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Amber, from deposit to inclusions: new data

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In memory to Gérard Breton

We wish to dedicate this special issue devoted to amber to the memory of our recently deceased colleague Gérard Breton. Associate professor in Natural Sciences, doctor of state "ès-science", Gérard Breton first taught in secondary schools and then served for 32 years as director of the Museum of Natural History of Le Havre (1973–2005). As a true naturalist animated by a constant scientific curiosity, Gérard Breton, tackled many study themes in the field of paleontology. More particularly, its contribution to the knowledge of micro-inclusions of amber for over the past twenty years has been constant and rich in information and concepts. Following a few authors who have described and figured microorganisms contained in amber (*e.g.* Poinar, 1977, 1992; 1994; Waggoner, 1993, 1994; Poinar *et al.*, 1993a, 1993b; Dörfelt and Schäfer, 1998; Schönborn *et al.*, 1999), he was the first to tackle the difficult exercise of identifying these micro-inclusions in French ambers. In a first work, he thus mentioned the microflora contained in amber of Sparnacian age in the South of France (Breton *et al.*, 1999). Aware of the difficulty of directly assimilating micro-inclusions to current microorganisms determined today on genomic bases, he developed a comparative taxonomy essentially based on morphology (Breton, 2010). He is the author of numerous new taxa of actinomycetes, bacteria, cyanobacteria and filamentous fungi (Breton and Tostain, 2005; Breton, 2010, 2012; Breton *et al.*, 2013, 2014). From a taphonomic point of view, he first favored the trapping process, especially on the surface of resin flows, to explain the presence of real microbial mats (Breton and Tostain, 2005; Breton, 2007), then he integrated subsequently the colonization process by networks of centripetal growth microorganisms in the resin (Breton, 2010, 2011, 2012, Breton *et al.*, 2013, 2014, 2018). Consequently, he considered the resin as a real culture medium (Breton, 2011). Thanks to his knowledge of amber microorganisms, he has also been able to provide his expertise and collaborate in numerous works (Girard *et al.*, 2008, 2009a, 2009b; 2011; 2013; Adl *et al.*, 2011; Néraudeau *et al.*, 2020).

À la mémoire de Gérard Breton

Nous avons souhaité dédier ce numéro spécial consacré à l'ambre à la mémoire de notre collègue Gérard Breton récemment décédé. Titulaire de l'agrégation en Sciences Naturelles, docteur d'État es-sciences Gérard Breton a d'abord enseigné dans des établissements d'enseignement secondaire puis a exercé pendant 32 ans les fonctions de directeur du Muséum d'histoire naturelle du Havre (1973–2005). En véritable naturaliste animé d'une constante curiosité scientifique, Gérard Breton, a abordé de nombreux thèmes d'études dans le domaine de la paléontologie. Plus particulièrement, son apport pour la connaissance des micro-inclusions de l'ambre depuis un peu plus d'une vingtaine d'années a été constant et riche en informations et concepts. À la suite des auteurs qui ont décrit et figuré des microorganismes contenus dans des ambres d'âge et provenances variées (*e.g.* Poinar, 1977, 1992; 1994 ; Waggoner, 1993, 1994 ; Poinar *et al.*, 1993a, 1993b ; Dörfelt and Schäfer, 1998 ; Schönborn *et al.*, 1999), il a été le premier à aborder le difficile exercice d'identification de ces micro-inclusions dans les ambres de France. Il a ainsi évoqué dans un premier travail la microflore contenue dans l'ambre d'âge sparnacien du Sud de la France (Breton *et al.*, 1999). Conscient de la difficulté d'assimiler directement les micro-inclusions à des microorganismes actuels déterminés aujourd'hui sur des bases génomiques, il a développé une taxonomie comparative essentiellement basée sur la morphologie (Breton, 2010). Il est ainsi l'auteur de nombreux nouveaux taxons d'actinomycètes, de bactéries, de cyanobactéries et de champignons filamenteux (Breton and Tostain, 2005 ; Breton, 2010, 2012 ; Breton *et al.*, 2013, 2014). Du point de vue taphonomique, il a d'abord plutôt privilégié le processus de piégeage, surtout en surface des coulées de résine, pour expliquer la présence de véritables feutrages microbiens (Breton and Tostain, 2005 ; Breton, 2007), puis il a intégré par la suite le processus de colonisation par des réseaux de microorganismes à croissance centripète dans la résine (Breton, 2010, 2011, 2012 ; Breton *et al.*, 2013, 2014, 2018).

