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POSSIBLE FOSSIL FISH IN AMBER

ABSTRACT

The author describes possible fossil fish remains trapped in amber. The remains were identified in fragments of amber from Cretaceous of Myanmar and from Pliocene of Madagascar. Although these remains leave margins of uncertainty in their interpretation, the reported discoveries nevertheless fill the gap represented by the absence of reports of fossil fish in amber, despite the fact that many recent evidences have definitively demonstrated the presence of inclusions derived from organisms living in aquatic habitat in many ambers of various origins and antiquities. The remains described here potentially indicate that the fish trapped in amber may have belonged to fish of both possible freshwater limnetic and possible marine littoral environment.

Key words: Amber inclusions, Cretaceous of Myanmar, Eocene of Baltic, Pliocene of Madagascar

INTRODUCTION

Amber is considered to be the fossilized resin of land plants, although debate persists as to which plant species gave rise to this resin (Wolfe *et al.*, 2009). Due to its origin, unequivocally linked to terrestrial plants, amber usually contains remains of terrestrial organisms. Nonetheless, organisms of limnetic and littoral marine origin have only exceptionally been found as inclusions in amber, but there have been long discussions and mainly speculative interpretations on how these organisms – typical of aquatic environments – could have remained trapped in amber. Experimental observations have also been conducted on which mechanisms can allow the introduction of marine macro- and micro-organisms within modern coastal conifer forest with highly resinous Cook pine of New Caledonia (Schmidt *et al.*, 2018).

Although microorganisms of marine origin, such as diatoms or spicules of sponges, can easily be found on the surface or in the cracks of amber nodules collected at sea (Gallipe, 1920; Girard *et al*., 2008), inclusions of organisms of marine or littoral origin are very rare. In fact, they have only been unequivocally demonstrated: (i) in Cretaceous amber from the Albian-Cenomanian of Charentes (Masure *et al*., 2013) and from the Turonian of Vendée (Saint Martin *et al*., 2015), both locations in France, (ii) from the Early Miocene of Mexico (Huys *et al*., 2016; Heard *et al*., 2018), and (iii) from the Cenomanian amber from Myanmar. In particular, this last, extraordinary amber has recently provided unequivocal and numerous evidence of inclusions of marine organisms: crinoid stems, corals and oysters, a giant ostracod, certainly from a marine environment (Xing *et al*., 2018), various marine gastropods, intertidal isopods and even an ammonite shell, trapped in this Cretaceous amber. All these inclusions demonstrated that the resin was mixed with both fragments of these marine organisms during its sedimentation phase (Mao *et al*., 2018) and mixed with all sorts of terrestrial organisms (Yu *et al*., 2019).

Furthermore, even if limnetic microorganisms may be present on the surface and in the cracks of the amber nodules that have floated in freshwater, microorganisms, such as algae and amoebae, typically of lacustrine habitats, however freshwater, may exceptionally be present as real inclusions in amber. And, in fact, exceptionally, amphipods (Coleman, 2004), amoebae (Smith and Ross, 2017), diving beetles (Gómez and Damgaard, 2014) have been found as amber inclusions.

The rarity of aquatic organisms still makes the explanation of how these remains ended up embedded in the resin of terrestrial plants is largely speculative. Probably not only one mechanism was at play, but many explanations could have been present at the same time, or in each deposit one mechanism may have prevailed over the other: littoral or estuarine forests could receive riverine contributions, but, on the opposite way, could receive seawater through high tides, from storms, from marine aerosols, etc. Although the evidence of the presence of inclusions of aquatic organisms has multiplied greatly in the last ten years, the apparent paradox of the co-occurrence in amber of organisms typical of marine and freshwater environments together with abundant terrestrial organisms remains in place.

