Mazraat Kfardibiane; **(9)** Ouata El-Jaouz; **(10)** Bqaatouta (El-Shqif); **(11)** Baskinta (Qanat Bakish); **(12)** Daychouniyyeh; **(13)** Kfar Selouan; **(14)** Kfar Selouan (Khallet Douaiq); **(15)** Mdeyrij-Hammana; **(16)** Falougha; **(17)** Ain Zhalta; **(18-19)** Ain Dara (two localities); **(20)** Sarhmoul; **(21)** Roum - Aazour - Homsiyeh; **(22)** Bkassine (Jouar Es-Souss); **(23)** Wadi Jezzine; **(24)** Maknouniyeh; **(25)** Rihane; **(26)** Esh-Sheaybeh; **(27)** Bouarij; **(28)** Aita El-Foukhar; **(29)** Ain Zhalta (Ain Azimeh). Outcrops with fossil insects preserved as compression-impression: **(A)** Qnat; **(B)** Hjoula; **(C)** Nammoura; **(D)** Qahmez; **(E)** Jdeidet Bkassine; **(F)** Sniyya. Red curves: boundaries of Governorates; blue curves: boundaries of districts.

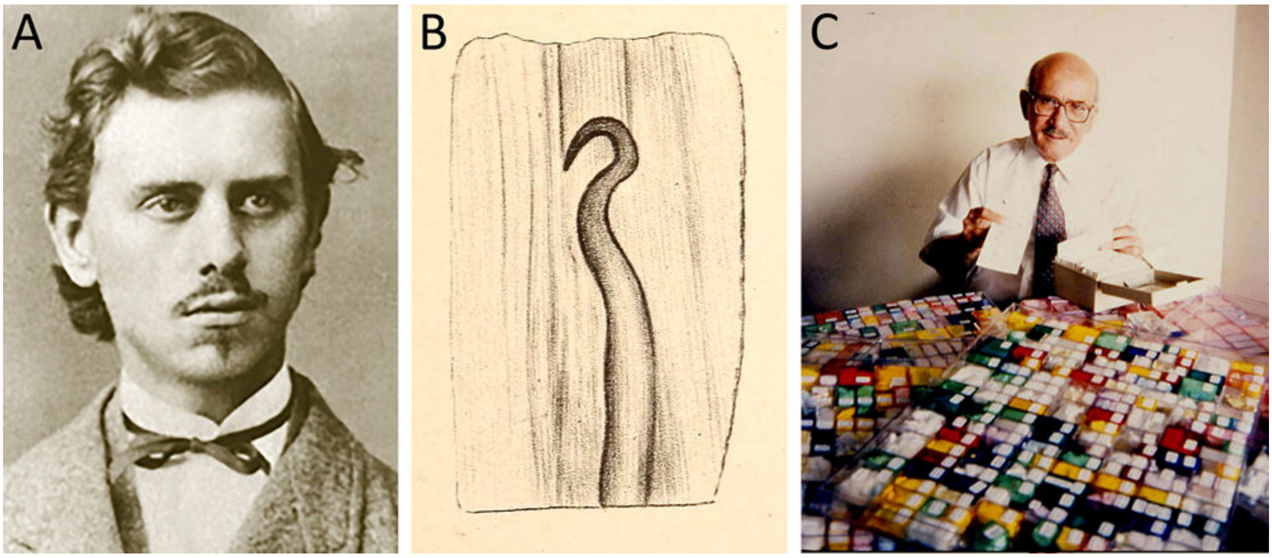


Figure 2: A- Hermann Julius Kolbe (1855-1939), a German entomologist from Halle, Westphalia. He was curator at the Berlin Zoological Museum from 1890 until 1921 specialising in Coleoptera, Psocoptera and Neuroptera. **B-** Fossil insect trace in silicified wood from Sahel Alma. **C-** Professor Aftim Acra (1922-2007), with his well-known collection from the outcrop of Jouar Es-Souss (Bkassine).

Phoenicians were probably the first tradesmen of amber in the Mediterranean (McDonald, 1940) and also the pioneers of the amber maritime route towards the shores of Northern Europe (Baltic area) to obtain the golden fossil resin in exchange for bronze between the thirteenth and fourteenth centuries BC. According to some authors, based on recent archeological discoveries, the amber was collected in Phoenicia (today Lebanon, Syrian coast and Northern Israel) and marketed in the Middle East by Phoenicians until Baltic amber, which is of better gemological quality, became available (Williamson, 1932; Nissenbaum, 1975). The oldest reliable publications describing fossil insects from Lebanon are those of Willi Hennig (b.1913-d.1976) and Dieter Schlee, both in 1970. These concerned fossil insects in Lower Cretaceous amber. Prior to 1994, only one amber outcrop with fossil insects was known, *viz*. Jouar Ess-Souss in Bkassine (Caza Jezzine, Southern Lebanon). Recent field work increased the number of amber localities with biological inclusions to 29 (D. Azar *et al.*, 2010b; D. Azar, 2012; Maksoud & D. Azar, 2020; Maksoud *et al.*, 2021a, 2021b).

In modern times, although the presence of amber in Lebanon has been documented several times by several authors since the beginning of the nineteenth century, occasionally while describing coal or lignite extraction in mines (Desmarest, 1811; Kastner, 1831; Botta, 1831; Brucchi, 1842; Russegger, 1843; Ritter, 1854; Fraas, 1876, 1878; John, 1878; Cuinet, 1896) and in the twentieth century (Zumoffen, 1926; Dubertret, 1950, 1951a, 1953, 1955), it was only late in the nineteen-sixties that fossil insects were recorded in this source (Schlee, 1970; Schlee & Dietrich, 1970; Hennig, 1970). It is noteworthy that the first geological maps of Lebanon made by Paul-Émile Botta (b.1802-d.1870), then by Joseph Ritter von Russegger (b.1802-d.1863), had the aim of locating the lignite and iron mines in order to exploit them for both fuel and industry.

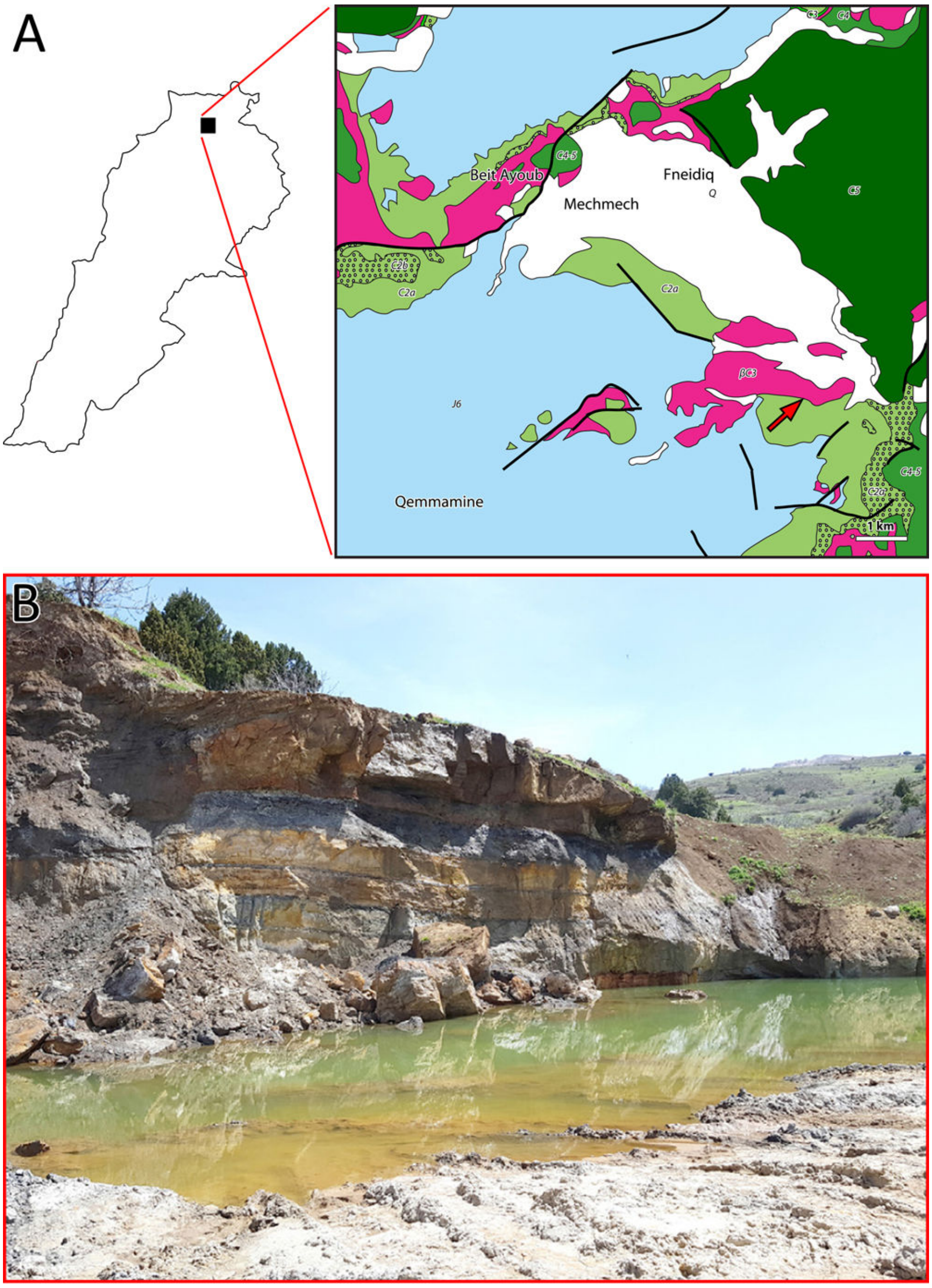
In 1962, Aftim Acra (b.1922-d.2007) (Fig. 2.C), while leading a palaeontological expedition in Daher-El-Baydar (Mount-Lebanon, Central Lebanon) and accompanied by his son Fadi (and Raif Milki), found a piece of amber. From then till the 1970s, they found several amber outcrops including the well-known one of Bkassine (Jouar Ess-Souss) in the Jezzine area, which was discovered independently and at the same time by a German expedition organised in 1968-1969.

The German expedition was carried out after M. Warth gave Willi Hennig (in 1967) some samples of amber from Bkassine (Southern Lebanon) housed in the Ludwigsburg collection of Stuttgart Museum (Germany). These samples were the remains of the collection of Oscar Fraas (b.1824-d.1897), a German geologist who was tasked by Rustem Pasha (Rustem Mariani b.1810-d.1885), the Italian Governor of Mount Lebanon (1873-1883), to study the geology of the region in order to establish coal mines.

From 1994 until the present day, the team of one of us (DA) has found about 450 amber-bearing deposits, ranging from the Late Jurassic to the Cenomanian (Late Cretaceous). Among these numerous outcrops only 29 hitherto yielded fossil insects. It is noteworthy that the clay and shale in one of the amber outcrops (Qahmez, in Kesserouan District, Central Lebanon, unpublished data) includes some fragments of insects originally floating with other organic and plant remains, deposited in an abandoned reaches of a fluvial system.

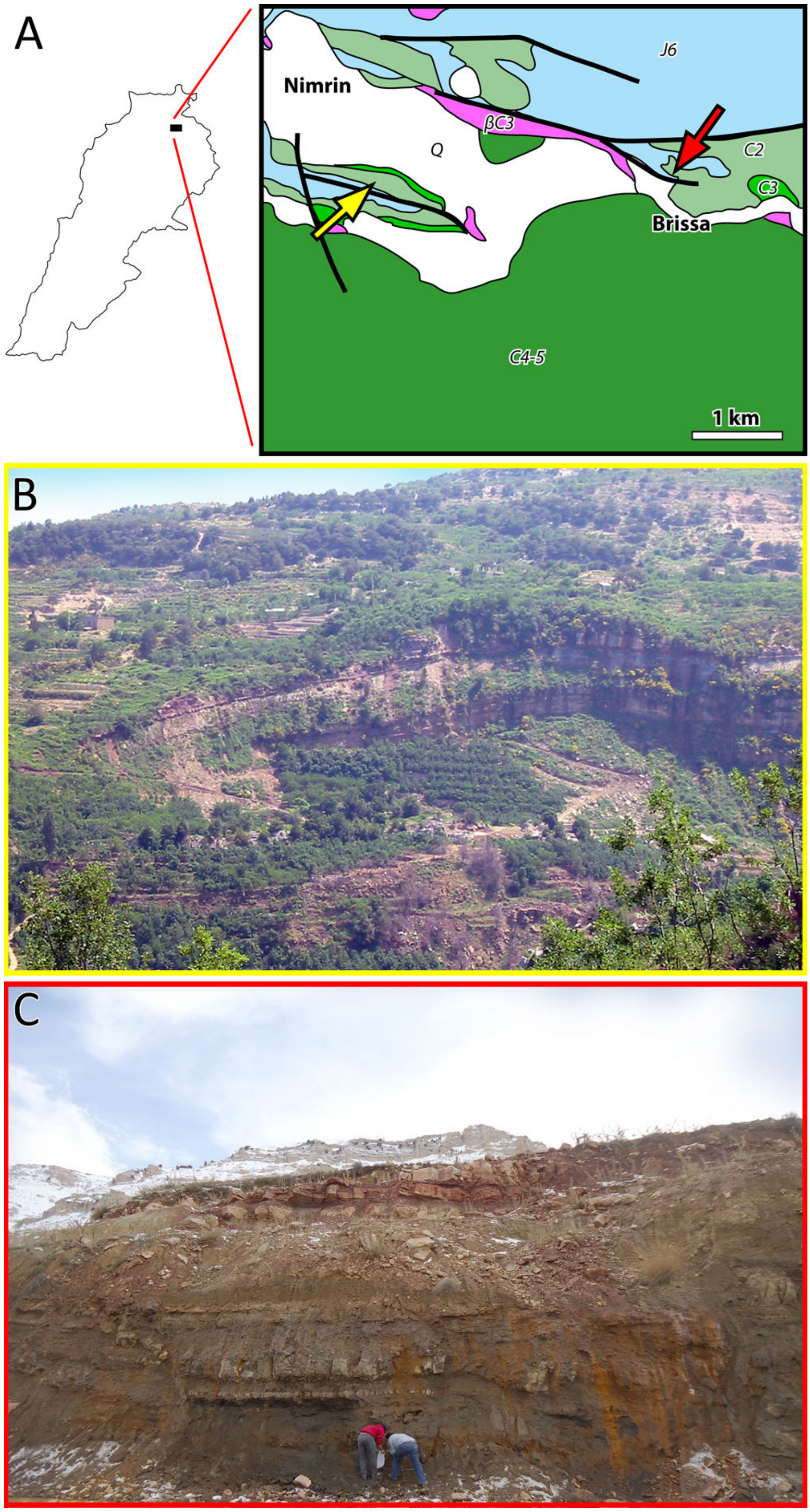
Table 1: Barremian (Lower Cretaceous) amber outcrops with arthropod (mainly insect) inclusions. The numbers in bold between brackets correspond to the placement of the localities on the general map of Figure 1.

Governorate	District	Outcrop	Inclusions	References
Akkar	Akkar	Mechmech (Ain El-Khyar) **[1]**; Fig. 3.A-B; Pl. 1, fig. A-D	4	MAKSOUD *et al.*, 2019, 2021b, 2021c
North Lebanon	Sir Ed-Danniyeh	Nimrin (El-Dabsheh) **[2]**; Fig. 3.A-B; Pl. 1, fig. E	~250	D. AZAR *et al.*, 2010b; SZWEDO *et al.*, 2013; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
		Brissa **[3]**; Fig. 3.A, D; Pl. 1, fig. F	~100	KIREJTCHUK & D. AZAR, 2013; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
	Bcharreh	near Bcharreh **[4]**; Fig. 4.A; GRIMALDI & ENGEL, 2005: 80, Fig. 2.56	~1000	GRIMALDI & ENGEL, 2005; AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
		Beqaa Kafra **[5]**; Fig. 4.A-B; Pl. 1, fig. G	6	D. AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
		Hadath El-Joubbeh **[6]**; Fig. 4.A, C; Pl. 1, fig. H	~5	D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
	El-Batroun	Tannourine **[7]**; Fig. 4.A, D; Pl. 1, fig. I	47	D. AZAR & ZIADÉ, 2005; AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
Jbeil - Kesserouan	Kesserouan	Mazraat Kfardibiane **[8]**; Fig. 6.A-B; Pl. 1, fig. J	2	MAKSOUD *et al.*, 2020, 2021c
		Ouata El-Jaouz **[9]**; Fig. 6.A, C; Pl. 2, figs. A-B	6	D. AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
		Bqaatouta **[10]**; Fig. 6.A, E; Pl. 2, figs. C-E	~40	MAKSOUD *et al.*, 2021a
Mount Lebanon	El-Matn	Baskinta **[11]**; Fig. 6.A, D; Pl. 2, figs. F-G	~40	MAKSOUD *et al.*, 2021a
		Daychouniyyeh **[12]**; Fig. 7.A-B; Pl. 2, fig. H	11	D. AZAR *et al.*, 2010b; SZWEDO *et al.*, 2011; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
	Baabda	Kfar Selouan **[13]**; Fig. 8.A-B; Pl. 2, figs. I-J	69	D. AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
		Kfar Selouan (Khallet Douaiq) **[14]**; Fig. 8.A, C; Pl. 2, figs. K-M	37	MAKSOUD *et al.*, 2021c
		Mdeyrij-Hammana **[15]**; Fig. 8.A, E; Pl. 3, figs. A-E	3200	D. AZAR *et al.* 1999, 2010b, 2011a; D. AZAR, 2012; SZWEDO *et al.*, 2013; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
		Falougha **[16]**; Fig. 8.A, D; Pl. 3, fig. F	~40	D. AZAR *et al.*, 2015; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
	Esh-Shouf	Ain Zhalta **[17]**; Fig. 9.A-B; Pl. 3, fig. G	20	D. AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
		Ain Zhalta (Ain Azimeh) **[29]**; Fig. 9.A-B; MAKSOUD *et al.*, 2022: 401, Fig. 1; 402, Fig. 2	30	MAKSOUD *et al.*, 2022
	Aley	Ain Dara (two localities) **[18-19]**; Fig. 9.A, F; Pl. 3, fig. H	130	D. AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
		Sarhmoul **[20]**; Fig. 10.A-B; Pl. 3, fig. I	29	D. AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
South Lebanon	Jezzine	Roum - Aazour - Homsiyeh **[21]**; Fig. 11.A, C; Pl. 3, fig. J	37	D. AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
		Bkassine (Jouar Es-Souss) **[22]**; Fig. 11.A, D; Pl. 3, fig. K	~3000	SCHLEE & DIETRICH, 1970; AZAR *et al.*, 2010b; Azar, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
		Wadi Jezzine **[23]**; Fig. 11.A-B; Pl. 3, fig. L	~20	MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
		Maknouniyeh **[24]**; Fig. 11.A, E; Pl. 3, fig. M	14	D. AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
		Rihane **[25]**; Fig. 12.A-B; Pl. 3, fig. N	~40	D. AZAR & NEL, 2013; SZWEDO *et al.*, 2013; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
Baalbeck - El Hermel	Baalbeck	Esh-Sheaybeh **[26]**; Fig. 13.A-B; Pl. 3, fig. O	22	D. AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c
Beqaa	Zahleh	Bouarij **[27]**; Fig. 9.A, G; Pl. 3, fig. P	220	D. AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD *et al.*, 2021c
	Rashaiya	Aita El-Foukhar **[28]**; Fig. 14.A-B	1	D. AZAR *et al.*, 2010b; D. AZAR, 2012; MAKSOUD & D. AZAR, 2020; MAKSOUD *et al.*, 2021c



◀ **Figure 3: A-** Geological map: fossiliferous outcrop of Mechmech (Ain El-Khyar) (red arrow) outcrop (modified after Dubertret, 1951c; Guerre, 1975). J6 = uppermost Jurassic; C2a = lower Barremian "Grès du Liban" sandstone; C2b = Barremian clay and oolitic deposition of the upper part of the "Grès du Liban" and oolitic deposition of the lower part of the Jezzinian; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C4-5 = Albian-Cenomanian; C5 = Cenomanian; Q = Quaternary scree; βC3 = Jezzinian volcanic deposition. Thick lines represent faults. Scale bar = 1 km. **B-** General view of the outcrop of Mechmech (Ain El-Khyar).