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En conséquence il a considéré la résine comme un véritable milieu de culture (Breton, 2011). De par sa connaissance des microorganismes de l'ambre il a pu également apporter son expertise et collaborer à de nombreux travaux (Girard *et al.*, 2008, 2009a, 2009b, 2011, 2013 ; Adl *et al.*, 2011 ; Néraudeau *et al.*, 2020).

2 Amber: deposits and biodiversity

The interest in the exceptional fossil material of amber has continued to grow along the time as testified by the large number of articles devoted to this theme. Classically, the inclusions of arthropods constitute the main topic in the majority of the work devoted to amber. Several scientific journals have thus proposed special issues, some dedicated more particularly to amber from France and their inclusions (Perrichot and Néraudeau, 2009; Girard and Néraudeau, 2013; Perrichot and Néraudeau, 2014; Wang *et al.*, 2020). However, new data is constantly providing more information in the various fields of investigation concerning amber. This is what motivated this special issue devoted to different aspects of amber research. So, the various articles in this special issue reflect three major concerns:

1 the highlighting of fossil biodiversity revealed by amber due to these remarkable qualities as a preservation medium;
2 the reconstitution of the paleoenvironments that accompanied the production of resin at the origin of amber and of the environments and processes of deposits;
3 the question of the botanical origin of amber and its possible evolution through the data provided by the amber-bearing deposits and by the inclusions themselves.

The revival in recent decades of the study of amber, its characteristics and its inclusions has been the result of numerous investigations in the field. This research was based in part on the already old knowledge of certain deposits, but also on discoveries of hitherto unlisted deposits. All amount of this work has enabled to clearly define the geological, stratigraphic, palaeontological and palaeoenvironmental framework of amber deposits. This prerequisite is particularly important in order to best link the inclusions, privileged objects of the studies, to a well-defined context. Several regions of France are concerned by these new data. In western France, several lower Cenomanian amber deposits have been discovered around the town of Chatellerault (department of Vienne) thanks to public works (roads, boreholes). In addition to amber, a whole faunistic and floristic association is revealed (Valentin *et al.*, 2020), thus completing the data provided by the deposit of the same age of Jaunay-Clan, located in the same sector (Valentin *et al.*, 2014; Polette *et al.*, 2019) and containing some pieces of amber. Further west, in the department of Mayenne, a new amber deposit dated from the Cenomanian has yielded a whole rich floristic association, including spores and wood fragments preserved in amber, which confers a unique character of the discovery (Néraudeau *et al.*, 2020). In the South-East of France, several new deposits presented in this special issue also enabled to address the palaeoenvironmental and sedimentological context of the formation of amber deposits. The presence of amber in the Santonian sediments (Upper Cretaceous) was thus noted throughout the Sainte Baume massif (Frau *et al.*, 2020) in association with faunas of variable character, from brackish to open marine. More broadly throughout Provence, in several departments, a review of amber deposits based on many new discoveries, allows us to outline a vision of the evolution of the phenomenon of amber production from the Lower Cretaceous to the Miocene (Saint Martin *et al.,* 2020). On the largest scale of a continent, the first synthesis of African deposits yielding copal and amber brings up a picture of a potential source of informations, until now quite unknown, especially concerning the botanical origin of resins, (Bouju and Perrichot, 2020).