Regardless of their environment of origin, the organisms included in amber are first of all vegetal in nature, secondly they are invertebrate animals; other organisms are equally present sporadically, such as those of fungal origin, and of microbic nature. Finally, vertebrates are absolutely exceptional and are represented by remains pertaining to near all the classes of vertebrates: reptiles (Poinar and Poinar, 1999), very few amphibians (Poinar, 1992), birds (Poinar and Wake, 2015), and mammals (Poinar and Poinar, 1999). These animals are known above all through remains of their integu-

ments or, more frequently, remains of integumentary annexes, such as scales, feathers, hair. More complete and better determinable remains which have also allowed a taxonomic classification are very rare everywhere (Daza *et al*., 2020).

In this panorama, fish are currently completely missing (Poinar and Poinar, 1999). Yet if aquatic organisms in general could – we still don't know precisely how – become trapped in amber, we should perhaps ask ourselves why we have no evidence of fish remains fossilized in this way.

The present work focuses attention on this last point and reports both a single finding emerging from the examination of the very ancient literature (Agassiz, 1833-43), as well as some new potential examples of fossil fish remains preserved in amber coming from at least two different deposits all over the world, and dated to the Late Cretaceous and to the Pliocene.

MATERIAL AND METHODS

To fill this inexplicable gap, over the last two decades I have subjected to direct observation many thousands of amber samples, predominantly of Burmese and Baltic origins. Since most of the fossil remains of vertebrates preserved in amber from all periods and all deposits are traces of their integuments or their integumentary annexes, I hypothesized that I should look for possible traces referable to the scaly covering also most fish. In this light, the field of possible traces of fish preserved in amber is very narrow. Unless we are faced with complex and more or less complete remains, it is a difficult distinction, based only on the morphology which is certainly affected by the state of conservation of the remains which, despite it being a so-called *in toto conservation*, it has often led to the destruction of mineralized parts or to dismemberments and torsions, that prevent the relief of salient characters; and in fact most of the findings cannot be determined.

However, the scales of the fishes present sufficiently distinctive characters to be recognized with some ease. For the morphological determination and anatomical nomenclature of the fish scales, I followed the standard proposed by Sire *et al*. (2009) and – first of all – by Bräger and Moritz (2016).

All the material described in this paper belonging to the "Luigi Capasso Public Collection" (CCC). This is a Public Collection that was established two centuries ago, and is protected by the Italian Government. It is legally registered by two Decrees of the Ministry for Cultural Heritage, such as the no. 14, dated October 11, 1999, and no. 6259-A, dated April 29, 2020, both according to Italian law 1089/39 for the protection of the National Cultural Heritage. The specimens of this Collection were publicly-accessible for studies on the basis of the Article 30 of Italian law N ° 42/2004.

The samples examined for this work are the following four:

(i) - one amber fragment with inclusions collected before 2015 from the Hukawng Valley, near Danai, Myanmar, dated to the Late Cretaceous; inventory number no. CCC-S#2046;

(ii and iii) - two pieces of "cognac amber" transformed into women's scarf pins, coming from an unspecified location on the Baltic coast of Latvia, dated to the Eocene; inventory numbers no. CCC-S#2044 A and CCC-S#2044 B;

(iv) - a piece of very transparent yellow amber, coming from the village of Sambava, north-east Madagascar coast, dated to the Pliocene; inventory number no. CCC-S#804.

To carry out the necessary anatomical comparisons, I also examined the tree additional samples of fossil fish, as indicated in the following list:

(i) - a complete specimen of *Lepidotes sp. ind.*, TL = 300 mm ca., Aptian, Early Cretaceous, of Pietraroja, Italy; CCC-S#344;

(ii) - a complete specimen of *Lepidotes jurongensis* Li, 2009, TL = 123 mm, preserved in nodule, Early Triassic, Jurong, Jiangsu Province Jurassic, China; CCC-S#211;

(iii) – a complete specimen of *Dapedium punctatus* Agassiz, 1833-43, TL = 210 mm, Toarcian, Early Jurassic, Holzmaden, Germany; CCC-S#1463.

