Illustration of diversity in plant fossil environment

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Abstract

Fossil plants provide information on the ancient environment and evolution. Plant fossil inclusions are found in both amber and limestones and provide information on syninclusions with other organisms. In this study, amber pieces from Burma, Baltic Sea and Dominican Republic were studied together with London Clay Formation petrified wood, Welo opal from Ethiopia, German fossil pinecone, American Pennsylvanian fossil fern, Australian fossil leaf, and Brazilian fossil grasshopper with plant thalloid liverworts. Plants were identified in all pieces with syninclusions of lichens, animal remains, enhydro water bubbles, winged ant, nematode, crane flies, ants, millipedes, Betsy beetle, mollusks and grasshopper. The results of the study approached ecosystem representations from different regions and epochs (ancient to recent ca. 0.01 to 359 Mya, Pleistocene, Miocene, Oligocene, Eocene, Cretaceous, Permian, Carboniferous) with coexistence of plants with different organisms with and without possible ecological interactions.

Keywords: Amber; Environment; Evolution; Fossil; Limestone; Opal; Plant; Syninclusions

Introduction

Fossils provide evidence of the evolution of life on Earth in a geologic context (de la Fuente 2026a). Fossil organisms are found in amber and limestones and are not only connected with science, but also with art, education and communication (de la Fuente 2025, 2026b).

The fossil amber comes from sticky terpene resin exuded by coniferous trees in which other organisms and remains from mainly arthropods but also plants, gastropods, aquatic organisms, vertebrates and environmental microorganisms get trapped in the fresh resin and before polymerization into copal in water (de la Fuente 2026a, 2026b). Fossilization of the copal then occurs during millions of years by pressure, heat, oxidation and removal of essential oils to produce the hard and stable amber with inclusions (e.g., de la Fuente and Estrada-Peña 2026; reviewed by de la Fuente 2026a, 2026b, de la Fuente et al. 2026).

Plant fossils have been described in limestones (Steadman et al. 2007, Stockey et al. 2020) and amber pieces (Poinar Jr. 1994, Pérez-de la Fuente et al. 2016, Sadowski et al. 2018, Heinrichs et al. 2018, Sadowski and Schmidt 2020, Sadowski et al. 2021, Sadowski and Hofmann 2023, Huang and Wang 2025, de la Fuente and Estrada-Peña 2026, de la Fuente 2026a) from different locations and epochs with and without syninclusions with other organisms.

As approached in this study, the description of plant fossil inclusions with and without syninclusions in amber and limestones provides information not only for the study of the evolution of these organisms, but also about the diversity in environments in which ancient plants were present. This information can be used in paleoecological and paleoclimatic studies to reconstruct ancient ecosystems, climates, and plant-animal coexistence with possible interactions.

Materials and Methods

Fossils

To illustrate the diversity of plant fossil environment, the study used plant fossil inclusions from different materials, geographic origins and epochs. Amber pieces were polished under natural conditions and certified as authentic by tests with UV light, saltwater floating, sinks in fresh water, acetone resistant, and heat-smell of pine resin. Fossil pieces originated from KGJ Collection (Ciudad Real, Spain) and ensures that "Amber provider knows that in line with the laws and regulations in his country it is allowed to sell/export these objects”. London Clay Formation petrified wood was provided and certified by Lithologia (https://www.lithologia.com). Ethiopian Welo opal was selected by Antonio Rapisarda, TonyMinerals (www.tonyminerals.it).

Burmese amber (Burmite). From Hukawng Valley, Myanmar, Cretaceous, ca. 99 Mya, 31.5 x 14.7 x 7.6 mm, 2.54 g, KGJ Collection reference G3 (Figs. 1A, 1B, 2A-2E). Burmite originated from coniferous trees of the Araucariaceae family and *Metasequoia* dawn redwood.

Russian Baltic amber. From Sambian Peninsula, Kaliningrad, Russia, Eocene, ca. 35-48 Mya, 65 x 35 x 18 mm, 24g, KGJ Collection reference G8 (Figs. 3A-3D). Fossil resin was primarily produced by coniferous trees from the Sciadopityaceae family umbrella pines.

Ukrainian Baltic amber. From Ukrainian Baltic Sea. Eocene, ca. 35-48 Mya, 55 x 10 x 23 mm, 20g, KGJ Collection reference G9 (Figs. 4A-4D). Fossil resin was primarily produced by coniferous trees from the Sciadopityaceae family umbrella pines.

Dominican amber. From Siete Cañadas, Cordillera Oriental, Santiago de Caballeros, Dominican Republic, Oligocene-Eocene, ca. 20-25 Mya, 100 x 85 x 30 mm, 530 cts, 106 g, KGJ Collection reference G7 (Figs. 5A-5C, 6A, 6B). Fossil resins originate mainly from the Fabaceae *Hymenaea protera* tree (Stach et al. 2020).