Due to a remarkable conservation quality of inclusions, amber is sometimes considered an example of Konservat-laggerstäte. (Nudds and Selden, 2008; Briggs, 2014; Labandeira, 2014). Obiously the inclusions of arthropods represent the vast majority of work devoted to amber. In this special issue, several works present the description of new taxa of arthropods: Ferwer and Nel (2020) propose a new genus and a new species of Odonates from Baltic amber; Chény *et al.* (2020) describe a new species of Eocene amber hymenoptera from Oise (France); concerning spiders, Carbuccia *et al.* (2020) describe a new species of spider from the Archaeidae family represented for the first time by a male specimen in Eocene amber from Oise (France). The plant inclusions in amber are also a source of information about the environments of ancient forests and resin-producing trees. The discovery in the Cenomanian amber of Charente Maritime (France) of meso-relains of Cheirolepidiaceae conifers attributed to the genus *Plagiophyllum* allows to trace the environmental conditions of flora adapted to coastal environments (Moreau *et al.*, 2020). From a quantitative point of view, the inclusions most frequently observed in Cretaceous ambers are represented by microorganisms. Resulting from trapping and/or colonization processes, micro-inclusions can sometimes completely invade amber grains (Frau *et al.*, 2020; Néraudeau *et al.*, 2020; Saint Martin *et al.*, 2020). In other very rare cases the amber may have trapped marine microorganisms. The presence of marine diatoms was therefore first reported in Cretaceous amber from Vendée and Charente-Maritime in France (Girard *et al.*, 2008, 2009; Saint Martin *et al.*, 2015). Another exceptional case of inclusion of a marine diatom attributed to the genus *Hemiaulus* is described in Late Jurassic amber from Thailand (Girard *et al.*, 2020), thus significantly going back in time the known fossil record of this genus. Among the micro-inclusions, the detection of spermatozoa constitutes an unexpected exceptional case of the preservation of organic structures rarely observed in the fossil record (Poinar and Breton, 2020).

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References

Adl SM, Girard V, Breton G, Lak M, Maharning A, Mills A, *et al*. 2011. Reconstructing the soil food web of a 100 million-year-old forest: the case of the mid-Cretaceous fossils in the amber of Charentes (SW France). *Soil Biology and Biochemistry* 43: 726–735.

Bouju V, Perrichot V. 2020. A review of amber and copal occurrences in Africa and their paleontological significance. *Bulletin de la Société Géologique de France – Earth Sciences Bulletin* 191: 17. https://doi.org/10.1051/bsgf/2020018.

Breton G. 2007. La bioaccumulation de micro-organismes dans l'ambre : analyse comparée d'un ambre cénomanien et d'un ambre sparnacien et de leurs tapis algaires et bactériens. *Comptes rendus Palevol* 6: 125–133.

Breton G. 2010. Les Actinomycétales de l'ambre sparnacien des Corbières (Aude, France) : taphonomie et diversité. *Annales de la Société géologique du Nord* 17(2è sér.): 3–22.

Breton G. 2011. L'ambre, un milieu de culture fossilisé. *Bulletin de la Société d'Etudes et des Sciences Naturelles d'Elbeuf* (2è trim). 28–29.

Breton G. 2012. L'ambre des Corbières (Aude – France). Carcassonne: SESA, 96 p.

Breton G, Bilotte M, Eychenne G. 2013. L'ambre campanien du Mas d'Azil (Ariège, France) : gisement, micro-inclusions, taphonomie. *Annales de Paléontologie* 99: 317–337.

Breton G, Champion S, Bilotte M. 2018. L'ambre turonien du ruisseau des Tarquès (Commune de Duilhac-sous-Peyrepertuse, Aude, France). *Bulletin de la Société d'Histoire Naturelle de Toulouse* 154: 161–176.

Breton G, Gauthier C, Vizcaïno D. 1999. Land and freshwater microflora in a Sparnacian amber from the Corbières (South France): first observations. *Estudios del Museo de Ciencias naturales de Álava* 14(núm. espc. 2): 161–166.

Breton G, Serrano-Sánchez M de L, Vega FJ. 2014. Filamentous micro-organisms, inorganic inclusions and pseudo-fossils in the Miocene amber from Totolapa (Chiapas, Mexico): taphonomy and systematics. *Boletín de la Sociedad Geológica Mexicana* 66(1): 199–214

Breton G, Tostain F. 2005. Les micro-organismes de l'ambre cénomanien d'Ecommoy (Sarthe, France). *Comptes rendus Palevol* 4: 31–46.

Briggs DEG. 2014. Konservat-lagerstatten 40 years on: the exceptional becomes mainstream. *The Paleontological Society Papers* 20: 1–13.