The rediscovery of dysodiles, unusual Lower Cretaceous continental deposits in Lebanon, brought important and exceptional palaeontological assets (El Hajj *et al.*, 2019, 2021a, 2021b; D. Azar *et al.*, 2019a). Dysodiles are sedimentary rocks characterised by finely laminated (micrometric) layers (papershales), with high organic content (Cordier, 1808) and well-preserved fossils (Fraas, 1878). Lebanese dysodiles were formed in different lacustrine deposits in different areas, during the lower Barremian and Albian. Their presence was mentioned in some nineteenth century publications in the Lower Cretaceous sandstones of Mount Lebanon (Botta, 1831), and in the South (Fraas, 1878) and Centre of Lebanon (Janensch, 1925). Fraas (1878) was the first author to point out their richness in fossils including fish and plant debris, and he identified some plant species that were later reviewed by Edwards (1929) and attributed to *Zamites* sp. and *Weichselia reticulata*. In 1925, Janensch identified two small actinopterygian fishes as *Pleuropholis koerti* and *Thrissops* sp. Then, since the 1930s, dysodiles were forgotten until their recent rediscovery through the extensive geological fieldwork of our team which resulted in the finding of seven localities, five of them in the lower Barremian and two in the Albian. Among those dysodile outcrops, two lower Barremian ones (Jdeidet Bkassine and Sniyya) and one Albian (Qnat, where dysodiles are associated with cinerite, unpublished data) produced fossil insects. Recently D. Azar *et al.* (2019a) described an ephemeropteran larva and El Hajj *et al.* (2021a) illustrated several fossil insects from the lower Barremian dysodiles of Jdeidet Bkassine.



◀ **Figure 4: A-** Geological map: fossiliferous outcrops of Nimrin (El-Dabsheh) (yellow arrow) and Brissa (red arrow) outcrops (modified after Dubertret, 1951c). J6 = uppermost Jurassic; C2 = lower Barremian "Grès du Liban"; C3 = Jezzinian (uppermost Barremian-lowermost Aptian); C4-5 = Albian-Cenomanian; C5 = Cenomanian; Q = Quaternary scree; βC3 = Jezzinian volcanic deposition. Thick lines represent faults. Scale bar = 1 km. **B-** General view of Nimrin (El-Dabsheh) outcrop. **C-** General view of Brissa outcrop.

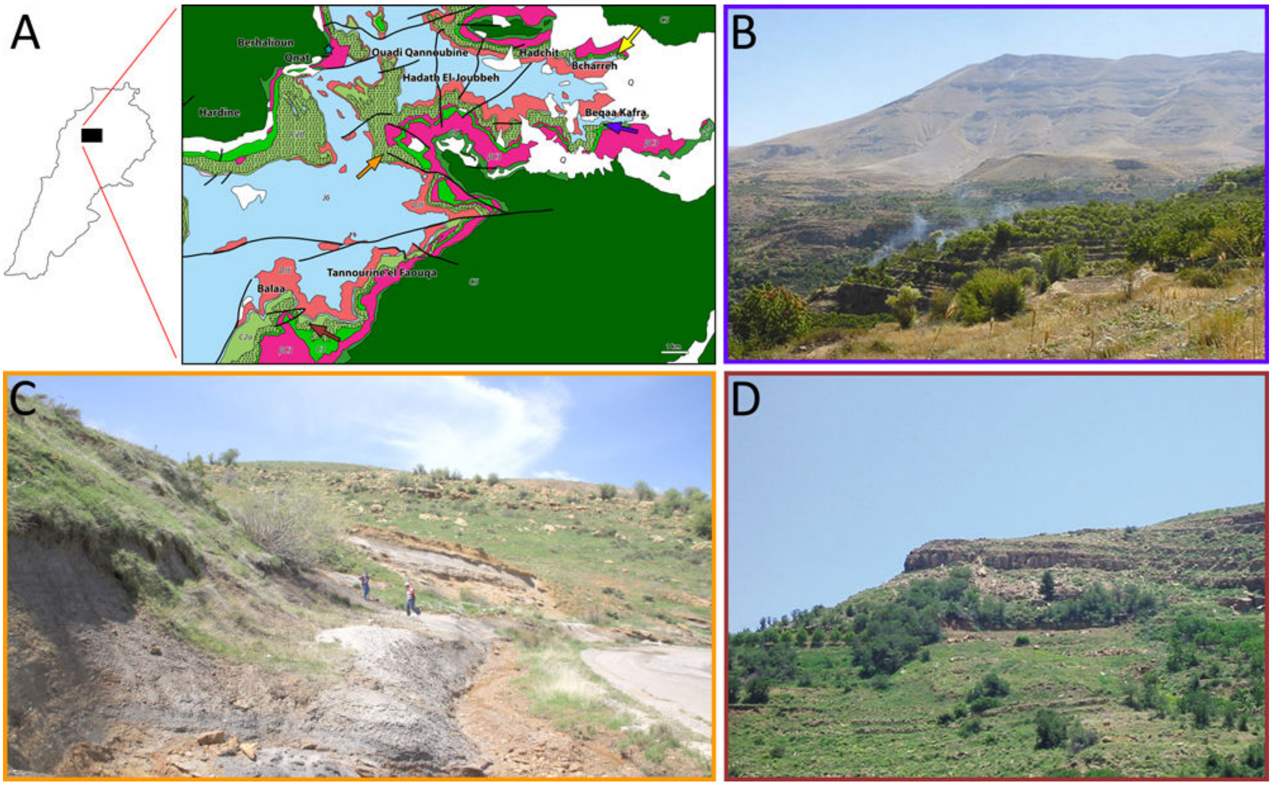


Figure 5: A- Geological map: fossiliferous outcrops of Bcharreh (yellow arrow), Beqaa Kafra (blue arrow), Hadath El-Joubbeh (orange arrow), Tannourine (brown arrow) and Qnat (clear blue star) outcrops (modified after DUBERTRET & WETZEL, 1945, 1951; DUBERTRET, 1949b, 1951c). J6 = uppermost Jurassic; C2a = lower Barremian "Grès du Liban" sandstone; C2b = Barremian clay and oolitic deposition of the upper part of the "Grès du Liban" and oolitic deposition of the lower part of the Jezzinian; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C5 = Cenomanian; Q = Quaternary scree; βJ6 = Kimmeridgian volcanic deposition; βC3 = Jezzinian volcanic deposition. Thick lines represent faults. Scale bar = 1 km. **B-** General view of Beqaa Kafra outcrop. **C-** General view of Hadath El-Joubbeh outcrop. **D-** General view of Tannourine outcrop.

Apart from amber, Lebanon is world-wide famous in palaeontology for its rich Upper Cretaceous marine fish deposits in Sahel Alma, Haqel, Nammoura, and Hjoula. Recently, the two latter outcrops surprisingly yielded some complete and undisarticulated fossil insects (A. NEL *et al.*, 2004; VRŠANSKÝ & MAKHOUL, 2013; MAKSOUD & D. AZAR, 2021; D. AZAR *et al.*, 2019b), indicating a depositional marine palaeoenvironment, close to a palaeo-shoreline during the mid-Cenomanian.

Lower Barremian fossil insect outcrops

Amber

Of the 450 amber outcrops in Lebanon, 430 outcrops contain early Barremian amber, among which 29 have yielded amber with bioinclusions. Up to 10% of Lebanon's total land surface could potentially yield amber (Fig. 1).

The list of the fossiliferous amber outcrops is given in Table 1 ranging from the North to South of Lebanon.

The clay-shale layers of one of the amber outcrops, in Qahmez (Kesserouan District, Central Lebanon, KÁČEROVÁ & D. AZAR, *in press*) (Figs. 6.A, 15.A) produced some fossil fragments of insects originally floating with other organic and vegetal remains, deposited in an abandoned reach of a fluvial system. The outcrop today is a sand quarry (a vulnerable site that almost disappeared with the growth of the quarry); the sand layers are intercalated with centimetric-scale layers of grey silty clay-shale rich in floated organic remains. In one of these layers (the thickest, *ca*. 50 cm thick) corresponding to a lens of *ca*. 6 metres width, formed by a palaeo-fluvial channel, a cockroach forewing (belonging to Mesoblattinidae) was recovered (Pl. 4, fig. A) (KÁČEROVÁ & D. AZAR, *in press*).

Dysodiles

Lower Barremian dysodiles crop out in five localities across Lebanon (Fig. 1) at the base of the "Grès du Liban" unit; in Qrayn (North of Lebanon, Sir Ed-Danniyeh District), Tarchich (Central Lebanon, Baabda District), Jdeidet Bkassine, Sniyya and Zhalta (South of Lebanon, Jezzine District) (EL HAJJ *et al.*, 2021a).

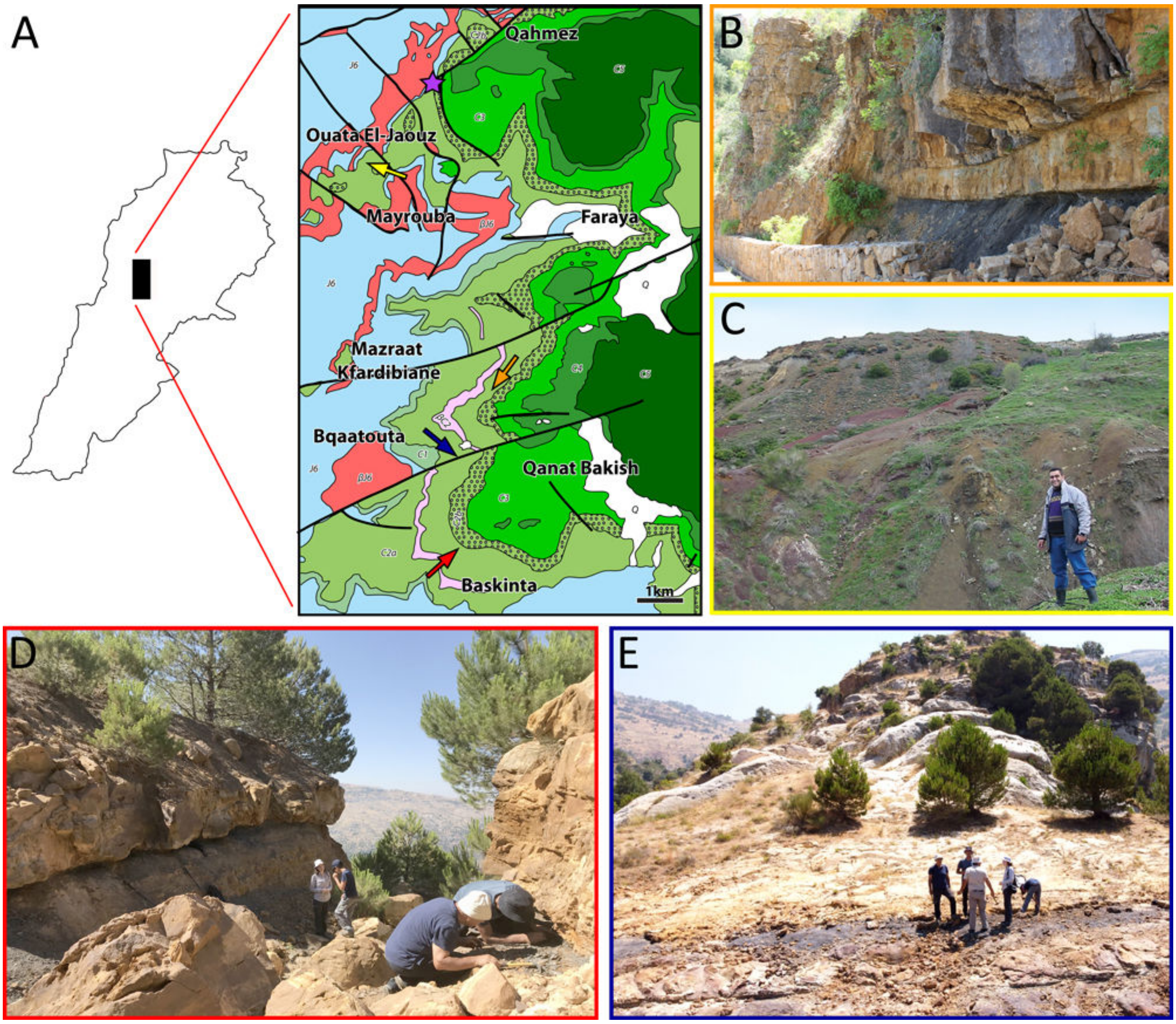


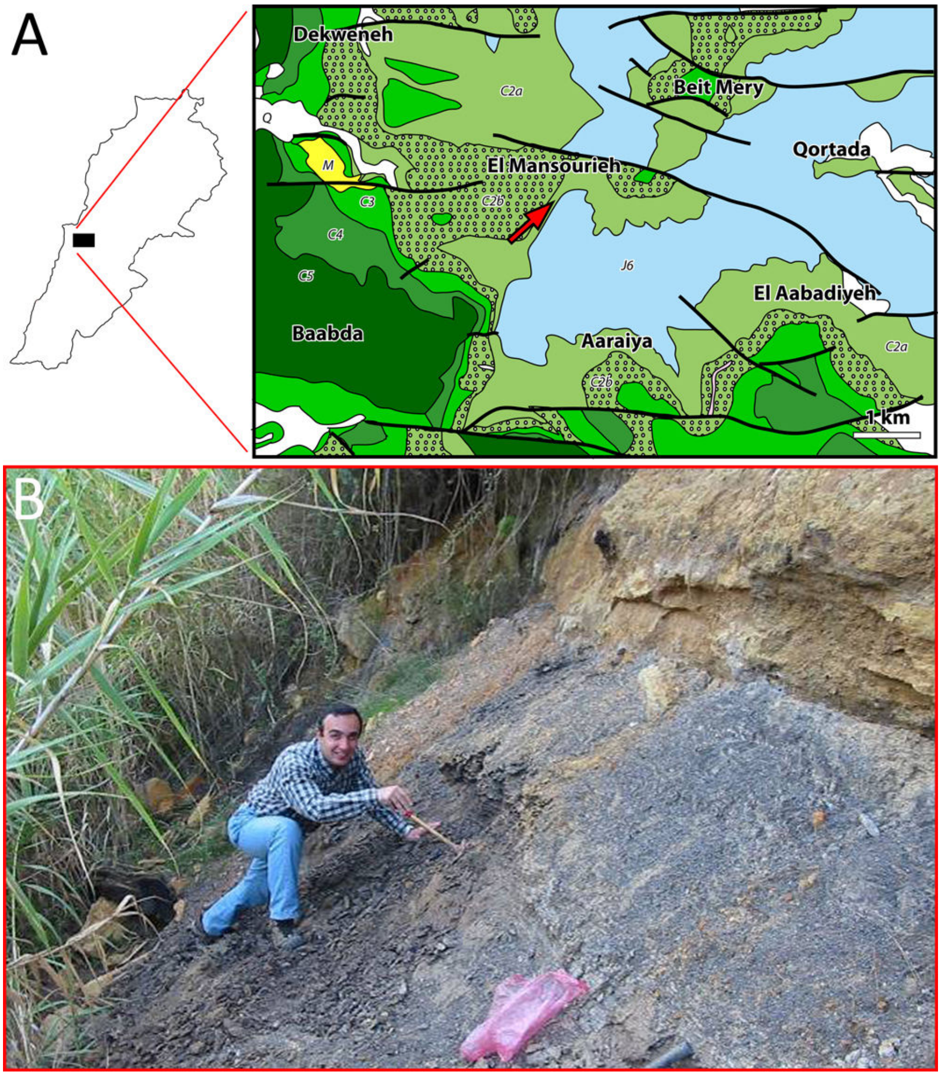
Figure 6: A- Geological map: Ouata El-Jaouz (yellow arrow), Mazraat Kfardibiane (Red Rock) (orange arrow), Baskinta (Qanat Bakish) (red arrow), Bqaatouta (blue arrow) and Qahmez (purple star) outcrops (modified from DUBERTRET, 1945, and DUBERTRET & WETZEL, 1945). J6 = uppermost Jurassic; C1 = Salima Formation (lower Valanginian); C2a = lower Barremian "Grès du Liban" sandstone; C2b = Barremian clay and oolitic deposition of the upper part of the "Grès du Liban" and oolitic deposition of the lower part of the Jezzinian; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C5 = Cenomanian; Q = Quaternary scree; βJ6 = Kimmeridgian volcanic deposition; βC2 = lower Barremian volcanic deposition. Thick lines represent faults. Scale bar = 1 km. **B-** General view of Mazraat Kfardibiane outcrop. **C-** General view of Ouata El-Jaouz outcrop. **D-** General view of Baskinta (Qanat Bakich) outcrop. **E-** General view of Bqaatouta outcrop.

Though the five outcrops all present a great potential for fossil insects, nevertheless to date only two of them, *viz*. Jdeidet Bkassine (Figs. 11.A, 15.B) and Sniyya (Figs. 11.A, 15.C), produced some insect samples (Pl. 4, figs. B-E, Q) among which a mayfly larva, *Libanoephemera inopinatabranchia* D. AZAR *et al.*, 2019a, and an adult cockroach belonging to Blattulidae (KÁČEROVÁ & D. AZAR, *in press*) were described. These paper shales (*ca*. 95-100 cm thick) were formed in small, isolated palaeolakes and/or swamps, within the "Grès du Liban" unit.