UK-London Clay Formation petrified wood. From Isle of Sheppey, Kent, England, United Kingdom, London Clay Formation, Eocene, 34-56 Mya, 220 x 140 x 20 mm, 1.08 Kg, KGJ Collection reference J1 (Figs. 7A-7D). Polished on one side (Fig. 7A) and natural on the other side (Fig. 7B).

Ethiopian Welo (or Wollo) opal. Hydrophane precious opal (SiO_2 nH_2O) discovered in 2008 near Wegel Tena in Wollo Province, Ethiopia, Miocene, ca. 15 Mya, 12.5 x 9 x 7 mm, 0.69 g, 3.45 cts, KGJ Collection reference J2. Polished with untreated multicolor with highest brightness 4.5 out of 5.0 (B4.5 on the 1–5 or B1–B7 scale) considered very bright to brilliant (Figs. 8A and 8B).

German fossil pinecone. Fossil pinecone, *Picea abies* (Norway spruce) from a gravel quarry on the Rhine in Germany, Pleistocene (0.0117-2.58 Mya), 55 x 28 x 25 mm, KGJ Collection reference J3 (Fig. 9A).

American Pennsylvanian fossil fern. Fossil seed fern, *Macroneuropteris scheuchzeri* from the Late Carboniferous (Pennsylvanian) period (299-359 Mya), Moscovian/Desmoinesian age strata of Mazon Creek, Grundy County, Illinois, USA, 70 x 42 mm, KGJ Collection reference J4 (Fig. 9B). The fossil was collected in the 1920s and stored in a long-ago collection for ca. 100 years.

Australian fossil leaves. Fossil leaves, extinct *Glossopteris browniana* (Brongniart 1892) from the Late Permian period (251-260 Mya), Illawarra Coal Measures, Dunedoo Formation, Cobbora, Central West District, New South Wales, Australia, 128 x 106 x 18 mm, KGJ Collection reference J5 (Fig. 10).

Brazilian fossil grasshopper with plant remains. Fossil limestone with syninclusions of a grasshopper and plant remains from Cretaceous Aptian period (ca. 92-113 Mya), Crato Formation, Araripe Basin, Northeastern Brazil, 100 x 100 x 20 mm, KGJ Collection reference J6 (Fig. 11). Acquired at Sainte Marie show in 2008.

Image capture and morphological analysis

Images of amber pieces were captured as previously reported (de la Fuente et al. 2024, de la Fuente et al. 2026, de la Fuente and Estrada-Peña 2026) using a Leica (L`Hospitalet de Llobregat, Barcelona, Spain) M80 routine stereomicroscope with a 1X PLAN objective and a 2X-6X zoom (https://www.leica-microsystems.com/products/light-microscopes/stereo-microscopes/p/leica-m80/) and a Carl Zeiss stereomicroscope (SteREO Discovery V12, Munich, Germany) using the ZEN 2 pro software. Microscope images were analyzed using Image J program (https://imagej.net/ij/) and interpretative camera drawings were generated with the Befunky application (https://www.befunky.com/features/photo-to-sketch/). The Camera Canon EOS 90D with lens Canon MP-E 65mm f/2.8 1–5x Macro and StackShot Macro Rail Package Helicon software (Cognisys, https://cognisys-inc.com) was also used for some images. For classification of fossil inclusions, morphology references by Fossil Identifier (https://www.identifyrock.net/tools/fossil-identifier) and published literature were used. Drawings were generated with ColorifyAI (https://colorifyai.art/photo-to-sketch/).

Results and Discussion

Angiosperm Fagaceae beech family flowering plants and flower-like lichens orange dots with animal bone sysninclusions in Cretaceous Burmese amber fossil environment (Cretaceous, ca. 99 Mya)

The Burmite (Fig. 1A) includes Cretaceous syninclusions of Angiosperm flowering plants with flower-like lichens red dots, enhydro water bubbles, animal bone and/or coprolite remains and other plant inclusions (Figs. 1B, 2A-2E) (Wing and Boucher 1998).