The historical case

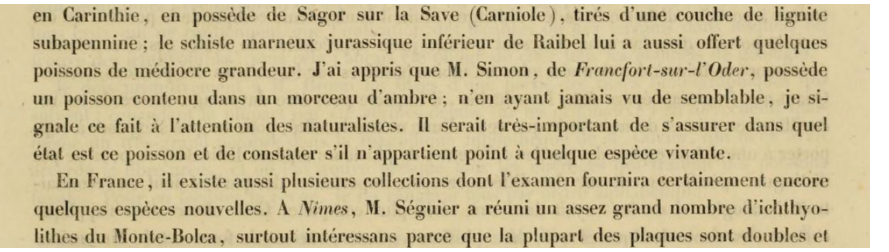
Dr. Louis Agassiz, the father of paleo-ichthyology, in Volume I of his monumental work (1833-43) "Recherches sur les Poissons Fossiles", concludes the Chapter I, titled "*Renseignemens sur les collections de poisons fossils que j'ai examinées, et sue le matériaux qui on été a ma disposition pour en determiner les espèces*", with a very important note entitled: "*Notice sur les collections que je nai pas vues*". This note contains the detailed list of the collections, but also of the individual specimens, that he would have liked to examine in order to arrive at a more complete, exact and timely draft of his impressive work on fossil fish. This list of not examined, but considered relevant to paleo-ichthyology, specimens includes also the following description: "*J'ai appris que M. Simon, de Francfort-sur-l'Oder, possède un poisson contenu dans un morceau d'ambre; n'en ayant jamais vu de semblable, je signale ce fait à l'attention des naturalistes. Il serait très-important de s'assures dans quel état est ce poisson et de constater s'il n'appartient point à qualque espèce vivante*" ("I learned that Mr. Simon, from Frankfurt (Oder), owns a fish trapped in a piece of amber; having never seen anything like it, I draw this fact to the attention of naturalists. It would be very important to ascertain what condition this fish is in and to see if it does not belong to some living species.").

Naturally, I tried to track down the elusive Mr. Simon of Frankfurt (Germany) who owned a collection of fossils, but the search was completely fruitless.

What remains is the unequivocal quote from Louis Agassiz who, almost two hundred years ago, reported the existence of a possible record of fossil fish preserved in amber.

By carefully rereading Agassiz's brief description (Fig. 1), however, perhaps we understand his doubts, not so much about the actual existence of such a find, but perhaps precisely about its authenticity: in fact, he points out that it will be necessary to verify with great attention the state of conservation of the fish and whether it does not belong to a living species. Perhaps with these references he actually wanted to refer to the need to verify the authenticity of the fossil.

What is certain is that Agassiz was aware of the possible existence of fossil fish remains trapped in amber and underlined their great paleontological relevance two centuries ago.



en Carinthie, en possède de Sagor sur la Save (Carniole), tirés d'une couche de lignite subapennine ; le schiste marneux jurassique inférieur de Raibel lui a aussi offert quelques poissons de médiocre grandeur. J'ai appris que M. Simon, de *Francfort-sur-l'Oder*, possède un poisson contenu dans un morceau d'ambre ; n'en ayant jamais vu de semblable, je signale ce fait à l'attention des naturalistes. Il serait très-important de s'assurer dans quel état est ce poisson et de constater s'il n'appartient point à quelque espèce vivante.

En France, il existe aussi plusieurs collections dont l'examen fournira certainement encore quelques espèces nouvelles. A *Nimes*, M. Séguier a réuni un assez grand nombre d'ichthyolithes du Monte-Bolca, surtout intéressans parce que la plupart des plaques sont doubles et

Fig. 1 - Reproduction of part of page 41 of Volume 1 of the work by Louis Agassiz, printed from 1833 and 1843 by Petitpierre Publisher in Neuchâtel, Switzerland, entitled "*Reserches sur les poissons fossiles*", Chapter I, with the note entitled: "*Notice sur les collections que je nai pas vues*", in which the author quotes and describes a fossil fish preserved in amber.