Carbuccia B, Wood HM, Rollard C, Nel A, Garrouste R. 2020. A new Myrmecarchaea (Araneae: Archaeidae) species from Oise amber (earliest Eocene, France). *Bulletin de la Société Géologique de France – Earth Sciences Bulletin* 191: 24. https://doi.org/10.1051/bsgf/2020023.

Chény C, Guillam E, Nel A, Perrichot V. 2020. A new species of Ampulicomorpha Ashmead from Eocene French amber, with a list of fossil and extant Embolemidae (Insecta: Hymenoptera) of the world. *Bulletin de la Société Géologique de France – Earth Sciences Bulletin* 191: 20. https://doi.org/10.1051/bsgf/2020020.

Dörfelt H, Schäfer U. 1998. Fossile Pilze in Bernstein der alpischen Trias. *Zeitschrift für Mykologie* 64(2): 141–151.

Ferwer W, Nel A. 2020. A new damselfly genus and species from Baltic amber (Odonata: Zygoptera: Euphaeidae). *Bulletin de la Société Géologique de France – Earth Sciences Bulletin* 191: 12. https://doi.org/10.1051/bsgf/2020015.

Frau C, Saint Martin J-P, Saint Martin S, Mazières B. 2020. An overview of the Santonian amber-bearing deposits of the Sainte-Baume Massif, southeastern France. *Bulletin de la Société Géologique de France – Earth Sciences Bulletin* 191.

Girard V, Néraudeau D. 2013. Ambres de France nouveaux ou peu connus. *Annales de Paléontologie* 99 : 285–288.

Girard V, Schmidt AR, Saint Martin S, Struwe S, Perrichot V, Saint Martin JP, *et al*. 2008. Evidence for marine microfossils from amber. *Proceedings of the National Academy of Sciences of the USA* 105: 17426–17429.

Girard V, Schmidt AR, Struwe S, Perrichot V, Breton G, Néraudeau D. 2009. Taphonomy and palaeoecology of mid-Cretaceous French amber-preserved microorganisms from South-western France. Geodiversitas 31: 153–162.

Girard V, Néraudeau D, Breton G, Saint Martin S, Saint Martin J-P. 2009a. Contamination of amber samples by recent microorganisms and remediation evidenced by mid-Cretaceous amber of France. *Geomicrobiology Journal* 26(1): 21–30.

Girard V, Saint Martin S, Saint Martin J-P, Schmidt AR, Struwe S, Perrichot V, *et al*. 2009b. Exceptional preservation of marine diatoms in upper Albian amber. *Geology* 37: 83–86.

Girard V, Néraudeau D, Adl SM, Breton G. 2011. Protist-like inclusions in amber, as evidenced by Charentes amber. *European Journal of Protistology* 47(2): 59–66.

Girard V, Breton G, Perrichot V, Bilotte M, Le Loeuff J, Nel A, *et al*. 2013. The Cenomanian amber of Fourtou (Aude, Southern France): taphonomy and palaeoecological implications. *Annales de Paléontologie* 99: 301–315.

Girard V, Néraudeau D, Breton G, Morel N. 2013. Palaeoecology of the Cenomanian amber forest of Sarthe (western France). *Geologica Acta* 11 (3): 321–330.

Girard V, Saint Martin S, Buffetaut E, Saint Martin JP, Néraudeau D, Peyrot D, *et al*. 2020. Thai amber: insights into early diatom history? *Bulletin de la Société Géologique de France – Earth Sciences Bulletin* 191: 23. https://doi.org/10.1051/bsgf/2020028.

Labandeira CC. 2014. Amber. *The Paleontological Society Papers* 20: 163–215.

Moreau J-D, Néraudeau D, Perrichot V. 2020. Conifers from the Cenomanian amber of Fouras (Charente-Maritime, western France). *Bulletin de la Société Géologique de France – Earth Sciences Bulletin* 191: 16. https://doi.org/10.1051/bsgf/2020014.

Néraudeau D, Vullo R, Bénéfice P, Breton G, Dépré E, Gaspard D, *et al*. 2020. The paralic Albian-Cenomanian Puy-Puy Lagerstätte (Aquitaine Basin, France): an overview and new data. *Cretaceous Research* 111: 104124.