Albian fossil insect outcrop

Cinerite associated with dysodiles

In Qnat (Bcharreh District, North of Lebanon), Albian cinerite and a dysodile associated with volcanism yielded fishes, vegetal remains, turtles, and insects (Figs. 5.A, 15.D). To date, a complete articulated Mantodea imago, bearing several plesiomorphic structures, has been recovered in the cinerite from this outcrop (Pl. 4, fig. F).



◀ **Figure 7: A-** Geological map: Daychouniyyeh (red arrow) outcrop (modified from Dubertret, 1951a). J6 = uppermost Jurassic; C2a = lower Barremian "Grès du Liban" sandstone; C2b = Barremian clay and oolitic deposition of the upper part of the "Grès du Liban" and oolitic deposition of the lower part of the Jezzinian; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C5 = Cenomanian; Q = Quaternary scree; M = mid-Miocene. Thick lines represent faults. Scale bar = 1 km. **B-** General view of Daychouniyyeh outcrop.

Mid-Cenomanian limestone with fossil insects

Marine fossil fish deposits

Late Cretaceous marine fish deposits in Sahel Alma, Haqel, Nammoura and Hjoula are famously known. Recently the two latter outcrops yielded unexpectedly complete and undisarticulated fossil insects (A. Nel *et al.*, 2004; Vršanský & Makhoul, 2013; D. Azar *et al.*, 2019b; Maksoud & D. Azar, 2021), indicating an exceptional depositional marine palaeoenvironment, close to a shoreline during the mid-Cenomanian.

The Nammoura outcrop is located in El Ghabour, a valley at the North end of the village of Nammoura, in the Kesserouan District (Vršanský & Makhoul, 2013), in a quarry dedicated to extracting limestone slabs (Fig. 16.A-C). To date, some specimens of the archaeorthopteran *Chresmoda libanica* A. Nel *et al.*, 2004 (Chresmodidae), and one specimen of a mesoblattinid cockroach, *Mieroblattina pacis* Vršanský & Makhoul, 2013 (Pl. 4, figs. G-H), have been recovered from this locality.

The Hjoula outcrop is situated in Hjoula (Jbeil District, Northern part of Central Lebanon), in the valley beneath the mosque of this village (Fig. 17.A-B). Hitherto, ten complete and articulated fossil insects were recovered from this outcrop (Maksoud & D. Azar, 2021): six Odonata (belonging to three or four different taxa), including one liupanshaniid, *Libanoliupanshania mimi* D. Azar *et al.*, 2019b; a libanocorduliid, *Libanocordulia debiei* D. Azar *et al.*, 2019b, and two undetermined Anisoptera; a scarabaeoid coleopteran; a cicadellid hemipteran, a saucrosmylid neuropteran (*Lebanosmylus leae* D. Azar & A. Nel, 2022); and an unidentified insect (Pl. 4, figs. I-P).

3. Geological settings

3.1. Lower Barremian fossil insect outcrops

Amber

Lower Cretaceous Lebanese amber occurs in silts and dark shales with lignite and plant debris (sometimes including leaves from the resin-producing tree) in three intervals of the upper part

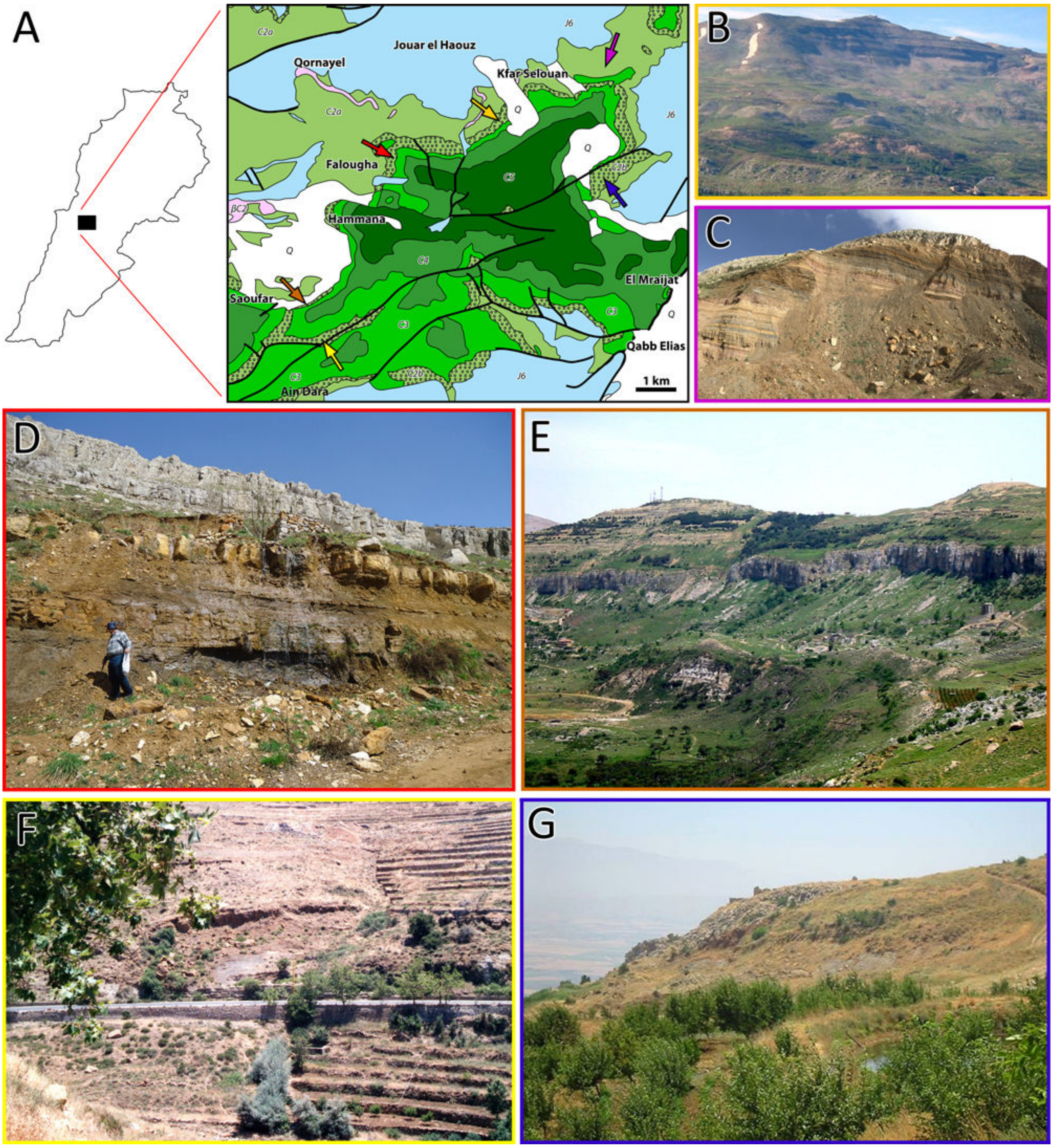
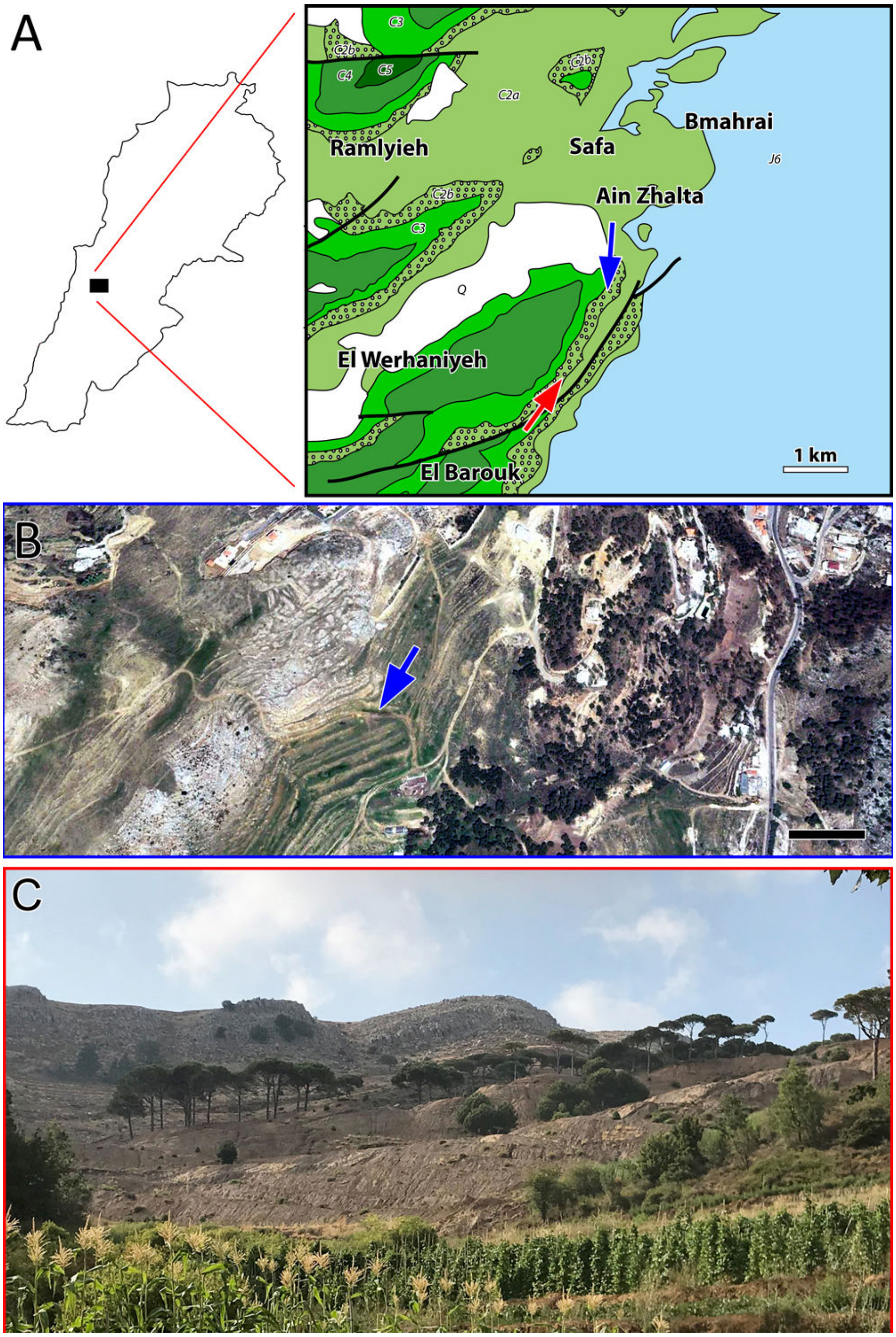


Figure 8: A- Geological map: Kfar Selouan (orange arrow), Kfar Selouan (Khallet Douaiq) (purple arrow), Bouarij, Mdeyrij-Hammana (brown arrow), Falougha (red arrow) and Ain Dara (yellow arrow) outcrops (modified from DUBERTRET, 1951a, 1953). J6 = uppermost Jurassic; C2a = lower Barremian "Grès du Liban" sandstone; C2b = Barremian clay and oolitic deposition of the upper part of the "Grès du Liban" and oolitic deposition of the lower part of the Jezzinian; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C5 = Cenomanian; Q = Quaternary scree; βC2 = lower Barremian volcanic deposition. Thick lines represent faults. Scale bar = 1 km. **B-** General view of Kfar Selouan outcrop. **C-** General view of Kfar Selouan (Khallet Douaiq) outcrop. **D-** General view of Falougha outcrop. **E-** General view of Mdeyrij-Hammana outcrop. **F-** General view of Ain Dara outcrop. **G-** General view of Bouarij outcrop.

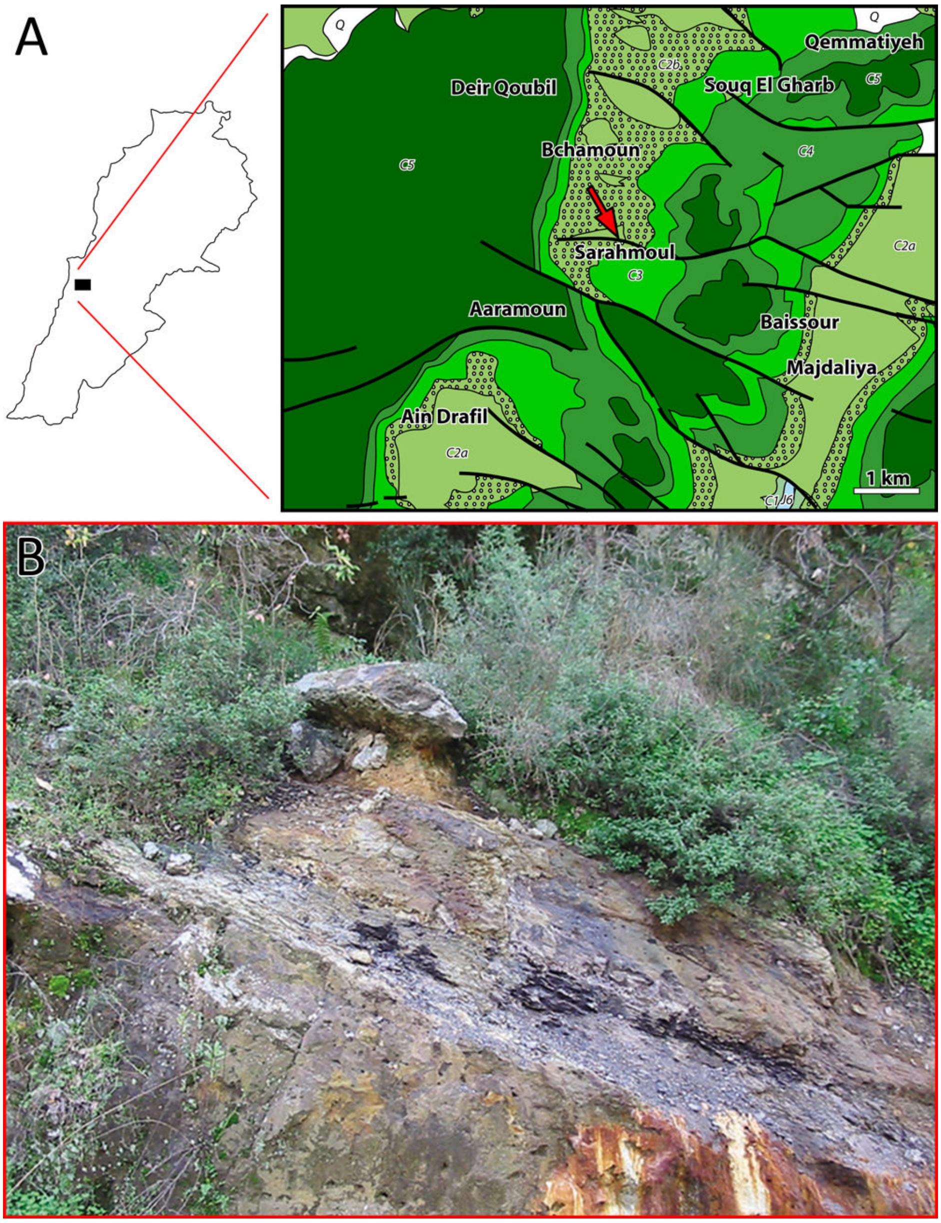
of the "Grès du Liban". These deposits correspond to siliciclastic coastland estuarine environments based on the co-occurrence of bioturbation, echinoids and bivalves in the transgressive marine layers and amber and lignite in the regressive layers. The entomofaunal associations of the amber inclusions indicates a thick resin-producing forest under a warm tropical climate, which is also corroborated by the palynological data (D. AZAR *et al.*, 2011).



◀ **Figure 9: A-** Geological map: Ain Zhalta (red arrow) and Ain Zhalta (Ain Azimeh, blue arrow) (modified from DUBERTRET, 1950, 1951a). J6 = uppermost Jurassic; C2a = lower Barremian "Grès du Liban" sandstone; C2b = Barremian clay and oolitic deposition of the upper part of the "Grès du Liban" and oolitic deposition of the lower part of the Jezzinian; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C5 = Cenomanian; Q = Quarternary scree. Thick lines represent faults. Scale bar = 1 km. **B-** General aerial view of Ain Zhalta (Ain Azimeh) outcrop. Scale bar = 50 m. **C-** General view of Ain Zhalta outcrop.

Lower Cretaceous Lebanese amber found in the lowest interval of the upper part of the "Grès du Liban" is buried in a primary deposit, whilst it has been re-deposited in the mid and upper intervals. Until now, about 8,500 biological inclusions (mainly insects) have been found in the 29 Lebanese amber outcrops.

For a long time, the Lower Cretaceous amber outcrops were dated as Neocomian-Aptian (ZUMOFFEN, 1926) or Neocomian-early Aptian (DUBERTRET & VAUTRIN, 1937), or even Valanginian-Hauterivian in age (SCHLEE & DIETRICH, 1970), *i.e.*, various ranges across the whole Early Cretaceous Subperiod, except Albian, relegated to the late Aptian. The age of the overlying limestone unit, *i.e.*, the "Falaise de BLANCHE" [Blanche Cliff], was also poorly constrained until a recent detailed holostratigraphic study by MAKSOUD *et al.* (2014). These authors merged the whitish micritic limestones of the "Falaise de Blanche" with the immediate underlying yellowish grainy limestones in a single lithostratigraphic unit. This Unconformity Bounded Unit, now dubbed the Jezzinian regional stage, is dated as late Barremian-earliest Aptian (= early Bedoulian).



◀ **Figure 10: A-** Geological map: Sarhmoul (red arrow) (modified from DUBERTRET, 1949c, 1950, 1951b). J6 = uppermost Jurassic; C1 = Salima Formation (lower Valanginian); C2a = lower Barremian "Grès du Liban" sandstone; C2b = Barremian clay and oolitic deposition of the upper part of the "Grès du Liban" and oolitic deposition of the lower part of the Jezzinian; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C5 = Cenomanian; Q = Quaternary scree; βJ6 = Kimmeridgian volcanic deposition. Thick lines represent faults. Scale bar = 1 km. **B-** General view of Sarhmoul outcrop.

In Lebanon, the Lower Cretaceous fossiliferous amber outcrops are mainly found in three intervals in the upper part of the "Grès du Liban" (Fig. 18):

• the upper interval is located between the Jezzinian above and the "Banc de Mrejatt" below. Amber outcrops belonging to this interval are those of the waterfall at Jezzine (South Lebanon); Hammana, Kfar Selouan (Khallet Douaiq), Ain Zhalta (Ain Azimeh) and Bouarij (Central Lebanon);

• the middle interval is located between the "Banc de Mrejatt" above and a pisolitic interval below. Amber 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. Amber outcrops belonging to this interval are those of Rihane, Maknouniyeh, Roum-Aazour-Homsiyeh and Jouar Es-Souss in Bkassine (South Lebanon); Ain Zhalta, Baskinta, Bqatouta and Mazraat Kfardibiane (Central Lebanon).