New possible evidences

The case of Baltic amber (Eocene): the "sun spangles" as pseudo-fossils fish

Baltic amber, already known and appreciated as a precious stone starting from the Late Neolithic (fourth millennium BC) (Murillo-Barroso *et al.*, 2023) and its use both as an ornamental stone and as an amulet is attested throughout the Mediterranean area, in the Greek, Etruscan and Roman world (Beck and Bouzek, 1993).

has long been recovered from the Baltic Sea, both on its shores and through fishing nets; today it is extracted directly from the sediments that contain it, especially in the Kaliningrad Oblast, Russia. It was formed during the Eocene and the inclusions it contains belong to plant remains and animal remains, almost exclusively invertebrates, as well as microorganisms and fungi (Poinar and Poinar, 1999). Even in this case, no inclusion, even just hypothetically, has ever been interpreted as the remains of fish.

Two large fragments of Baltic amber, collected in the 19th century from

an unknown location on the sea coast of Latvia, were worked to make large brooches that served as clasps for female neckerchiefs, widely used in the Victorian era. These two ancient jewels were made with so-called "cognac amber", due to its darker color and credibly come from a single original piece (Fig. 2). The two pieces have a rounded and elongated shape, have a clean and polished surface, and respectively have the following dimensions: CCC-S#2044A with width 70 mm, height 32 mm and thickness 19 mm; CCC-S#2044B with width 52 mm, height 45 mm and thickness 9 mm. Both of these large fragments of Baltic amber contain a myriad of inclusions with a sub-circular or sub-oval profile, with a diameter varying from 5 mm to 12 mm, scattered throughout the amber matrix; they all have a very small and almost homogeneous thickness, of the order of a third of one mm. The individual structures possess, regardless of their profile, a radial ornamentation, made up of shallow grooves which, from the central area of the structure, go towards the periphery and interrupt, in one direction, the profile of each structure.

A

Fig. 2 - A fragment of Eocene "cognac amber" collected on the Baltic shores of Latvia and transformed into women's brooche in the Victorian era, containing structures with a circular or ovoid profile, with a maximum diameter of 12 mm, with a thickness of less than half a millimetre. These structures are not rare in cognac amber and are popularly called "sun spangles". They present some morphological characteristics that make them comparable to fish scales; however, according to a recent hypothesis, they should be interpreted as air bubbles collapsed due to the heat to which the cognac amber was exposed in the early stages of its fossilization (Eriksson and Poinar, 2015); therefore, the sun spangles would represent real pseudofossils of fish. CCC-S#2044A. Scale in cm.

Observation under the microscope made it possible to highlight the presence of very thin, and discontinuous concentric lines, which intersect the ornamental lines with a radial pattern, and which can be interpreted as growth lines.

The general morphology just described could allow us to interpret these inclusions as cycloid fish scales. All the preserved inclusions, however, have lost mutual contact and are dispersed without any order in the context of the amber matrix; therefore, if we wanted to interpret these inclusions as true fish scales, we would have to admit that the scales derive from the initial decomposition and taphonomic dispersion of the scaly covering of a medium or large-sized teleost fishes.

In particular, to interpret the real nature of the described inclusions in Baltic amber, one must also consider that on most cycloid scales we can see a separation between the free zones and those covered by other scales, which is not the case here. Additionally, the size of the scales is very different, which is unexpected considering that this accumulation comes likely from a single specimen of fish. These data are contrary to interpreting the inclusions as real scales, but the embarrassment in their real nature remains unchanged, which, conclusively, also includes the possibility that they are fish scales.

A recent study, however, has finally clarified an alternative possible nature of these inclusions, which are particularly sought after, as they give amber the presence of shiny internal reflections, very pleasant to look at, so that cognac amber with this kind of inclusions has often become the raw material for making jewels. Eriksson and Poinar (2015), in fact, studied these reflective discs, colloquially known as "sun spangles", which appear like golden discs floating in the amber matrix and asserted that they "*are former trapped air bubbles that have expanded and cracked into disc-like fractures, after heating the amber in dry sand*".