Néraudeau D, Saint Martin J-P, Saint Martin S, Moreau J-D, Philippe M, Polette F, *et al*. 2020. Amber and plant-bearing deposits from the Cenomanian of Neau (Mayenne, northern France). *Bulletin de la Société Géologique de France – Earth Sciences Bulletin* 191. https://doi.org/10.1051/bsgf/2020039.

Nudds J, Selden P. 2008. Fossil-Lagerstätten. *Geology Today* 24(4): 153–158.

Perrichot V, Néraudeau D, 2014. Introduction to thematic volume "Fossil arthropods in Late Cretaceous Vendean amber (northwestern France)". *Paleontological contributions* 10A: 1–4.

Perrichot V, Néraudeau D. 2009. Cretaceous ambers from southwestern France: geology, taphonomy, and palaeontology). *Geodiversitas* 31(1): 7–11.

Poinar GO Jr. 1977. Fossil nematods from Mexican amber. *Nematologica* 23: 232–238.

Poinar GO Jr. 1992. Life in amber. *Stanford University Press*, 321 p.
Poinar GO Jr. 1994. Fossils in amber. *Current Sciences* 66(6): 417–420.
Poinar GO Jr, Breton G. 2020. Synopsis of rare fossil animal spermatozoa in amber and sedimentary deposits. *Bulletin de la Société Géologique de France – Earth Sciences Bulletin* 191: 31. https://doi.org/10.1051/bsgf/2020014.
Poinar GO Jr, Waggoner BM, Bauer UC. 1993a. Terrestrial soft-bodies protists and other micro-organisms in Triassic amber. *Science* 259: 222–224.
Poinar GO Jr, Waggoner BM, Bauer UC. 1993b. Description and paleoecology of a Triassic amoeba. *Naturwisenschaften* 80: 566–568.
Polette F, Licht A, Cincotta A, Batten DJ, Depuydt P, Neraudeau D, *et al*. 2019. Palynological assemblage from the lower Cenomanian plant-bearing Lagerstätte of Jaunay-Clan-Ormeau-Saint-Denis (Vienne, western France): stratigraphic and paleoenvironmental implications. *Review of Palaeobotany and Palynology* 271: 104102. https://doi.org/10.1016/j.revpalbo.2019.104102.
Saint Martin J-P, Dutour Y, Ebbo L, Frau C, Mazières B, *et al*. 2020. Reassessment of amber-bearing deposits of Provence, southeastern France. *Bulletin de la Société Géologique de France – Earth Sciences Bulletin* 191. https://doi.org/10.1051/bsgf/2020048.
Saint-Martin S, Saint Martin J-P, Schmit AR, Girard V, Néraudeau D, Péririchot V. 2015. The intriguing marine diatom genus Corethron in Late Cretaceous amber from Vendée (France). *Creataceous Research* 52: 64–72.
Schönborn W, Dörfelt H, Foissner OW, Krienitz L, Schäfer U. 1999. A fossilized microcenosis in Triassic amber. *Journal of Eukaryotic Microbiology* 46: 571–584.
Valentin X, Gomez B, Daviero-Gomez V, Charbonnier S, Ferchaud P, Kirejtshuk A, *et al*. 2014. Plant-dominated assemblage and invertebrates from the lower Cenomanian of Jaunay-Clan, western France. *Comptes Rendus Palevol* 13(5): 443–454.
Valentin X, Garcia G, Gomez B, Daviero Gomez V, Boiteau J, Saint Martin S, *et al*. 2020. New fossil assemblage with amber, plants and vertebrates from the lower Cenomanian near Châtellerault (Vienne, western France). *Bulletin de la Société Géologique de France – Earth Sciences Bulletin* 191 (1): 29. https://doi.org/10.1051/bsgf/2020034.
Waggoner BM. 1993. Fossil actinomycetes and other bacteria in Eocene amber from Washington State, USA. *Tertiary Research* 14: 155–160.
Waggoner BM. 1994. Fossil actinomycete in Eocene-Oligocene Dominican amber. *Journal of Paleontology* 68: 398–401.
Wang B, Perrichot V, Jarzembowski E. 2020 in progress. Cretaceous ecosystems trapped in amber. *Cretaceous Research*.

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