Stratigraphic details of these three intervals are given in MAKSOUD *et al.* (2017). All three fossiliferous amber-bearing intervals cited above are very rich in biological inclusions, mostly terrestrial arthropod remains such as insects, spiders and mites (D. AZAR, 1997a, 1997b, 2012; D. AZAR *et al.*, 2010b) but also plants and vertebrate remains. Nevertheless, their entomofaunal associations are very similar, which suggests that they have very close, if not the same age (D. AZAR *et al.*, 2003; D. 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 imply 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 pieces found in the middle and

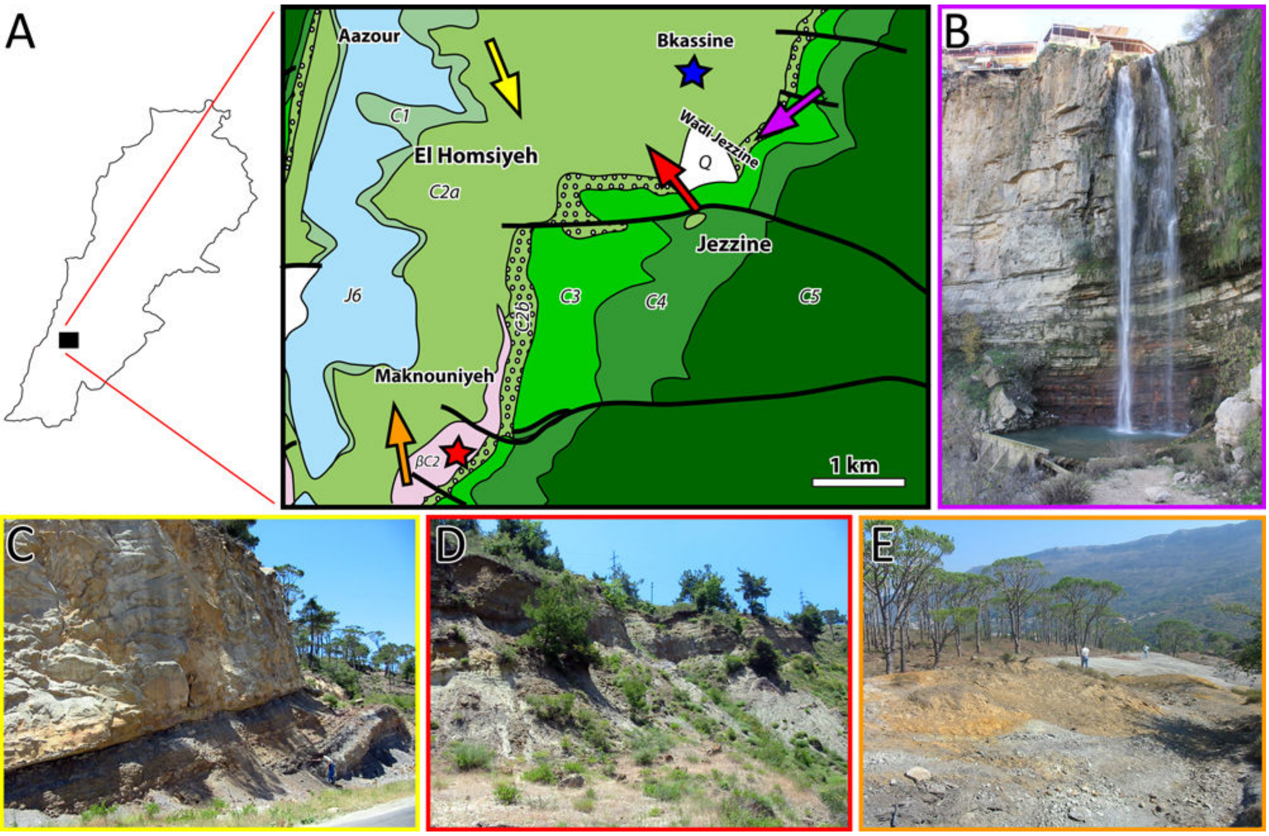


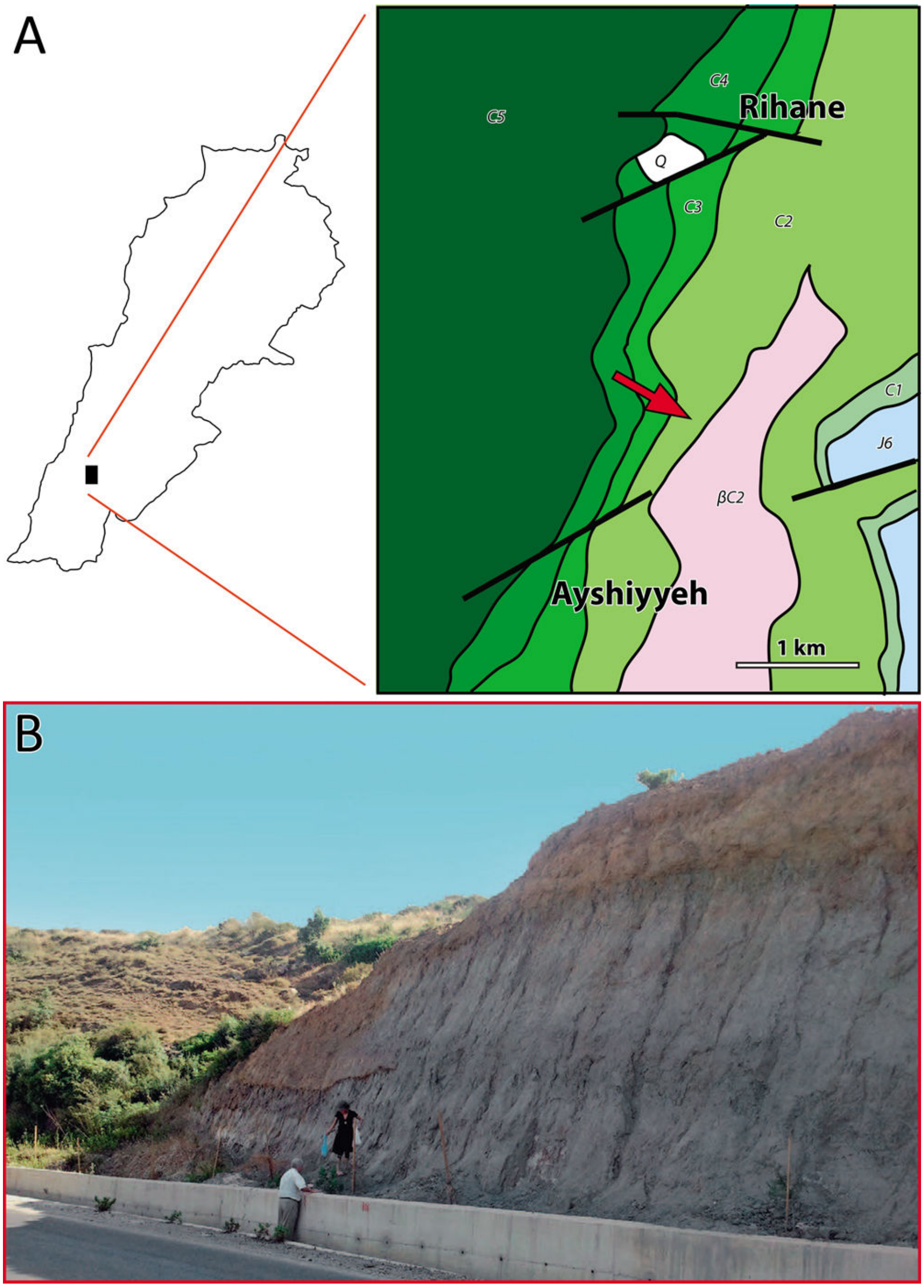
Figure 11: A- Geological map: Jdeidet Bkassine (blue star) and Sniyya (red star) dysodile outcrops and of the Roum - Aazour - Homsiyeh (yellow arrow), Bkassine (Jouar Es-Souss) (red arrow), Wadi Jezzine (purple arrow), Maknouniyeh (orange arrow) amber outcrops (modified from DUBERTRET, 1950). J6 = uppermost Jurassic; C1 = Salima Formation (lower Valanginian); C2a = lower Barremian "Grès du Liban" sandstone; C2b = Barremian clay and oolitic deposition of the upper part of the "Grès du Liban" and oolitic deposition of the lower part of the Jezzinian; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C5 = Cenomanian; Q = Quaternary scree; βC2 = Barremian volcanic deposiion. Thick lines represent faults. Scale bar = 1 km. **B-** General view of Wadi Jezzine outcrop. **C-** General view of Roum - Aazour - Homsiyeh outcrop. **D-** General view of Bkassine (Jouar Es-Souss) outcrop. **E-** General view of Maknouniyeh outcrop.

upper intervals are rounded and commonly bored by martesiine pholadid bivalves, suggesting that the resin was already hardened and then transported to a transitional environment (*i.e.* deltaic zone) where it could be bored by bivalves before being deposited and buried. 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 inclusions in the amber (of Hammana), though this taxon does not exist in the palynological assemblage of the embedding sediments (D. AZAR *et al.*, 2011). This 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 obsolete so-called "Abeih Formation" (the middle and higher intervals), have been most likely reworked from older deposits. It is noteworthy to mention that the first use of fossil insects entombed in amber in biostratigraphy and relative dating is from Lebanese amber (D. AZAR *et al.*, 2003).

The age of the amber from the Lower Cretaceous or "Grès du Liban" is currently attributed to the early Barremian (GRANIER *et al.*, 2016; MAKSOUD *et al.*, 2017; MAKSOUD & D. AZAR, 2020).

Rock impression/compression (adpressions)

The clay-shale layers at Qahmez (Kesserouan District, Central Lebanon, KÁČEROVÁ & D. AZAR, *in press*) (Pl. 4, fig. A) in the "Grès du Liban" unit are dated as early Barremian by GRANIER *et al.* 2015. The sand layers are fluvial and include deltaic deposits not far from the sea with tidal influence, witnessed by the presence of dinoflagellates in the sediment. The sand layers are intercalated with centimetric-thick layers of grey silty clay shale rich in floated organic fragments, especially plant remains, and occasionally insect fragments. The fragmentary state of the organic matter witnesses a transport system before deposition or even flotation after decomposition. One of the silty clay shale rich layers is thick (about 50 cm) and corresponds to a lens of about 6 metres wide, formed in a fluvial channel. The organic remains were originally transported in the fluvial system and deposited in a cut-off arm of water or an oxbow lake.

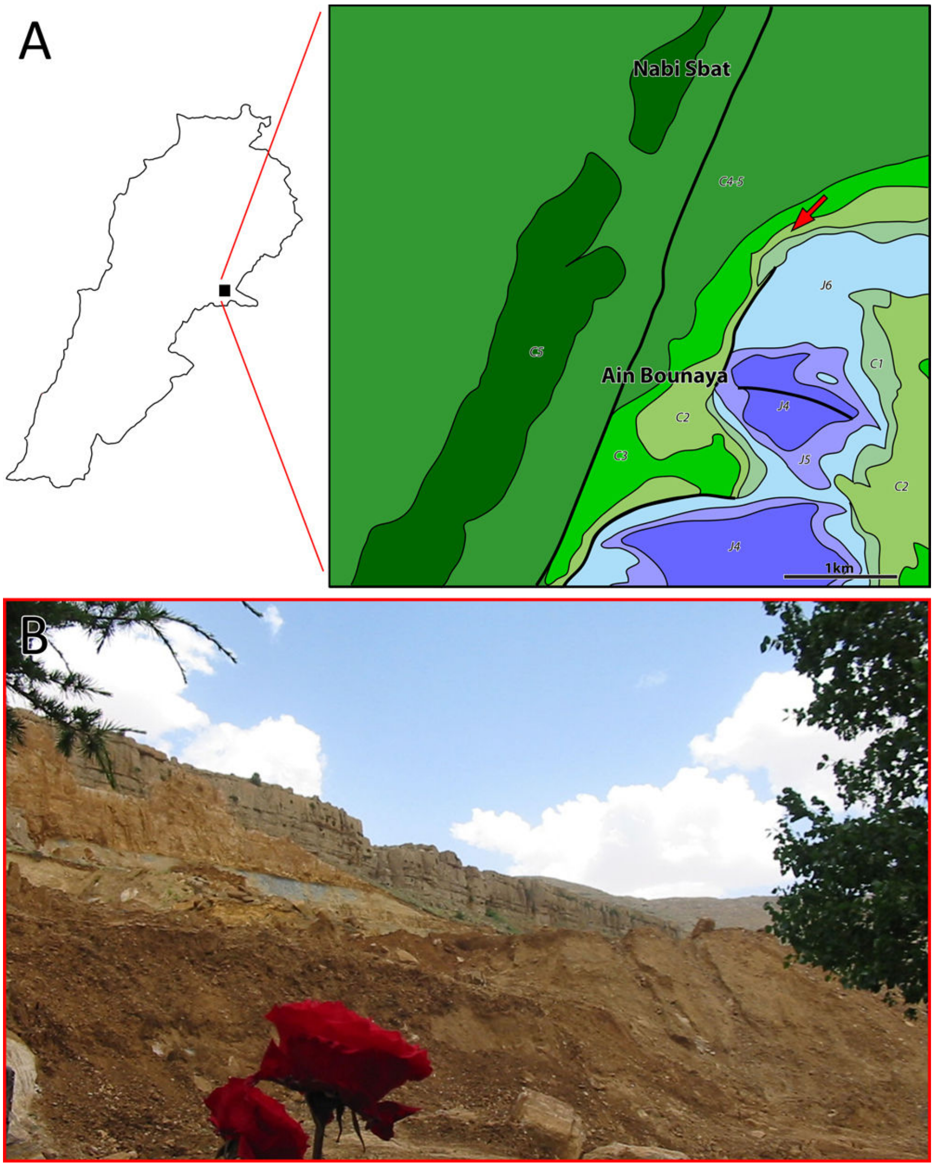


◀ **Figure 12: A-** Geological map: Rihane (red arrow) amber outcrop (modified from DUBERTRET, 1951b). J6 = uppermost Jurassic; C1 = Salima Formation (lower Valanginian); C2 = lower Barremian "Grès du Liban" sandstone; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C5 = Cenomanian; Q = Quaternary scree; βC2 = Barremian volcanic deposition. Thick lines represent faults. Scale bar = 1 km. **B-** General view of Rihane outcrop.

Dysodile

Lower Barremian dysodiles in South Lebanon (in the three localities of Jdeidet Bkassine, Sniyya and Zhalta) overlie altered volcanic claystone deposits and nodular carbonates. It is noteworthy that these southern outcrops are not distant from each other, suggesting that during deposition they could have been interconnected under certain conditions as demonstrated by the geochemical analyses (EL HAJJ *et al.*, 2019).

During the lower Barremian, Lebanon was located in the northeastern Gondwana supercontinent, under a warm tropical climate on a continental border. VELTZ (2008) highlighted that the deposition of the sandstone occurred in a tectonically unstable continental context. During the lower Barremian, Lebanon also witnessed many volcanic episodes related to fault reactivation (BREW *et al.*, 2001), and faults might have promoted the development of small lakes and/or swamps. The dysodiles are associated with volcanic ash deposits; the volcanic activity occurring both prior to (DUBERTRET, 1955) and during the dysodile deposition since ash could also be identified within the dysodile layers. In addition, the claystone associated with dysodiles could be the result of an alteration of the basalt. Therefore, we envisage a close relationship between volcanism and dysodile formation.



◀ **Figure 13: A-** Geological map: Esh-Sheaybeh (red arrow) amber outcrop (modified from DUBERTRET, 1949b). J4 = Middle Jurassic; J5 = Oxfordian; J6 = uppermost Jurassic, Kimmeridgian; C1 = Salima Formation (lower Valanginian); C2 = lower Barremian "Grès du Liban" sandstone; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C5 = Cenomanian; C4-5 = Albian – Cenomanian. Thick lines represent faults. Scale bar = 1 km. **B-** General view of Esh-Sheaybeh outcrop.

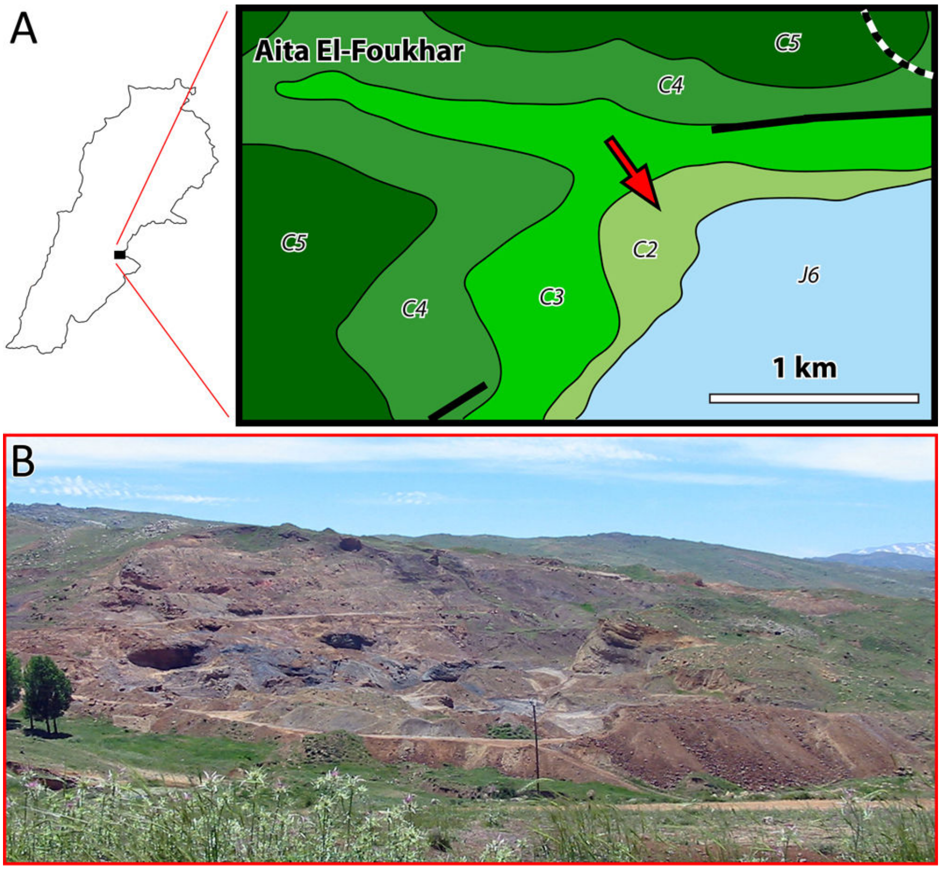
The palaeogeographic situation of Lebanon, mostly influenced by the tectonic events and the warm tropical climate, may have enhanced the primary productivity and diversity of these lake systems. Volcanic activity would have enriched the lakes and/or swamps with nutrients favouring the proliferation of organisms (VELTZ, 2008). However, volcanic activity could have also rendered lake waters toxic, leading to mass mortalIty (VELTZ, 2008).