The "sun spangles", therefore, are a very fitting example of how numerous inclusions in amber, while closely resembling fossil fish scales, represent true pseudo-fossils. Their presence confirms that great caution is needed in interpreting inclusions in amber as possible fossil remains.

Nevertheless, I believe that at least the two following examples deserve to be discussed with the utmost care in the sense of their interpretation as possible fossil fish remains.

The case of Burmese amber (Late Cretaceous)

Myanmar amber (so called "burmite"), dated to the earliest Cenomanian, Cretaceous (Schmidt *et al.*, 2010), such as 98.19 ±0.62 Ma (Shi *et al*., 2012), has been known for over a century (Noetling, 1892); it has provided an extraordinary variety of fossil organisms described, especially in the last two decades, coinciding with a great increase in amber extraction activities as

well as in systematic study of its inclusions; so that we have reached the number of 1013 described species (Mao *et al.*, 2018). No description took into account the possible existence of fish remains.

The examination of approximately two thousand pieces of burmite collected in the Hukawng Valley, near Danai, allowed me to identify only one remain which can possibly represent the remains of fossil fish.

It is a fragment of amber with a well-polished surface, 20 mm of length, 12 mm width, and 8 mm height; inventory no. CCC-S#2046. This piece of amber trapped, among other numerous inclusions, a fragment of integument 4.7 mm long and 3.5 mm wide, with a tapered profile on one side and clearly truncated on the other side (Fig. 3). It is made up of a series of robust, imbricated scales, small in size and rhomboidal in shape, arranged in 25 rows. At least 16-18 thread-like fragments are connected to the most tapered pole of the possible integumental fragment, with both swollen ends and a thinned median part, varying in length from 0.7 to 1.0 mm.

Fig. 3 - Fragment of integument, possibly of a fry fish, with possible rhomboidal ganoid scales still imbricated and with remains of possible fin rays gathered at the right pole of the fragment. Myanmar, Late Cretaceous. Scale in mm.

The scales have a distinctly ganoid appearance, with a rhomboidal profile, monomorphic, almost one-dimensional. When observed under a reflected light optical microscope, the external superficial capillary growth lines, typical also of this type of scale.

The minute size of the scales, together with the presence of a certain space between them, is consistent with an individual of such small size as the one hypothesized here, which could therefore be a fry. Moreover, it has been demonstrated that some specimens of semionotiformes (attributed to the genus *Propterus*) of minute size possess similar and similarly assembled scales because they are fry; they have been described and depicted both in the lithographic limestone of the Late Jurassic of Solnhofen, Germany (Frickinger, 1994) as well as in the Lower Cretaceous limestone of Pietraroja, Italy (Capasso, 2007).