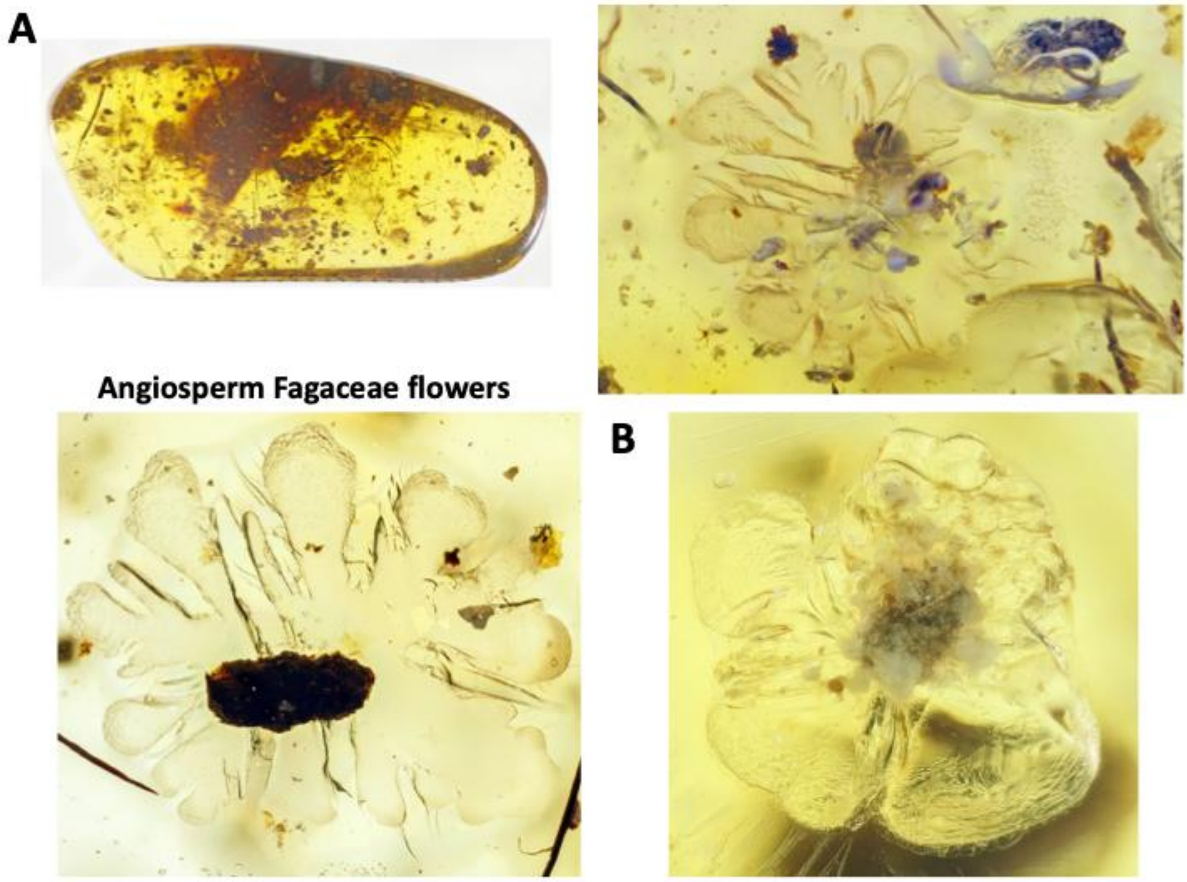

Figure 1. Angiosperm Fagaceae beech family flowering plants in Burmese amber fossil environment (Cretaceous, ca. 99 Mya). (A) Burmite piece (31.5 x 14.7 x 7.6 mm, 2.54 g). (B) Angiosperm Fagaceae flowers (flowers size, ca. 2-3 mm).

The flowers show a pentamerous structure with radial arrangement of thin, spreading petal-like lobes around a darker central mass that resembles a central reproductive core typical in Angiosperm Fagaceae (beech family) flowering plants (Fig. 1B). The lobes are translucent and laminar with gentle curvature like corolla petals or sepals, and the central cluster could be stamens and a pistil or aggregated anthers and pollen. Amber commonly preserves small blossoms intact, and the overall symmetry and soft-tissue appearance match a small flowering-plant corolla preserved in resin. Stellate trichome from a Fagaceae family plant further support plant identification (Fig. 2A). Botanical debris from Fagaceae and possible other plants are abundant amber inclusions (Fig. 2B)

Flower-like foliose lichens such as *Xanthoria parietina*, known as common orange lichens, are visually striking symbiotic organism fungi with algae/cyanobacteria that grow in rosette, leafy or shrub-like forms on trees and other surfaces (Fig. 2C). They are habitat and food source for animals and birds, key environmental indicators for air quality and provide vital ecosystem services as bioindicators of air pollution.

Enhydro amber contains rare, ancient water droplets trapped inside fossilized resin for millions of years featuring visible movable or not air bubbles (Fig. 2D). Enhydro water bubbles found in Burmese amber represent liquid from the dinosaur era.

Animal bone and/or coprolite remains were identified in close contact with plant debris and enhydro water bubbles (Fig. 2E), which reflets ancient coexistence of these syninclusions.