The excellent preservation of the organic matter and fossils could have been facilitated by calm, anoxic bottom conditions, evidenced by the microscopic fine parallel lamination and absence of bioturbation, as well as by the high content in total organic carbon or TOC (EL HAJJ *et al.*, 2019), with a Pristane/Phytane ratio lower than 1 (PETERS *et al.*, 2005; EL HAJJ *et al.*, 2019), and the absence of biodegradation. Rapid burial in these aquatic ecosystems could also have contributed to excellent preservation of fossil insects by inhibiting the degradation of organic matter.

3.2. Albian fossil insect outcrop

Cinerite associated with dysodiles

Qnat (Bcharreh District, North of Lebanon) Albian volcanism allowed formation of palaeo-relief that enabled the development of a warm and mineral rich palaeo-lake. This allowed the development of successively repeated bacterial and algal films that were deposited as a dysodile of nearly 30 cm thickness followed by nearly 35 m of cinerites showing successive alternation of layers extremely rich with ostracods and others almost only with cinerites, witnessing a succession of several phases of ostracod blooming that occurred in the nutrient rich and warm water, with each of those phases followed by a generalised asphyxia caused by the continuous deposition of cinerite due to volcanic activity. These cinerites buried rapidly the plants, insects, fishes and turtles.



◀ **Figure 14: A-** Geological map: Aita El-Foukhar (red arrow) amber outcrop (modified from DUBERTRET, 1960). J6 = uppermost Jurassic; C2 = lower Barremian "Grès du Liban" sandstone; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C5 = Cenomanian. Thick lines represent faults. Scale bar = 1 km. Thick lines represent faults. Dotted line represents the boundary between Lebanon and Syria. Scale bar = 1 km. **B-** General view of Aita El-Foukhar outcrop.

3.3. Mid-Cenomanian limestone with fossil insects

Marine fossil fish deposits

The Hjoula and Nammoura Konservat-Lagerstätten are located respectively at the villages of Hjoula (Jbeil District, northern part of Central Lebanon) and Nammoura (Kesserouan District, Central Lebanon). They have historically been given several ages depending on different authors. BOTTA (1833) attributed the sediments in the co-eval Haqel outcrop to the Cretaceous. LEWIS (1878) and FRAAS (1878) postulated a Turonian age. Later PATTERSON (1967) and HÜCKEL (1970) recognized a Cenomanian age. PATTERSON (1967) estimated a mid-Cenomanian age based on the fish fauna, whereas HÜCKEL (1970) considered the beds at Haqel as lower Cenomanian based on the presence of the foraminiferan *Orbitolina concava* (LAMARCK, 1816) and the ammonite *Mantelliceras mantelli* (SOWERBY, 1814) already reported by ZUMOFFEN (1926). Biostratigraphical studies of DUBERTRET (1959, 1966) and SAINT-MARC (1974) determined the sequences at Hjoula to be lower Cenomanian. HEMLEBEN (1977), dated them as late Cenomanian based on a planktonic foraminiferal assemblage, including *Praeglobotruncana stephani* (GANDOLFI, 1942), *Rotalipora cushmani* (MORROW, 1934) and *Rotalipora greenhornensis* (MORROW, 1934). WALLEY (1997) assigned the outcrop to the Sannine Formation. Recently, WIPPICH and LEHMANN (2004) confirmed a late Cenomanian age for Hjoula based on the presence of the ammonite *Allocrioceras* cf. *annulatum* (SHUMARD, 1860), which is a member of the lower upper Cenomanian *Sciponoceras gracile* Zone in the Western Interior of the USA and the *Metoicoceras geslinianum* Zone of the international standard. FUCHS *et al.* (2009) confirmed a late Cenomanian age for Hjoula as well.

During the mid-Cenomanian, Lebanon was mostly submerged and positioned on a shallow carbonate platform (where there were some small islands present) on the North-East of the Arabo-African palaeocontinent at nearly 8° latitude (PHILIP *et al.*, 1993; BARRIER & VRIELYNCK, 2008). Although the outcrop of Hjoula is clearly marine, continental fossils indicate deposition close to a shoreline during the mid-Cenomanian (more precisely early late Cenomanian), *viz*. continental plants (pteridophytes, gymnosperms, and angiosperms), invertebrates, and complete skeletons and isolated bone of pterosaurs (KELLNER *et al.*, 2019), turtles and fish, in addition to nine newly discovered complete and not disarticulated fossil insects.

According to KRASSILOV & BACCHIA (2000), this mid-Cenomanian floral assemblage differs markedly from both the Lower Cretaceous and the Turonian plant assemblages of the Middle East and represents a distinct stage of the regional floristic evolution. These authors concluded that the phytogeographic affinities of the fossil fish outcrops of the mid-Cenomanian of Lebanon are in like contemporaneous floras of North America, Central

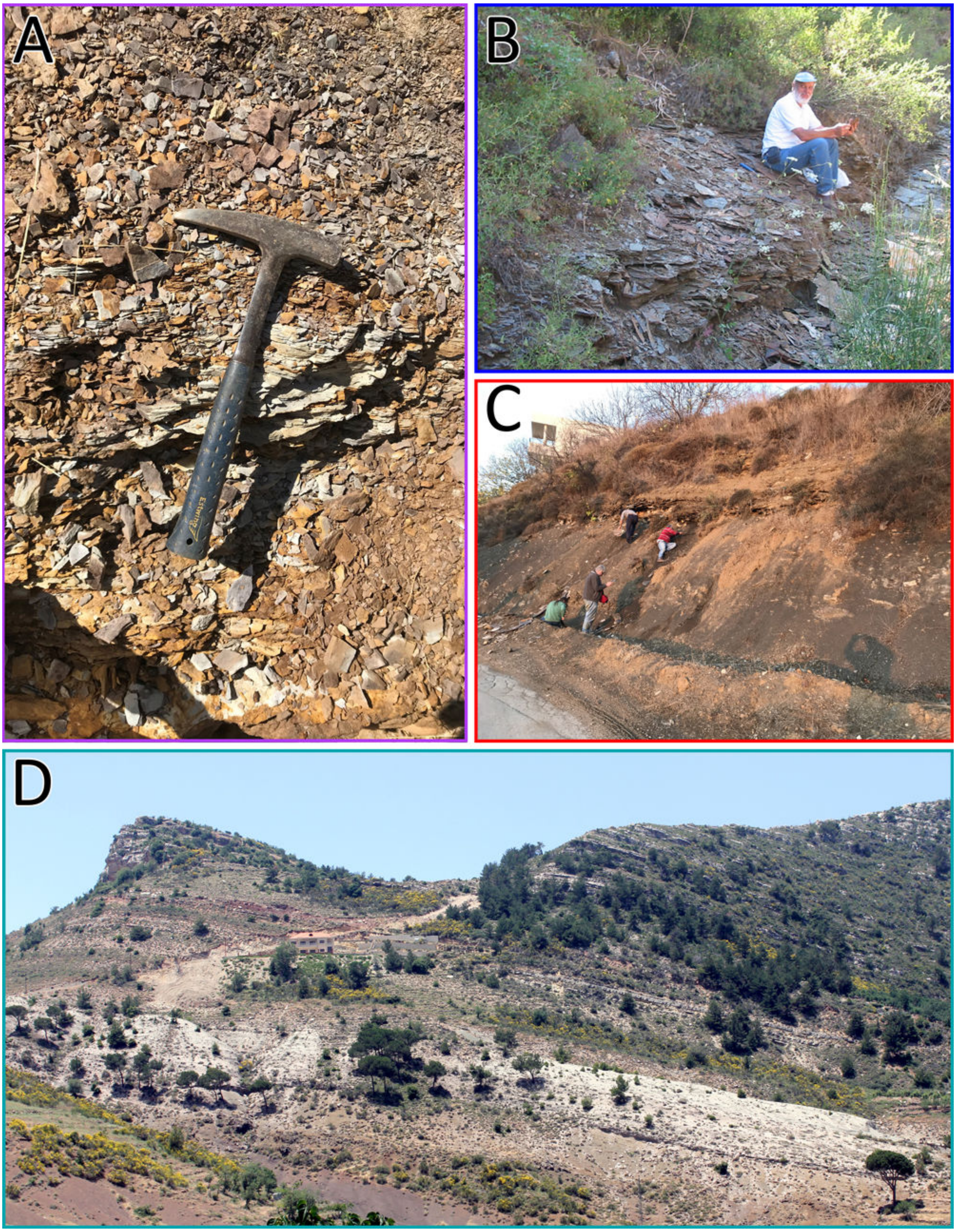
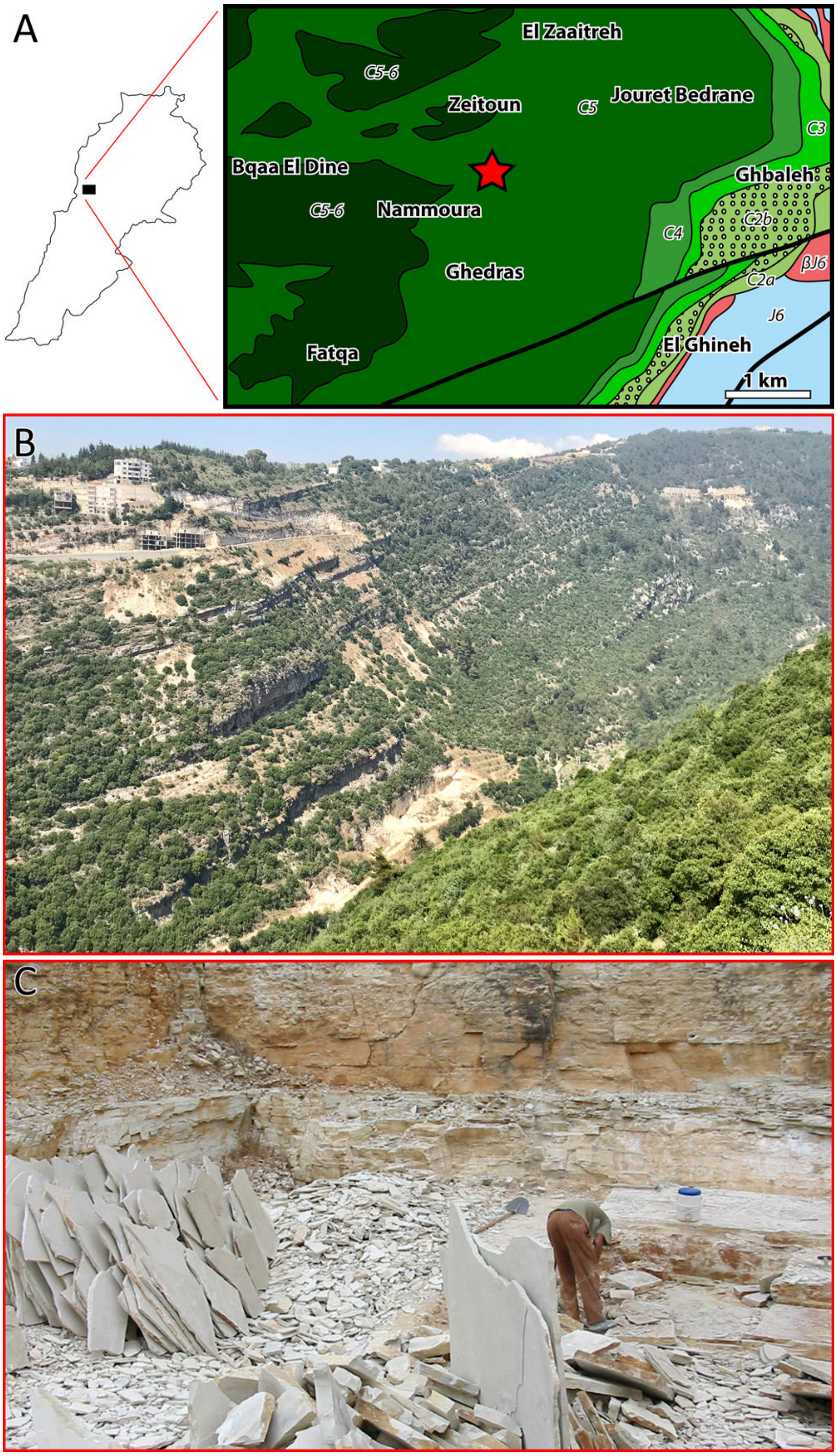
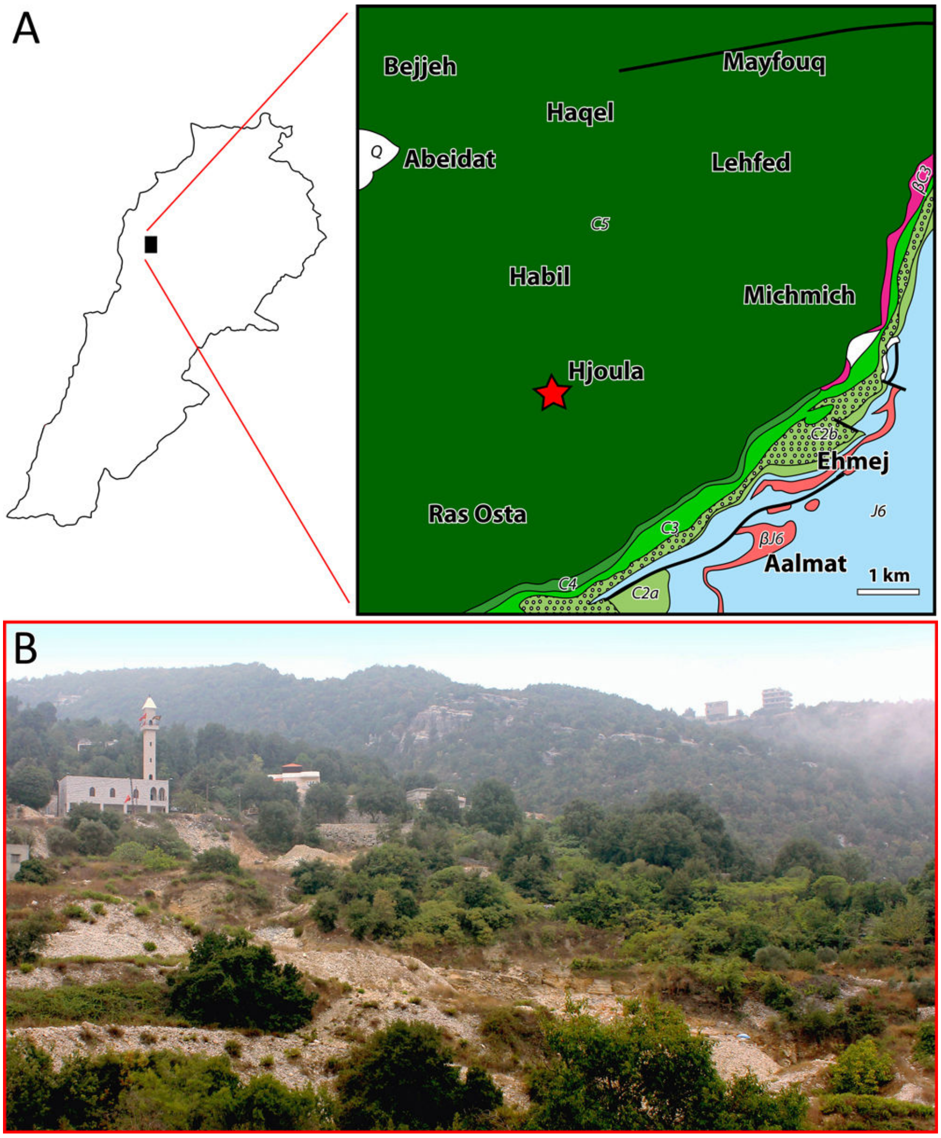


Figure 15: A- Clay-shale layers in Qahmez presenting fossil insects' fragments. **B-** General view of the lower Barremian dysodile outcrop in Jdeidet Bkassine. **C-** General view of the lower Barremian dysodile outcrop in Sniyya. **D-** General view of Qnat outcrop.



◀ **Figure 16: A-** Geological map: Nammoura Lagerstätte (red star) (modified from Dubertret, 1945). J6 = uppermost Jurassic; C2a = lower Barremian "Grès du Liban" sandstone; C2b = Barremian clay and oolitic deposition of the upper part of the "Grès du Liban" and oolitic deposition of the lower part of the Jezzinian; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C5 = Cenomanian; C5-6 = Cenomanian – Turonian; βJ6 = Kimmeridgian volcanic deposition. Thick lines represent faults. Scale bar = 1 km. **B-** General view of Nammoura Lagerstätte. **C-** Detail of the geological layers in Nammoura outcrop.

Europe, and the Crimea; thus, a combination of features like xeromorphism, the prevalence of compound leaves, and the presence of deciduous angiosperms and gymnosperms may indicate climatic conditions similar to those of the present-day Mediterranean area (Krassilov & Bacchia, 2000).



◀ **Figure 17: A-** Geological map: Hjoula Lagerstätte (red star) (modified from Dubertret, 1945; Dubertret & Wetzel, 1945). J6 = uppermost Jurassic; C2a = lower Barremian "Grès du Liban" sandstone; C2b = Barremian clay and oolitic deposition of the upper part of the "Grès du Liban" and oolitic deposition of the lower part of the Jezzinian; C3 = micritic part of the Jezzinian (uppermost Barremian-lowermost Aptian); C4 = Albian; C5 = Cenomanian; Q = Quaternary scree; βJ6 = Kimmeridgian volcanic deposition; βC3 = Jezzinian volcanic deposition. Thick lines represent faults. Scale bar = 1 km. **B-** General view of Hjoula Lagerstätte.

4. Importance of the Lebanese fossil insects

The above cited outcrops yielding fossil insects are all from the Cretaceous Period, most of them from the Lower Cretaceous (lower Barremian) whilst remainder from the 'mid-Cretaceous' (Albian and Cenomanian). The Cretaceous is one of the most interesting and important geological periods in the history of the Earth. It is when the origin and radiation of the angiosperms took place, and most of the extant insect families first appeared (Grimaldi & Engel, 2005).

The Lebanese amber with its fossil insects is considered by most scientists as one of the most important deposits as it belongs to the Lower Cretaceous. For the first time, a large area with a significant amount of amber appears in the fossil record during the appearance and radiation of the flowering plants (angiosperms) -which is a major event in terrestrial evolution, as angiosperms constitute today more than ¾ths of the world flora. While the relationship between insects and plants is of considerable biological interest, it is important that, if we want to understand the origin of all recent ecosystems, we must go back to the subperiod of their starting point, which is in the Early Cretaceous. Moreover, this subperiod has not an important insect record, except Lebanese amber, which increases considerably the importance of this material. Insects can be found in Lebanese amber every 25 to 30 pieces in fossiliferous amber outcrops. To date, this amber contains no less than about 23 entomological (hexapod) orders, including Archaeognatha, Blattodea, Coleoptera, Collembola, Dermaptera, Dictyoptera (Blattodea, Isoptera, Mantodea), Diptera, Ephemeroptera, Hemiptera, Hymenoptera, Lepidoptera, Mecoptera, Neuroptera, Odonata, Orthoptera, Plecoptera, Psocodea, Strepsiptera, Thysanoptera, Thysanura, and Trichoptera.