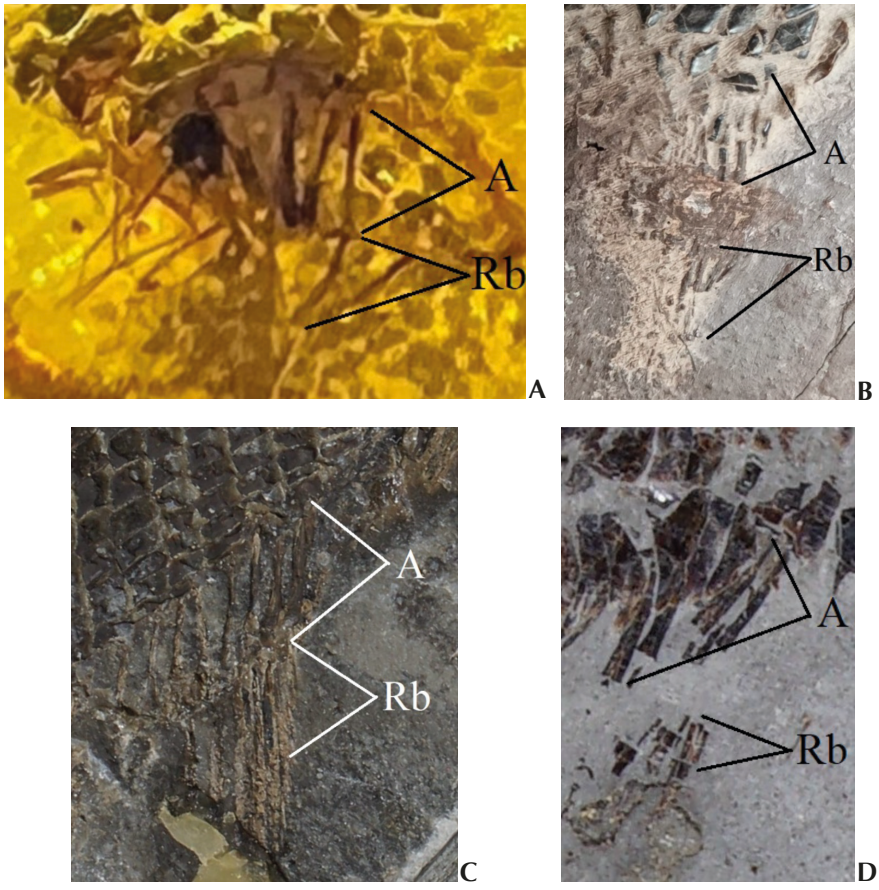
The filamentous structures have a morphology similar to that of the basal rays of a fin; their dimensions are graduated and the most robust elements are located in the center of the group of the small structures, which however appear scattered having been partially dispersed by early taphonomic processes. There is anatomical continuity between the most peripheral row of presumed ganoid scales and the base of the filiform structures. By observing these areas of amber under a stereomicroscope from a different point of view, it is possible to exclude that the presumed scales are simply superimposed on the filamentous structures interpreted as fin rays; this confirms that the two groups of structures described are in anatomical and not casual topographic relationships.

Therefore, both the morphology of the individual scales, as well as their arrangement, their imbricated assembly, their surface microstructure, as well as the morphology of the small filamentous structures, their topographic arrangement and their relationships with the dermal fragment covered with scales, suggest that the described fossil represents a segment of integument of a ganoid fish, perhaps belonging to Semionotiformes or Lepisosteiformes.

On the other hand, I compared the described structures preserved in amber with the region of the emergence of the anal fin in some Mesozoic Lepisosteifiomes and Semionotiformes from other deposits, and the comparison appears truly convincing. In fact, above all the morphology of the pterygiophores and the first, robust basal rays of the anal fin, such as the little bony elements characteristic of the base of the anal fin, present an almost completely overlapping morphology in the specimens preserved in stratified limestone rocks compared to this single fragment preserved in amber (Fig. 4). Equally convincing is the topography of the relationships between the margin of the fragment of integument covered by scales and the emergence of the pterygiophores *vs* basal rays of the fin, probably the anal one (Li, 2009).

The case of Madagascar amber (Pliocene)

On the north-east coast of Madagascar, substantial amounts of amber are found, originating during the Pliocene from resin of the conifer *Hymenaea verrucosa*. This amber probably arrives on the coast coming through runoff from the mountains of Antananarivo, Diana Region, Antsiranana District.



A **B** **C** **D**

Fig. 4 - Comparison between the assumed scaly-coated integumentary fragment shown in Figure 3 and the region of the anal fin insertion in some Mesozoic fishes. A, the Late Cretaceous fragment in Myanmar amber; B, *Lepidotes* sp. ind. (Albian, Pietraroja, Italy); C, *Lepidotes jurongensis* (Early Triassic, Jiangsu, China); *Dapedium punctatus* (Early Jurassic, Holzmaden, Germany). In all the selected comparison cases, the scaly covering in the area immediately above the anal fin insertion is damaged, highlighting the structure and morphology of the pterygiophores to which the basal pieces of the anal fin rays are articulated; in B, however, the early taphonomic processes caused slight translations of both the pterygiophores and the basal pieces of the anal fin rays. A: CCC-S#2046; B: CCC-I#344; C: CCC-S#211; D: CCC-S#1463.