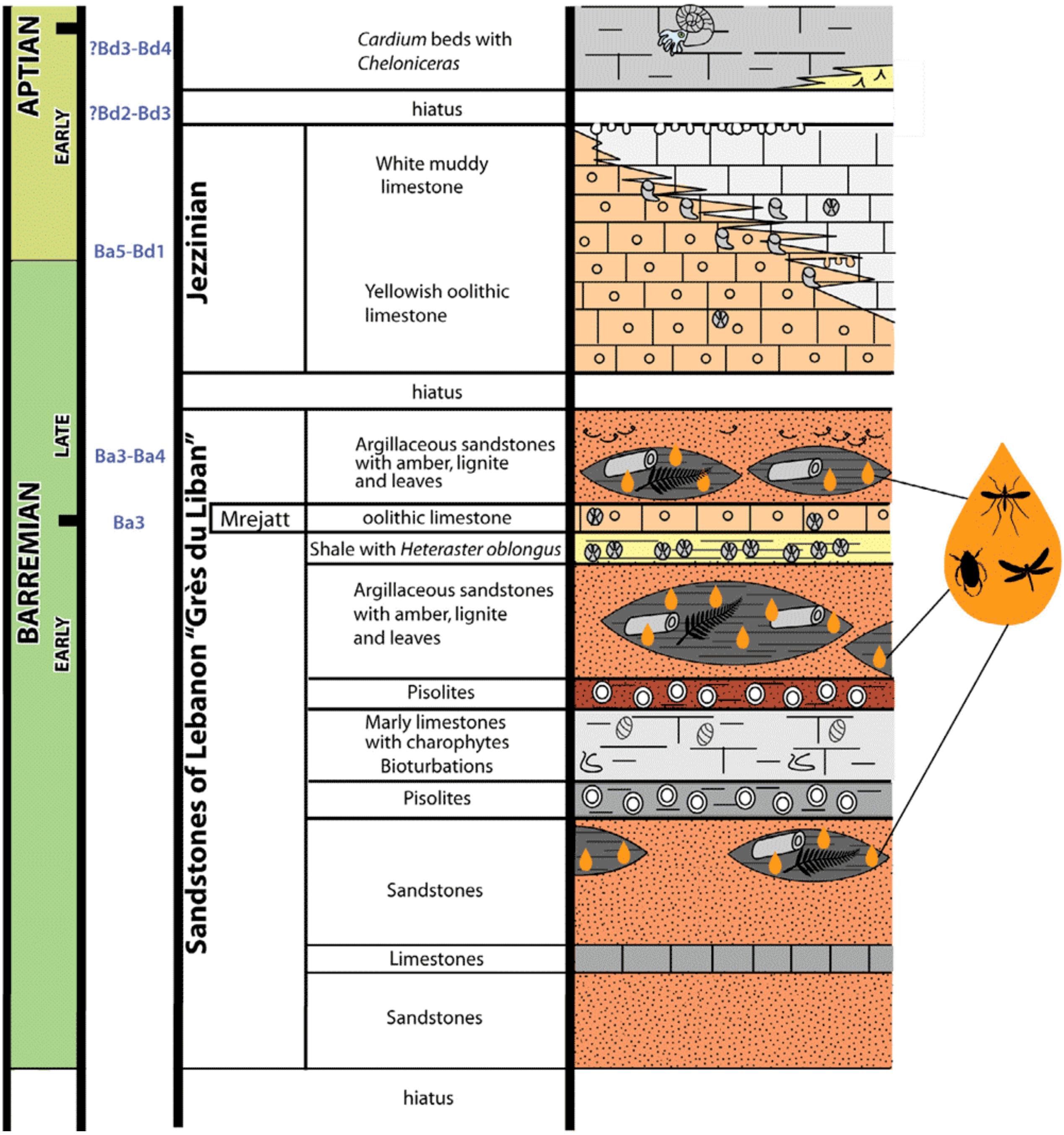


Figure 18: Simplified stratigraphic section showing the different intervals where the fossiliferous amber crops out in the Lower Cretaceous sandstone of Lebanon.

A single piece of amber can contain one or several inclusions. Some of those that are found alone may provide important indirect hints of the presence of other organisms or reflect a specific habitat or palaeogeograph extension. Regarding the specimens where several inclusions (or syninclusions) are found together, some of them are present only in a chance manner, but a number of associations correspond to ecological associations such as mating or parasitism, *etc.* Some insect inclusions can provide indirect evidences of specific habitats, or climate. The information provided by well-preserved inclusions corroborates the data from palynology: the palaeoenvironment of the resin deposits was a tropical dense, warm, and humid forest with a very complex fluvial system (lots of channels), altogether close to the sea. In addition, most of the fauna entombed in the Lebanese amber is the one living on the lower to mid parts of trees. This could be explained by the fact that this type of fauna has more chance to be trapped, since normally all the resin drops falling down from the tree pass inevitably and more frequently through these zones. The study of the different inclusions has allowed the reconstruction of the palaeoenvironment.

To date, 247 fossil insect species (mainly in amber) in 191 genera and 113 families have been described from Lebanon (see Appendix); others are still waiting identification. The discovery of outcrops yielding fossil insects preserved as compression/impression (adpressions) in sedimentary layers (silts, dysodiles, cinerites) of the same early Barremian age, augments our knowledge of the palaeobiodiversity in amber, as it is known that resin preserves insects in a selective way. Several factors affect the selectivity of the amber inclusions, like size, attraction/repulsion of the odour of the resin itself, proximity of resin producing trees to the habitat of the inclusion, and ecological behaviour of the insect.

The discovery of fossil insects in the Albian dysodiles/cinerites and in marine Cenomanian lithographic limestones of Hjoula and Nammoura adds knowledge of the previously unknown entomological biodiversity of the North-East of the Arabo-African palaeocontinent.

5. Conclusions

With its 35 Cretaceous outcrops yielding fossil insects, either in amber or as rock impressions-compressions (adpressions), Lebanon has contributed significantly to the advance of palaeoentomology and in our understanding of entomological evolution and palaeobiodiversity. Lebanon is among the countries with the highest densities of outcrops with insects. Amber is a material that has fascinated people so much and forever will not cease doing it. It constitutes a wonderful 'natural time capsule' as termed by Ross (1998, 2010), and an original material that not only preserves superb biological inclusions in their pristine three-dimensional detail, but also aspects of their ways of life and ecology. Preservation of life forms in amber increases significantly our knowledge of palaeobiodiversity, the palaeoecology of their inclusions, and diverse aspects of the palaeoenvironment, and gives the amber its attribute of exceptional 'window to the past' (Grimaldi, 2003a).

Lebanese amber contains a lot of extinct insect families (some of them are known only from Lebanon) and the records of the oldest representatives of many modern families of terrestrial arthropods. Lebanese inclusions constitute most of the time including "missing links" between the ancient Jurassic fauna and the modern one. The study of the Lebanese amber inclusions of insects is to date the only one that gives a clue to determining North-East Gondwanan biodiversity and environment in the extremely significant Early Cretaceous Subperiod. The recent discoveries of new and very diverse outcrops of fossiliferous amber in Lebanon help to meet the challenge of considerably enriching our knowledge of the Past. Efforts are under way to categorize this natural treasure from the Lower Cretaceous in the list of Heritage of Humanity. The different Lebanese outcrops are not yet officially protected against vandalism. Their destruction or pillaging would be a great loss to Human Heritage and to scientific knowledge.

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Plates

Plate 1: Fossil insects in amber. **A-** Diptera: Dolichopodidae: *Microphorites* sp., female, specimen number MCH-1B (Mechmech, Ain El-Khyar). **B-** Blattaria: Caloblattinidae: *Rhipidoblatta* ?, specimen number MCH-1D (Mechmech, Ain El-Khyar). **C-** Diptera: Dolichopodidae: female, *Microphorites* sp., male, specimen number MCH-1A (Mechmech, Ain El-Khyar). **D-** Hymenoptera: Platygastroidea: Scelionidae, specimen number MCH-1C (Mechmech, Ain El-Khyar). **E-** Hemiptera: Sternorrhyncha: Coccoidea: Monophlebidae, female, specimen number DAB-13 (Nimrin, El-Dabsheh). **F-** Neuroptera: Rhachiberothidae: *Raptorapax terribilissima*, specimen number NBS-1A (Brissa). **G-** Hymenoptera, specimen number BKK-1A (Beqaa Kafra). **H-** Hemiptera: Enicocephalidae: *Enicocephalinus acragrimaldi*, male, specimen number HDJ-1A (Hadath El Joubbeh). **I-** Diptera: Psychodoidea: *Xenopsychoda harbi*, female, holotype, specimen number T-1 (Tannourine). **J-** Diptera, Ceratopogonidae, female specimen number MKD-1 (Mazraat Kfardibiane). Scale bars in F = 1 mm, in all remaining figures = 0.5 mm.

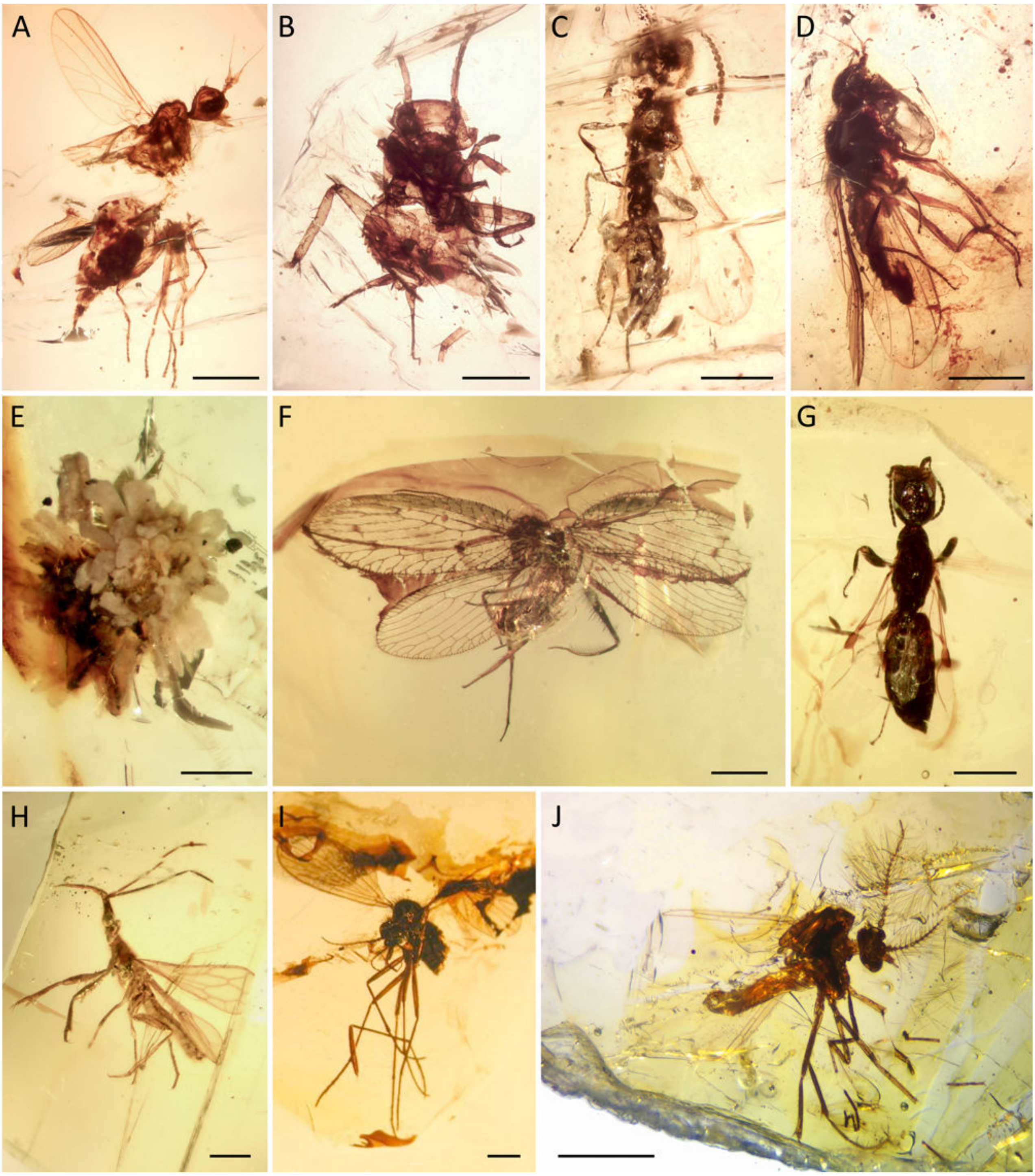
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Plate 2: Fossil insects in amber. **A-** Diptera: Ceratopogonidae, female, parasited by an Acari, specimen number OTJ-1BC (Ouata El-Jaouz). **B-** Ephemeroptera wing, specimen number OTJ-1A (Ouata El-Jaouz). **C-** Diptera: Chironomidae, male (Bqaatouta, El Shqif). **D-** Diptera: Ceratopogonidae, female (Bqaatouta, El Shqif). **E-** Diptera: Chironomidae, female (Bqaatouta, El Shqif). **F-** Hymenoptera (Baskinta, Qanat Bakish). **G-** Several inclusions including a Trichoptera, an Ephemeroptera, two Diptera: Ceratopogonidae, a Diptera (head): Brachycera (Baskinta, Qanat Bakish). **H-** Hemiptera: Progonocimicidae: *Ilahulgabalus endaidus*, male, holotype, specimen number DAY-1C (Daychouniyyeh). **I-** Hymenoptera, specimen number K (Kfar Selouan). **J-** Six Diptera: Brachycera, specimen number J- K23 A-M (Kfar Selouan). **K-** Diptera: Chironomidae: *Libanopelopia cretacica*, female (Kfar Selouan, Khallet Douaiq). **L-** Hemiptera: Sternorrhyncha: Coccoidea: Steingeliidae: *Palaeosteingelia* sp., male (Kfar Selouan, Khallet Douaiq). **M-** Thysanoptera: Tubulifera (Kfar Selouan, Khallet Douaiq). Scale bars in G-H = 1 mm, in all remaining figures = 0.5 mm.

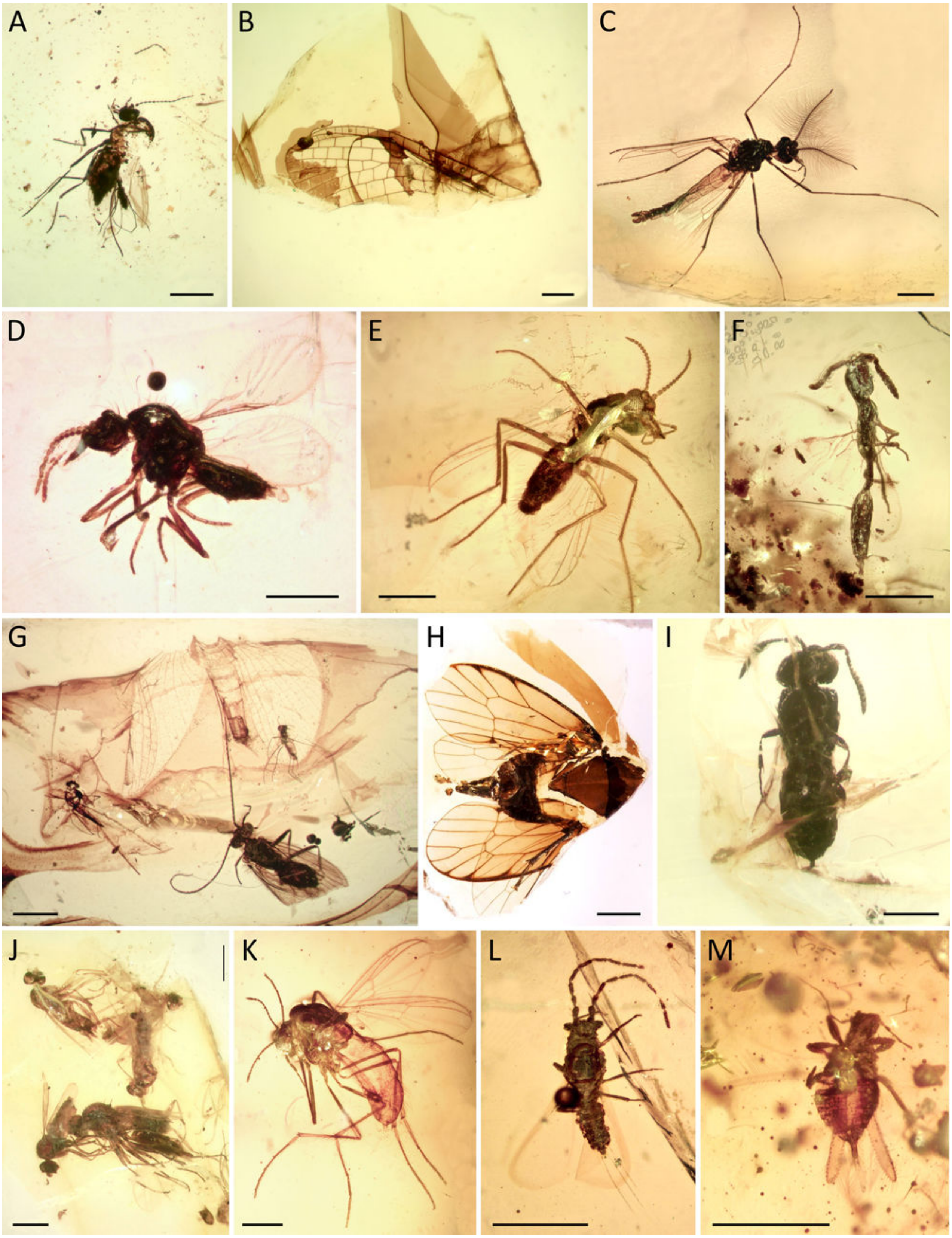
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Plate 3: Fossil insects in amber. **A-** Isoptera: *Lebanotermes veltzae*, holotype, specimen number 341C (Mdeyrij-Hammana). **B-** Hemiptera: Enicocephalidae: *Enicocephalinus acragrimaldi*, male, paratype, specimen number 14B (Mdeyrij-Hammana). **C-** Psocodea: Sphaeropsocidae: *Asphaeropsocites neli*, female, holotype, specimen number 1513 (Mdeyrij-Hammana). **D-** Dermaptera: *Rhadinolabis phoenicica*, female, holotype, specimen number 1013 (Mdeyrij-Hammana). **E-** Hymenoptera: Scolebythidae: *Uliobythus terpsichore*, holotype, specimen number 157A (Mdeyrij-Hammana). **F-** Psocodea: Pachytrocidae: *Libaneuphoris jantopi*, holotype, specimen number FAL-11A (Falougha). **G-** Diptera: Ceratopogonidae, female, trapped on a cobweb, specimen number AZH-1ABC (Ain Zhalta). **H-** Diptera: Psychodidae: *Protopsychoda leoi*, female, holotype, specimen number AD-65 (Ain Dara). **I-** Neuroptera: Chrysopoidea: *Tragichrysa ovoruptora*, neonate larvae and associated egg remains, specimen number S-7A-F (Sarhmoul). **J-** Diptera: Chironomidae: *Libanopelopia cretacica*, male, holotype, specimen number HAR-2 (Roum - Aazour - Homsiyeh). **K-** Diptera: Tanyderidae: *Nannotanyderus ansorgei*, male, holotype, specimen number JG. 385/2B (Bkassine, Jouar Es-Souss). **L-** Blattaria, larva (Wadi Jezzine). **M-** Hymenoptera: Maimetshidae: *Ahiromaimetsha najlae*, female, holotype, specimen number MKN-1A (Maknouniyeh). **N-** Diptera: Psychodidae, male, specimen number RIH-1C (Maknouniyeh). **O-** Diptera: Psychodidae: *Palopsychoda jacquelinea*, male, specimen number C-5C (Esh-Sheaybeh). **P-** Diptera: Nematocera, male, specimen number TAR-1B (Bouarij). Scale bars in A and M = 2 mm, in all remaining figures = 0.5 mm.

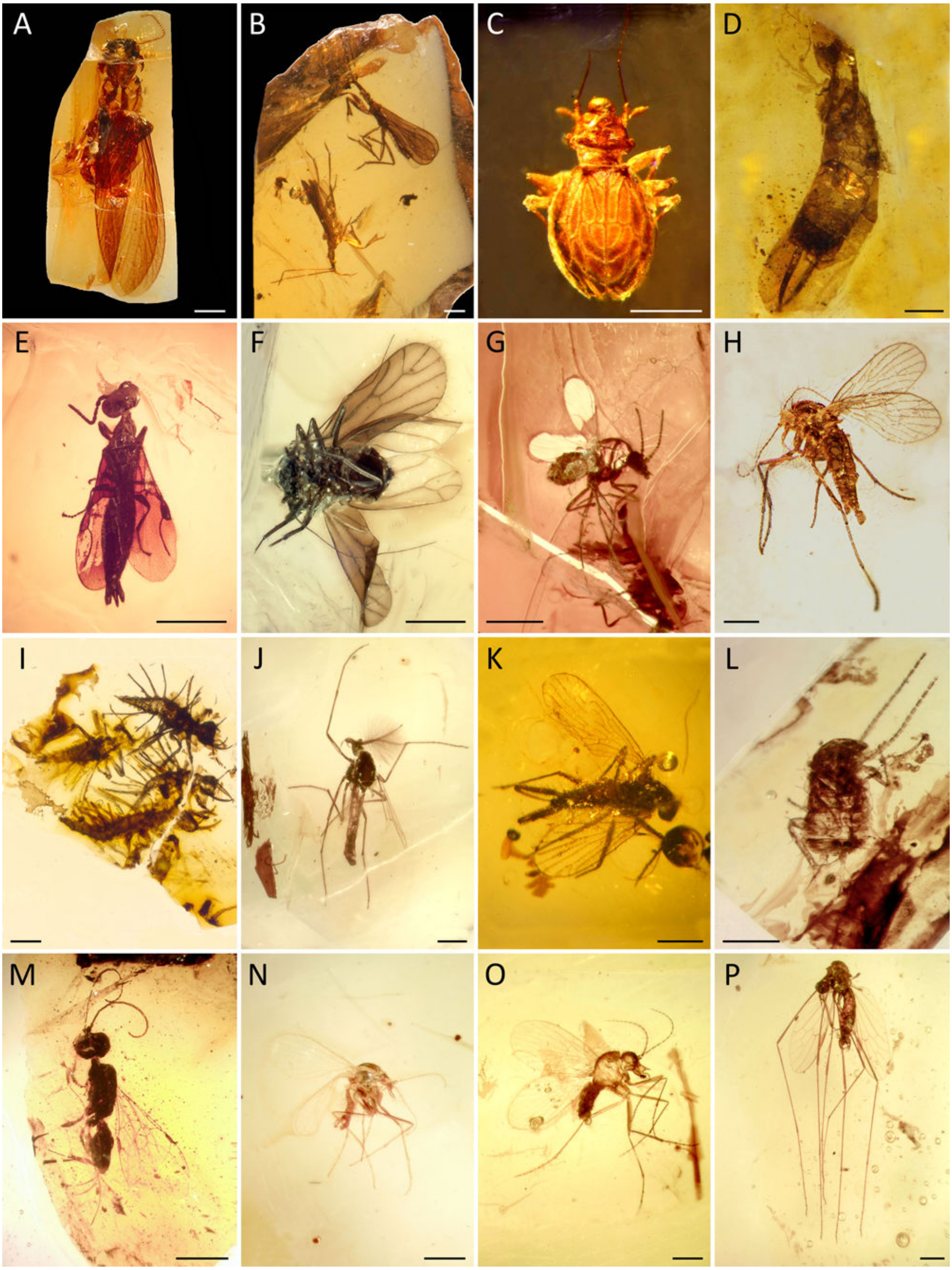
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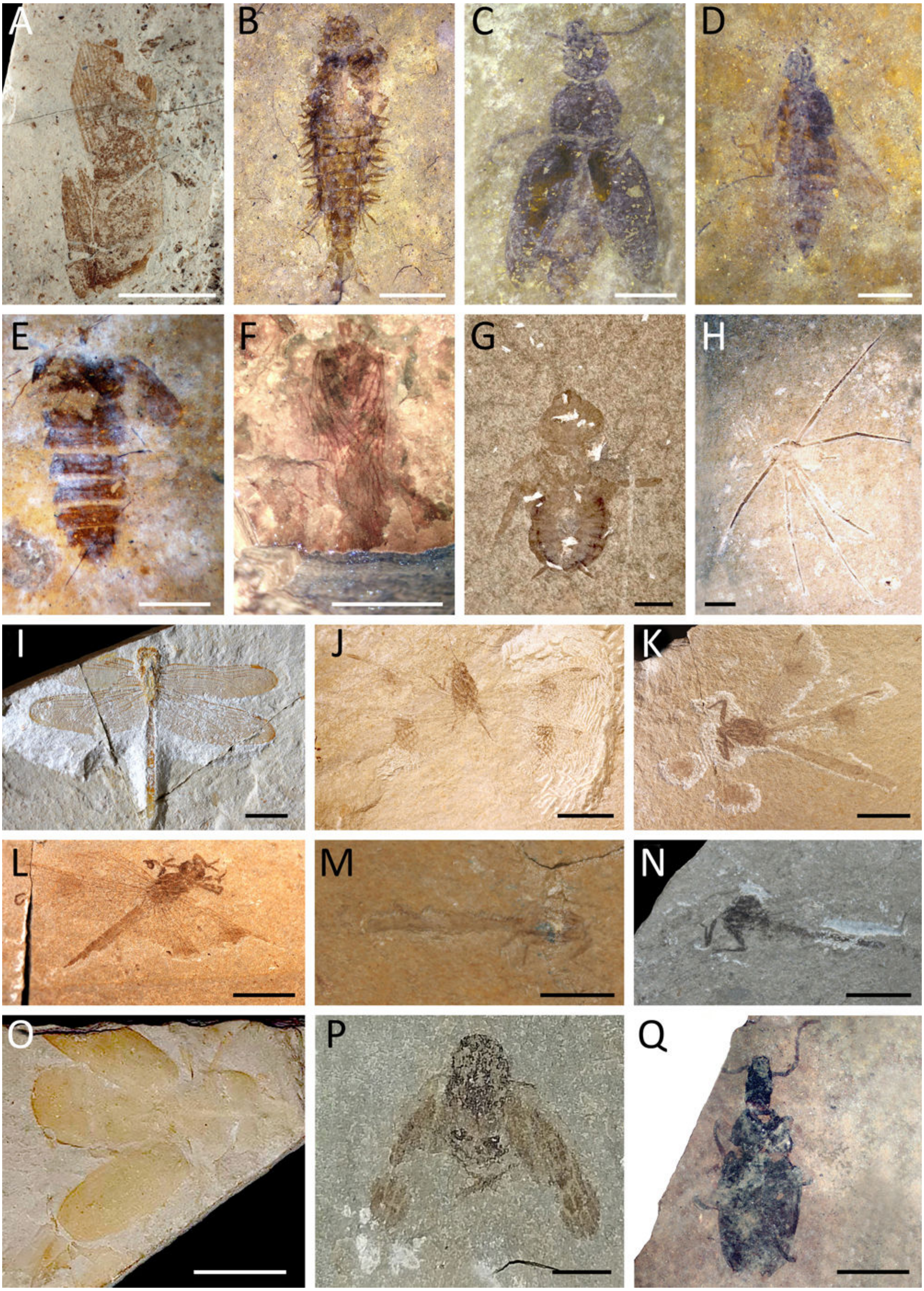
Plate 4: Fossil insects preserved as compressions/impressions from Lebanon. **A-** Blattaria wing, *Mesoblattina libanensis*, holotype, specimen number INS-26367/1 (Qahmez). **B-** Ephemeroptera: *Libanoephemera inopinatabranchia*, holotype, specimen number INS-63124/1 (Jdeidet Bkassine). **C-** Coleoptera: specimen number INS-63124/5 (Jdeidet Bkassine). **D-** Diptera, specimen number INS-63124/4 (Jdeidet Bkassine). **E-** Coleoptera: Staphylinoidea, specimen number INS-63124/3 (Jdeidet Bkassine). **F-** Mantodea (Qnat). **G-** Blattaria: Mesoblattinidae: *Mieroblattina pacis*, female, holotype, specimen number NI-5B (Nammoura). **H-** Orthoptera: Chresmodidae: *Chresmoda libanica*, female, holotype, specimen number NI-3A (Nammoura). **I-** Odonata: Anisoptera: Liupanshaniidae: *Libanoliupanshania mimi*, holotype, specimen number F63 (Hjoula). **J-** Odonata: Anisoptera: Libanocorduliidae: *Libanocordulia debiei*, holotype, specimen number F64 (Hjoula). **K-** Odonata: Anisoptera: Libanocorduliidae: *Libanocordulia debiei*, paratype, specimen number F65 (Hjoula). **L-** Odonata: Anisoptera: Libanocorduliidae: *Libanocordulia debiei* (Hjoula). **M-N-** Odonata (Hjoula). **O-** Coleoptera: Scarabaeoidea (Hjoula). **P-** Hemiptera: Cicadellidae (Hjoula). **Q-** Coleoptera (Sniyya). Scale bars = 5 mm in A, F-H and Q, 3 mm in B-C and P, 1 mm in D-E, 1 cm in I-N, 2 cm in O.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Appendix

List of fossil insects from Lebanon. Fossil insects preserved as impression-compression in rocks are preceded by an asterisk in the table below; all remaining taxa are preserved in amber.

Class	Order	Family	Taxa	Site name
Insecta	Archaeognatha	Meinertellidae	*Cretaceomachilis libanensis* STURM & POINAR, 1998	Jouar Es-Souss
			Glaesimeinertellus intermedius SÁNCHEZ-GARCÍA *et al.*, 2019	Mdeyrij-Hammana
			Macropsontus azari SÁNCHEZ-GARCÍA *et al.*, 2019	Rihane
			Macropsontus bachae SÁNCHEZ-GARCÍA *et al.*, 2019	Mdeyrij-Hammana
	Blattodea	Liberiblattinidae	*Cryptoblatta aquatica* SENDI & D. AZAR in VRŠANSKÝ *et al.*, 2019	Mdeyrij-Hammana
			Pseudomantina occisor SENDI in VRŠANSKÝ *et al.*, 2021	Mdeyrij-Hammana
		Blattellidae	*Ocelloblattula ponomarenkoi* ANISYUTIN & GOROCHOV, 2008	Mdeyrij-Hammana
			* *?Ocelloblattula striatus* KÁČEROVÁ & D. AZAR, *in press*	Jdeidet Bkassine
		Blattidae	*Anenev asrev* VRŠANSKÝ *et al.*, 2019	Bloudane
			Balatronis libanensis SENDI & D. AZAR, 2017	Ain Dara
		Mesoblattinidae	* *Mieroblattina pacis* VRŠANSKÝ & MAKHOUL, 2013	Nammoura
			* *Mesoblattina libanensis* KÁČEROVÁ & D. AZAR, *in press*	Qahmez
			Nymphoblatta azari VRŠANSKÝ & GRIMALDI, 2004	Bcharreh Mountains
		Umenocoleidae	*Cratovitisma cortexi* SENDI *in* PODSTRELENÁ & SENDI, 2018	Mdeyrij-Hammana
			Pseudojantaropterix lebani (VRŠANSKÝ & GRIMALDI, 2003)	Jouar Es-Souss
	Coleoptera	Anthicidae	*Camelomorphasa longicervix* KIREJTSHUK & D. AZAR, 2008	Mdeyrij-Hammana
		Cerophytidae	*Lebanophytum excellens* KIREJTSHUK & D. AZAR, 2008	Mdeyrij-Hammana
		Chelonariidae	*Eochelonarium belle* KIREJTSHUK & D. AZAR, 2013	Kfar Selouane
		Clambidae	*Eoclambus rugidorsum* KIREJTSHUK & D. AZAR, 2008	Mdeyrij-Hammana
		Curculionidae	*Cylindrobrotus pectinatus* KIREJTSHUK *et al.*, 2009	Mdeyrij-Hammana
		Dermestidae	*Cretonodes antounazari* KIREJTSHUK & D. AZAR, 2009	Mdeyrij-Hammana
		Elodophthalmidae	*Elodophthalmus gracilis* KIREJTSHUK & D. AZAR, 2008	Mdeyrij-Hammana
			Elodophthalmus harmonicus KIREJTSHUK & D. AZAR, 2008	Mdeyrij-Hammana
		Hybosoridae	*Libanochrus calvus* KIREJTSHUK *et al.*, 2011	Bouarij
		Kateretidae	*Lebanoretes andelmani* KIREJTSHUK & D. AZAR, 2008	Mdeyrij-Hammana
		Latridiidae	*Archelatrius marinae* KIREJTSHUK & D. AZAR, 2009	Mdeyrij-Hammana
			Atetrameropsis subglobosa KIREJTSHUK, 2013	Mdeyrij-Hammana
			Tetrameropsis mesozoica KIREJTSHUK & D. AZAR, 2008	Mdeyrij-Hammana
		Lebanophytidae	*Lebanophytum excellens* KIREJTSHUK & D. AZAR, 2008	Mdeyrij-Hammana
		Micromalthidae	*Cretomalthus acracrowsonorum* KIREJTSHUK & D. AZAR, 2008	Jouar Es-Souss
		Monotomidae	*Rhizophtoma elateroides* KIREJTSHUK & D. AZAR, 2009	Mdeyrij-Hammana
			Rhizophtoma synchrotronica KIREJTSHUK & D. AZAR, 2013	Mdeyrij-Hammana
			Rhizobactron marinae KIREJTSHUK & D. AZAR, 2013	Nabaa Es-Sukkar
		Nemonychidae	*Libanorhinus succinus* KUSCHEL & POINAR, 1993	Jouar Es-Souss
			Oropsis marinae LEGALOV & KIREJTSHUK, 2017	Bouarij
		Ptismidae	*Ptisma zasukhae* KIREJTSHUK & D. AZAR, 2016a, 2016b	Nabaa Es-Sukkar
		Throcidae	*Potergosoma gratiosa* KOVALEV & KIREJTSHUK, 2013	Mdeyrij-Hammana
			Rhomboaspis laticollis KOVALEV & KIREJTSHUK, 2013	Bouarij
		Sphindidae	*Libanopsis impexa* KIREJTSHUK, 2015	Mdeyrij-Hammana

		Libanopsis limosa Kirejtshuk, 2015	Jouar Es-Souss
		Libanopsis poinari Kirejtshuk, 2015	Mdeyrij-Hammana
		Libanopsis slipinskii Kirejtshuk, 2015	Nabaa Es-Sukkar
		Libanopsis straminea Kirejtshuk, 2015	Bouarij
	Staphylinidae	*Libanoeuaesthetus pentatarsus* Lefèbvre *et al.*, 2005	Mdeyrij-Hammana
Dermaptera	*incertae sedis*	*Rhadinolabis phoenicica* Engel *et al.*, 2011	Mdeyrij-Hammana
Diptera	*incertae sedis*	*Xenopsychoda harbi* D. Azar & Ziadé, 2005	Tannourine
	Archizelmeridae	*Zelmiarcha lebanensis* Grimaldi *et al.*, 2003	Mdeyrij-Hammana
	Chaoboridae	*Libanoborus lukashevici* D. Azar *et al.*, 2009	Mdeyrij-Hammana
	Chimeromyiidae	*Chimeromyia acuta* Grimaldi & Cumming, 1999	Bcharreh Mountains
		Chimeromyia intriguea Grimaldi & Cumming, 1999	Bcharreh Mountains
		Chimeromyia mediobscura Grimaldi & Cumming, 2009	Mdeyrij-Hammana
		Chimeromyia pilitibia Grimaldi & Cumming, 2009	Mdeyrij-Hammana
		Chimeromyia reducta Grimaldi & Cumming, 1999	Jouar Es-Souss
	Chironomidae	*Cretadiamesa arieli* Veltz *et al.*, 2007	Mdeyrij-Hammana
		Cretaenne kobeyssii D. Azar *et al.*, 2008	Mdeyrij-Hammana
		Cretaenne inexpectata D. Azar *et al.*, 2008	Mdeyrij-Hammana
		Cretapelopia salomea Veltz *et al.*, 2007	Mdeyrij-Hammana
		Lebanodiamesa deploegi Veltz *et al.*, 2007	Mdeyrij-Hammana
		Lebanorthocladius furcatus Veltz *et al.*, 2007	Mdeyrij-Hammana
		Libanochlites neocomicus Brundin, 1976	Jouar Es-Souss
		Libanopelopia cretacica Veltz *et al.*, 2007	Roum-Aazour-Homsiyeh
		Haematotanypus libanicus D. Azar *et al.*, 2008	Jouar Es-Souss
		Paicheleria magnifica D. Azar & A. Nel, 2010b	Mdeyrij-Hammana
		Wadelius libanicus Veltz *et al.*, 2007	Mdeyrij-Hammana
		Ziadeus kamili D. Azar & A. Nel, 2010b	Mdeyrij-Hammana
	Ceccidomyiidae	*Cretadicerura salimi* D. Azar & A. Nel, 2020	Bouarij
		Libanoclinorrhytis jaschhofi D. Azar & A. Nel, 2020	Mdeyrij-Hammana
		Libanohilversidia doryi D. Azar & A. Nel, 2020	Tannourine
		Libanowinnertzia perrichoti D. Azar & A. Nel, 2020	Mdeyrij-Hammana
	Ceratopogonidae	*Archiaustroconops annae* Choufani *et al.*, 2014	Mdeyrij-Hammana
		Archiaustroconops bocaparvus Borkent, 2000	Jouar Es-Souss
		Archiaustroconops ceratoformis Szadziewski, 1996	Jouar Es-Souss
		Archiaustroconops cretaceous (Szadziewski, 1996)	Jouar Es-Souss
		Archiaustroconops dominiakae Choufani *et al.*, 2014	Mdeyrij-Hammana
		Archiaustroconops hammanaensis Choufani *et al.*, 2014	Mdeyrij-Hammana
		Archiaustroconops hamus Borkent, 2000	Jouar Es-Souss
		Archiaustroconops szadziewskii Borkent, 2000	Bcharreh Mountains
		Austroconops fossilis Szadziewski, 1996	Jouar Es-Souss
		Austroconops gladius Borkent, 2000	Jouar Es-Souss
		Austroconops gondwanicus Szadziewski, 1996	Jouar Es-Souss
		Austroconops megaspinus Borkent, 2000	Jouar Es-Souss
		Fossileptoconops lebanicus Szadziewski, 1996	Jouar Es-Souss
		Lebanoculicoides bloudani Choufani *et al.*, 2015	Bloudan
		Lebanoculicoides daheri Choufani *et al.*, 2014	Mdeyrij-Hammana