This amber contains inclusions of plants, insects, spiders, and – absolutely occasionally – vertebrates, such as remains of terrestrial reptiles. In few occasion freshwater gastropods were demonstrated, as well as some fluvial gastropods (Poinar, 1992), demonstrating that even in this deposit there is a mix between inclusions of terrestrial origin and inclusions of aquatic origin, at

least of fresh water. We have a number of localities for collecting this fossiliferous amber, but the most important one is the village of Sambava, north-east Madagascar coast, from which come our specimen.

The single piece (CCC-S#804) has a rounded and more elongated shape, very light in color and perfectly translucent, with a clean and polished surface, and respectively have the following dimensions: width 106 mm, height 28 mm and thickness 21 mm (Fig. 5A). This nodule of amber contains a small group of flakes that show characteristics that can be interpreted as fish scales. This is a group of at least 13 flakes (Fig. 5B), whose mutual topographical relationships have certainly been altered by early taphonomic processes, but which still retain some reciprocal relationships. The shape of each scale is sub-circular *vs* rhomboid, but on one side there is a polarity of the scale showing an acute angle. All scales clearly show the presence of two separate areas: a posterior one, whose surface was exposed, and an anterior one, whose surface was imbricated beneath the facing scales (Fig. 5 C).

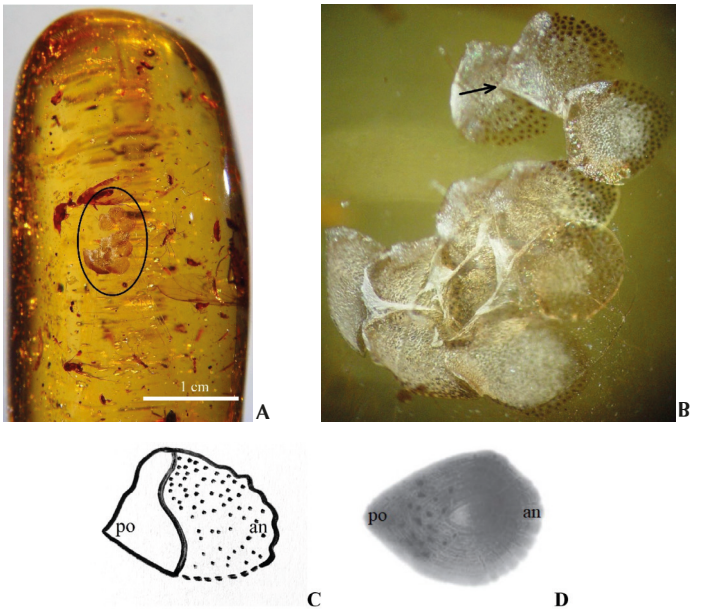


Fig. 5 - Large fragment of Pliocene amber perfectly yellow transparent, collected near the village of Sambava, north-east Madagascar coast (scale in mm) (A), containing a group of at least 13 assumed cycloid-type flakes (B), that perhaps belonged to a small teleost fish; note the presence of small colored macules on the anterior pole of the scales; the arrows point at the posterior apex (CCC-S#804). The surface of these scales shows both the free posterior zone (po) and the anterior zone (an), covered by the facing scales (C); the general morphology of these scales corresponds well to the "reversed ovoid" subtype of Bräger and Moritz (2016) (D) (reproduced from Bräger and Moritz, 2016, modified).

The general morphology of these scales corresponds to the "reversed ovoid" subtype of the Bräger and Moritz (2016) classification (Fig. 5D); it is a cycloid scale subtype that corresponds to the following description "*Rounded outline, slightly elongated in antero-posterior axis, with wider (never flattened) anterior field and narrower, slightly pointed posterior field.*" (Bräger and Moritz, 2016). Comparing the typology standardized by Bräger and Moritz (2016) with that of one of the scales from the Pliocene of Madagascar, the morphological correspondence can be better appreciated (Fig. 5 C,D). The surface of the scales is characterized, on the side opposite to the marginal angularity, by the presence of speckling which probably represents the remains of primary, original pigmentation. Observation under a reflected light optical microscope highlights the presence of the typical, almost concentric growth lines. The dimensions of the preserved scales vary approximately from 2 to 4 mm.