	Lebanoculicoides mesozoicus Szadziewski, 1996	Jouar Es-Souss
	Leptoconops amplificatus Borkent, 2001	Bcharreh Mountains
	Leptoconops antiquus Borkent, 2001	Bcharreh Mountains
	Minyohelea bacula Borkent, 2000	Jouar Es-Souss
	Minyohelea falcate Borkent, 2000	Bcharreh Mountains
	Minyohelea lebanica (Szadziewski, 1996)	Jouar Es-Souss
	Minyohelea minuta (Szadziewski, 1996)	Jouar Es-Souss
	Minyohelea nexuosa Pielowska-Ceranowska *et al.*, 2022	Mdeyrij-Hammana
	Minyohelea schleei Szadziewski, 1996	Jouar Es-Souss
	Minyohelea wirthi (Szadziewski, 1996)	Jouar Es-Souss
	Protoculicoides acraorum Borkent, 2000	Jouar Es-Souss
	Protoculicoides krzeminskii Choufani *et al.*, 2014	Mdeyrij-Hammana
	Protoculicoides punctus Borkent, 2000	Bcharreh Mountains
	Protoculicoides schleei (Szadziewski, 1996)	Jouar Es-Souss
	Protoculicoides succineus Szadziewski, 1996	Jouar Es-Souss
	Protoculicoides unus Borkent, 2000	Jouar Es-Souss
Corethrellidae	*Corethrella cretacea* Szadziewski, 1995	Jouar Es-Souss
Dolichopodidae	*Microphorites extinctus* Hennig, 1971	Jouar Es-Souss
	Microphorites oculeus Grimaldi & Cumming, 1999	Jouar Es-Souss
	Microphorites similis Grimaldi & Cumming, 1999	Jouar Es-Souss
	Sympycnites primaevus Grimaldi & Cumming, 1999	Bcharreh Mountains
Empididae	*Atelestites senectus* Grimaldi & Cumming, 1999	Bcharreh Mountains
	Avenaphora hispida Grimaldi & Cumming, 1999	Bcharreh Mountains
	Phaetempis lebanensis Grimaldi & Cumming, 1999	Bcharreh Mountains
	Trichinites cretaceous Hennig, 1970	Jouar Es-Souss
Hilarimorphidae	*Cretahilarimorpha lebanensis* Myskowiak *et al.*, 2016	Mdeyrij-Hammana
Ironomyiidae	*Lebambromyia acrai* Grimaldi & Cumming, 1999	Jouar Es-Souss
Limoniidae	*Lebania levantia* Podenas & Poinar, 2001	Jouar Es-Souss
	Lebania longaeva Podenas & Poinar, 2001	Jouar Es-Souss
	Helius lebanensis Kania *et al.*, 2013	Bouarij
	Helius ewa Krzemiński *et al.*, 2014	Mdeyrij-Hammana
Lonchopteroidea *incertae sedis* family	*Alonchoptera lebanica* Grimaldi, 2018	Bcharreh Mountains
Lonchopteridae	*Lonchopterites prisca* Grimaldi & Cumming, 1999	Bcharreh Mountains
	Lonchopteromorpha asetocella Grimaldi & Cumming, 1999	Bcharreh Mountains
Lygistorrhinidae	*Lebanognoriste prima* Blagoderov & Grimaldi, 2004	Jouar Es-Souss
Platypezidae	*Lebanopeza azari* Grimaldi, 2018	Mdeyrij-Hammana
Psychodidae	*Cretapsychoda inexpectata* D. Azar *et al.*, 1999	Mdeyrij-Hammana
	Eophlebotomus gezei D. Azar *et al.*, 2003	Mdeyrij-Hammana
	Libanophlebotomites ramyii D. Azar *et al.*, 2022a	Qanat Bakish (Baskinta)
	Libanophlebotomus lutfallahi D. Azar *et al.*, 1999	Mdeyrij-Hammana
	Libanopsychoda abillamai D. Azar *et al.*, 1999	Mdeyrij-Hammana
	Libanosycorax dimyi D. Azar *et al.*, 2018	Mdeyrij-Hammana
	Mesophlebotomites hennigi D. Azar *et al.*, 1999	Mdeyrij-Hammana
	Paleopsychoda inexpectata D. Azar & A. Nel, 2002	Mdeyrij-Hammana
	Paleopsychoda jacquelinae D. Azar *et al.*, 1999	Mdeyrij-Hammana

		Paleopsychoda jarzembowskii D. Azar & Maksoud, 2022	Mdeyrij-Hammana
		Paleopsychoda solignaci D. Azar *et al.*, 1999	Mdeyrij-Hammana
		Paralibanopsychoda agnieszkae D. Azar & A. Nel, 2002	Mdeyrij-Hammana
		Phlebotomites brevifilis Hennig, 1972	Jouar Es-Souss
		Phlebotomites longifilis Hennig, 1972	Jouar Es-Souss
		Protopsychoda hammanaensis D. Azar *et al.*, 1999	Mdeyrij-Hammana
		Protopsychoda leoi D. Azar & Maksoud, 2020	Ain Dara
		Protopsychoda nadiae D. Azar *et al.*, 1999	Mdeyrij-Hammana
	Ptychopteridae	*Leptychoptera dimkina* Lukashevich & D. Azar, 2003	Mdeyrij-Hammana
		Leptychoptera vovkina Lukashevich & D. Azar, 2003	Bcharreh Mountains
	Rhagionidae	*Lebanoleptis huangi* Angelini *et al.*, 2016	Bouarij
		Mesobolbomyia acari Grimaldi & Cumming, 1999	Jouar Es-Souss
		Paleochrysopilus hirsutus Grimaldi & Cumming, 1999	Bcharreh Mountains
	Sciadoceridae	*Archisciada lebanensis* Grimaldi & Cumming, 1999	Bcharreh Mountains
	Tanyderidae	*Nannotanyderus ansorgi* Krzemiński *et al.*, 2013	Jouar Es-Souss
	Trichoceridae	*Ewaurista pusilla* Shcherbakov & D. Azar, 2019	Mdeyrij-Hammana
	Xylomyidae	*Cretoxyla azari* Grimaldi & Cumming, 2011	Mdeyrij-Hammana
Ephemero-ptera	*incertae sedis*	* *Libanoephemera inopinatabranchia* D. Azar *et al.*, 2019a	Jdeidet Bkassine
	Leptophlebiidae	*Conovirilus poinari* McCafferti, 1997	Jouar Es-Souss
Hemiptera	*incertae sedis*	*Xiphos vani* Vea & Grimaldi, 2015	Mdeyrij-Hammana
	Aleyrodidae	*Aretsaya therina* Drohojowska & Szwedo, 2015	Ain Dara
		Baetylus kahramanus Drohojowska & Szwedo, 2011	Mdeyrij-Hammana
		Bernaea neocomica Schlee, 1970	Jouar Es-Souss
		Gapenus rhinariatus Drohojowska & Szwedo, 2013	Rihane
		Heidea cretacica Schlee, 1970	Jouar Es-Souss
		Milqartis azari Drohojowska & Szwedo, 2015	Mdeyrij-Hammana
		Shapashe aithiopa Drohojowska & Szwedo, 2015	Mdeyrij-Hammana
		Yamis libanotos Drohojowska & Szwedo, 2015	Mdeyrij-Hammana
	Cixiidae	*Karebodopoides aptianus* (Fennah, 1987)	Jouar Es-Souss
	Apticoccidae	*Apticoccus minutus* Koteja & D. Azar, 2008	Mdeyrij-Hammana
		Apticoccus fortis Vea & Grimaldi, 2015	Mdeyrij-Hammana
		Apticoccus longitenuis Vea & Grimaldi, 2015	Ain Dara
	Enicocephalidae	*Enicocephalinus acragrimaldii* D. Azar *et al.*, 1999	Mdeyrij-Hammana
	Hammanococcidae	*Hammanococcus setosus* Koteja & D. Azar, 2008	Mdeyrij-Hammana
	Hodgsonicoccidae	*Hodsonicoccus patefactus* Vea & Grimaldi, 2015	Bcharreh Mountains
	Lebanococcidae	*Lebanococcus longiventris* Koteja & D. Azar, 2008	Mdeyrij-Hammana
	Liadopsyllidae	*Liadopsylla apedetica* Ouvrard *et al.*, 2010	Mdeyrij-Hammana
	Neazoniidae	*Neazonia immature* Szwedo, 2007	Mdeyrij-Hammana
		Neazonia imprinta Szwedo, 2007	Jouar Es-Souss
		Neazonia tripleta Szwedo, 2007	Mdeyrij-Hammana
	Ortheziidae	*Cretorhezia hammanaica* Koteja & D. Azar, 2008	Mdeyrij-Hammana
	Perforissidae	*Aafrita biladalshama* Szwedo & D. Azar, 2013	Mdeyrij-Hammana
	Progonocimicidae	*Ilahulgabalus endaidus* Szwedo *et al.*, 2011	El-Dayshouniyyeh
	Protopsyllidae	*Talaya batraba* Drohojowska *et al.*, 2013	Mdeyrij-Hammana
	Pseudococcidae	*Williamsicoccus megalops* Vea & Grimaldi, 2015	Mdeyrij-Hammana

	Putoidae	*Palaeotupo danieleae* Koteja & D. Azar, 2008	Mdeyrij-Hammana
	Pennygullaniidae	*Pennygullania electrina* Koteja & D. Azar, 2008	Mdeyrij-Hammana
	Schizopteridae	*Libanohypselosoma popovi* D. Azar & A. Nel, 2010a	Mdeyrij-Hammana
	Steingeliidae	*Palaeosteingelia acrai* Koteja & D. Azar, 2008	Mdeyrij-Hammana
		Palaeosteingelia caudate Koteja & D. Azar, 2008	Mdeyrij-Hammana
	Tajmyraphididae	*Lebanaphis minor* Heie, 2000	Mdeyrij-Hammana
		Megarostrum azari Heie, 2000	Mdeyrij-Hammana
	Thelaxidae	*Gondvanoaphis estephani* Węgierek & Grimaldi, 2010	Bcharreh Mountains
	Yuripopovinidae	*Yuripopovina magnifica* D. Azar *et al.*, 2011b	Bouarij
Hymenoptera	Archaeoserphitidae	*Archaeoserphites melqarti* Engel, 2015	Bcharreh Mountains
	Bethylidae	*Lancepyris opertus* Azevedo & D. Azar, 2012	Mdeyrij-Hammana
	Dryinidae	*Archaeodryinus palaeophoenicius* (Olmi, 2000)	Jouar Es-Souss
	Evaniidae	*Eovernevania cyrtocerca* Deans, 2004	Mdeyrij-Hammana
		Lebanevania azari Basibuyuk & Rasnitsyn, 2002	Jouar Es-Souss
		Protoparevania lourothi Deans, 2004	Mdeyrij-Hammana
	Gallorommatidae	*Cretaceomma libanensis* Rasnitsyn & D. Azar *in* Rasnitsyn *et al.*, 2022	Mdeyrij-Hammana
	Maimetshidae	*Ahiromaimetsha najlae* Perrichot *et al.*, 2011	Maknouniyyeh
	Scelionidae	*Cretaxenomerus jankotejai* A. Nel & D. Azar, 2005	Mdeyrij-Hammana
		Proteroscelio gravatus Johnson *et al.*, 2008	Mdeyrij-Hammana
	Sclerogibbidae	*Sclerogibbodes embioleia* Engel & Grimaldi, 2006	Bcharreh Mountains
	Scolebythidae	*Libanobythus milkii* Prentice & Poinar *in* Prentice *et al.*, 1996	Jouar Es-Souss
		Uliobythus terpsichore Engel & Grimaldi, 2007	Mdeyrij-Hammana
		Zapenesia libanica Engel & Grimaldi, 2007	Mdeyrij-Hammana
	Serphitidae	*Leptoserphites iriae* Rasnitsyn & D. Azar *in* Rasnitsyn *et al.*, 2022	Qanat Bakish
		Leptoserphites pabloi Rasnitsyn & D. Azar *in* Rasnitsyn *et al.*, 2022	Qanat Bakish
		Microserphites libanensis Rasnitsyn & D. Azar *in* Rasnitsyn *et al.*, 2022	Mdeyrij-Hammana
	Spathiopteridae	*Mymaropsis baabdaensis* Krogmann *et al.*, 2016	Mdeyrij-Hammana
	Stigmaphronidae	*Libanophron astarte* Engel & Grimaldi, 2009	Mdeyrij-Hammana
Isoptera	*incertae sedis*	*Lebanotermes veltzae* Engel *et al.*, 2011a	Mdeyrij-Hammana
	Hodotermitidae	*Melquartitermes myrrheus* Engel *et al.*, 2007	Bcharreh Mountains
Lepidoptera	Micropterigidae	*Parasabatinca aftimacrai* Whalley, 1978	Jouar Es-Souss
Manthodea	Gryllomantidae	*Gryllomantis lebanensis* (Grimaldi, 2003b)	Bcharreh Mountains
Neuroptera	*incertae sedis* Chrysopidea	*Tragichrysa ovoruptora* Pérez de la Fuente *et al.*, 2018a	Sarhmoul
		Tyruschrysa melqart Pérez de la Fuente *et al.*, 2018b	Bouarij
	Berothidae	*Banoberotha enigmatica* Whalley, 1980	Jouar Es-Souss
		Sibelliberotha rihanensis D. Azar & A. Nel, 2013	Rihane
	Coniopterygidae	*Libanoconis fadiacra* (Whalley, 1980)	Jouar Es-Souss
		Libanosemidalis hammanaensis D. Azar *et al.*, 2000	Mdeyrij-Hammana
	Rhachiberothidae	*Chimerhachiberotha acrasarii* A. Nel *et al.*, 2005	Jouar Es-Souss
		Paraberotha acra Whalley, 1980	Jouar Es-Souss
		Raptorapax terribilissima Petrolevičius *et al.*, 2010	Bouarij
		Spinoberotha mickaelacrai A. Nel *et al.*, 2005	Mdeyrij-Hammana
	Saucrosmylidae	* *Lebanosmylus leae* D. Azar & A. Nel, 2022	Hjoula
Odonata	*incertae sedis*	*Libanolestes flecki* D. Azar *et al.*, 2010c	Ain Dara

	Libanocorduliidae	* *Libanocordulia debiei* D. AZAR *et al.*, 2019b	Hjoula
	Liupanshaniidae	* *Libanoliupanshania mimi* D. AZAR *et al.*, 2019b	Hjoula
Orthoptera	Chresmodidae	* *Chresmoda libanica* A. NEL *et al.*, 2004	Nammoura
	Haglotettigoniidae	*?Halotettigonia aenigmatosa* GOROKHOV, 2010	Mdeyrij-Hammana
	Rhaphidophoridae	*Aenigmaraphidophora mouniri* D. AZAR *et al.*, 2022b	Bqaatouta
Psocodea	? Amphientomidae	*Libanomphientomum nudus* CHOUFANI *et al.*, 2011	Mdeyrij-Hammana
	Paramesopsocidae	*Paramesopsocus lu* D. AZAR *et al.*, 2008	Mdeyrij-Hammana
	Prionoglarididae / Archaeatropidae	*Bcharrehglaris amunobi* D. AZAR & A. NEL, 2004	Bcharreh Mountains
		Libanoglaris chehabi D. AZAR & A. NEL, 2004	Mdeyrij-Hammana
		Libanoglaris mouawadi D. AZAR *et al.*, 2003	Mdeyrij-Hammana
		Libanoglaris randatae D. AZAR & A. NEL, 2004	Jouar Es-Souss
		Setoglaris reemae D. AZAR & A. NEL, 2004	Mdeyrij-Hammana
	Prionoglarididae	*Palaeosiamoglaris hammanaensis* HAKIM *et al.*, 2022	Mdeyrij-Hammana
	Pachytrocidae	*Libaneuphoris jantopi* D. AZAR *et al.*, 2015	Falougha
	Psyllipsocidae	*Libanopsyllipsocus alexanderasnitsyni* D. AZAR & A. NEL, 2011	Mdeyrij-Hammana
	Sphaeropsocidae	*Sphaeropsocites lebanensis* GRIMALDI & ENGEL, 2006	Jouar Es-Souss
		Asphaeropsocites neli D. AZAR *et al.*, 2010a	Mdeyrij-Hammana
Raphidioptera	Mesoraphidiidae	*Lebanoraphidia nana* BECHLY & WOLF-SCHWENNINGER, 2011	Jouar Es-Souss
Thysanoptera	Adiheterothripidae	*Neocomothrips hennigianus* STRASSEN, 1973	Jouar Es-Souss
		Progonothrips horridus STRASSEN, 1973	Jouar Es-Souss
		Rhetinothrips elegans STRASSEN, 1973	Jouar Es-Souss
		Scaphothrips antennatus STRASSEN, 1973	Jouar Es-Souss
		Exitelothrips mesozoicus STRASSEN, 1973	Jouar Es-Souss
		Jezzinothrips cretacicus STRASSEN, 1973	Jouar Es-Souss
	Moundithripidae	*Moundthrips beatificus* P. NEL *et al.*, 2007	Jouar Es-Souss
	Phlaeothripidae	*Rohrthrips libanicus* P. NEL *et al.*, 2010	Mdeyrij-Hammana
	Thripidae	*Tethysthrips libanicus* P. NEL *et al.*, 2010	Mdeyrij-Hammana
Trichoptera	Dipseudopsidae	*Phylocentropus succinolibanensis* WICHARD & D. AZAR, 2018	Mdeyrij-Hammana
	Ecnomidae	*Ecnomus cretacia* WICHARD & D. AZAR, 2018	Mdeyrij-Hammana