The macroscopic morphology and the microscopic structure of this find allow it to be potentially interpreted as a small group of cycloid scales, that perhaps belonged to a small, undeterminable teleost fish. However, in this regard it can be recalled that Bräger and Moritz (2016) themselves report that the cycloid scales of the reversed ovoid subtype are present in some species currently living in the Mediterranean and belonging to the Albuliformes, Clupeiformes and Gasterosteiformes.

DISCUSSION

The two cases presented here are possible fish remains trapped in amber. This was an almost impossible prospect until a few years ago, as the presence in amber of remains of aquatic organisms, but above all, of organisms typical of the marine environment, seemed to be a paradoxical contradiction. Above all, the most recent discoveries have not only demonstrated that this occurrence exists, but that it is very ancient: the demonstration of the shell of an ammonite – an unequivocally marine cephalopod – in the Late Cretaceous amber from Myanmar is emblematic under this point of view (Yu *et al.*, 2019).

Therefore, beyond the obvious uncertainty that the intertwining of the fossils I have presented here, a new contradiction opens up: among those inclusions in the amber, why shouldn't fish also be present, alongside the remains of all the other vertebrates, such as reptiles, amphibians, birds and mammals? In the absence of a convincing answer to this rhetorical question, more accurate observations must be made and attention paid to identifying clear characters that allow the presence of fish remains to be unequivocally distinguished among the resin inclusions.

Among the samples I have described here, some are certainly doubtful. In fact, the remains interpreted as flakes fish cycloids in Pliocene amber from Madagascar, could, perhaps, but it is frankly more difficult to find alternative interpretations, if we consider the convincing similarity with some subtypes of current cycloid scales.

The find from the Late Cretaceous amber from Myanmar seem to be equally doubtful, but it seems difficult to find credible alternatives to the interpretation proposed here. In fact, the association between scales convincingly of presumed ganoid structure, still imbricated in characteristic rows ordered, in association with filiform presumed bones which are arranged in a radial manner and which emerge from below the group of scales, leave little doubt that this remains is a fragment of the integument of a small specimen of Lepisosteiformes, comprising a part of its scaly ganoid integument and a part of a fin.

Nevertheless, the example of the "sun spangles", largely documented in Eocene ambers from the Baltic area, shows that there are also inclusions that present morphological characteristics clearly similar to those of the scales of some fish, even though they derive, according to the hypothesis put forward by Eriksson and Poinar (2015), from the thermal collapse of air bubbles.

CONCLUSIONS

The cases discussed in this paper demonstrate that (i) the preservation of fossil remains of fish – already cited by a single ancient author on the basis of specimens today unfortunately lost – is highly probable, especially in the light of new evidence that has unequivocally demonstrated the presence of fossil remains of aquatic organisms, even marine ones, present as inclusions in amber and that (ii) the determination of inclusions in amber as definitely fossil remains of fish is very difficult, also due to the presence of pseudofossils.

Nevertheless, at least two finds, described here in detail, concern the presence of possible fossil fish remains preserved in amber from different deposits: the Late Cretaceous of Myanmar and the Pliocene of Madagascar.

These finds indicate – for the first time and with different probability – that also fish can be counted among the bio-inclusions of amber and confirm that even vertebrates of aquatic origin, both limnic fresh water and littoral marine water, were trapped by the amber in various geological eras and in different geographical contexts.

The discovery reported here, therefore, potentially opens a new line of research on fossil fish, concretely offering the opportunity to collect evidence

also on the morphology and anatomy of the soft parts of these aquatic vertebrates, also relating to relatively ancient times and to extinct taxonymic groups, such as the teleosts and the semionotiformes *vs* lepisosteiformes fishes.

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