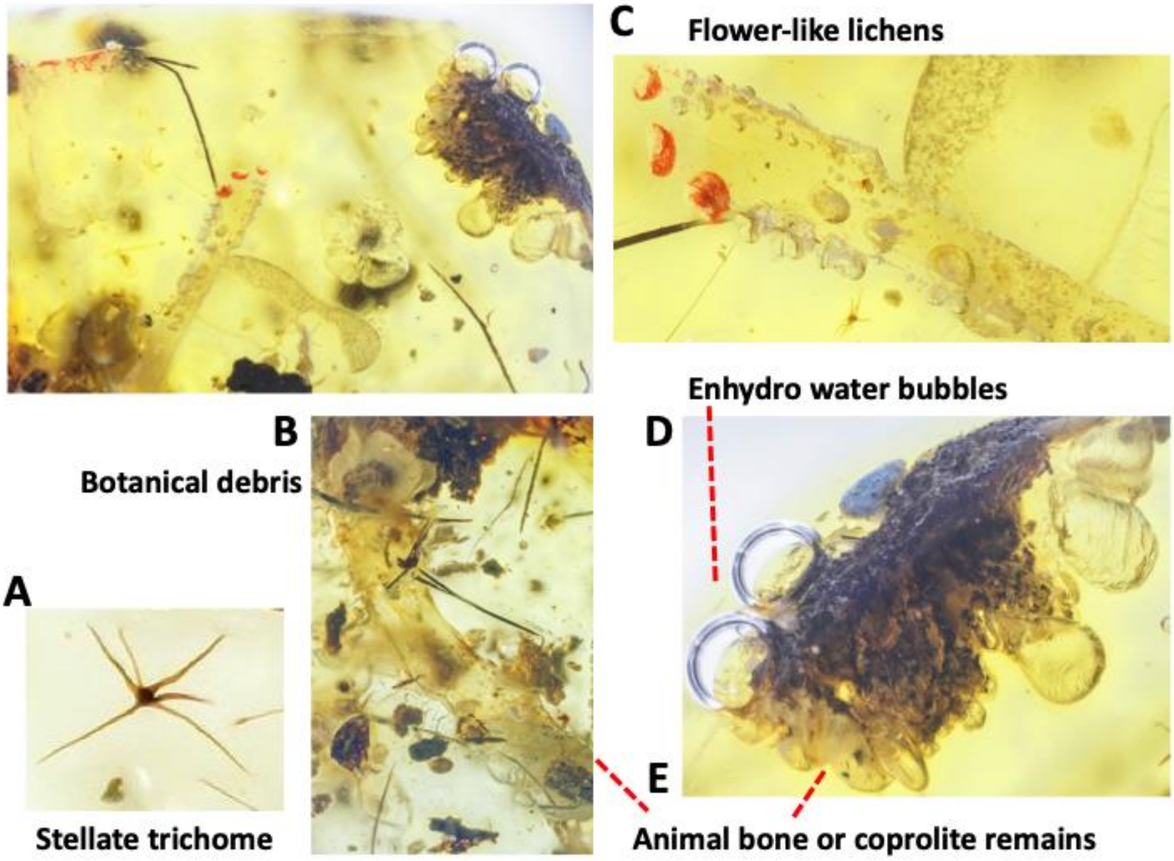

Figure 2. Flower-like lichens orange dots and other syninclusions in Burmese amber fossil environment (Cretaceous, ca. 99 Mya). (A) Stellate trichome. (B) Botanical debris. (C) Flower-like lichens orange dots. (D) Enhydro water bubbles. (E) Animal bone and/or coprolite remains associated with botanical debris and enhydro water bubbles.

Conifer cone scale with winged ant and nematode syninclusions in Russian Baltic amber fossil environment (Eocene, ca. 35-48 Mya)

In the Russian Baltic amber (Fig. 3A) were identified Eocene syninclusions including a plant moss likely conifer cone scale, an extinct male winged ant (Hymenoptera: Formicidae: *Formica* sp.), and a Mermithidae family nematode (putative *Mermis nigrescens*) (Figs. 3B-3D).

The Hymenoptera Winged ant (Formicinae, *Formica*) with ca. 5 mm showed a 12-13 segmented antennae and specialized wing venation (Fig. 3B). *Formica* wood ants have functional relationship with coniferous forests and are considered ecosystem engineers by building mounds of pine needles and twigs, maintaining high-density foraging trails, and fostering mutualistic relationships with aphids that feed on the trees (Kilpeläinen et al. 2009).

The conifer cone scale shows ca. 4.5 mm with a rigid, triangular, laterally compressed plate with a distinct pointed apex and a broader basal region, matching the classic outline of a seed-cone scale (Fig. 3D). The surface shows parallel, longitudinal striations and a tough texture consistent with woody or sclerified tissue rather than a soft petal or leaf lamina. The base appears broken or split where it would have attached to a cone axis, and the overall size and proportions are typical of small Pinaceae, or cupressaceous cone scales preserved in amber. Conifer cones (strobili) are the seed-bearing reproductive organs of gymnosperms, typically composed of woody, overlapping cone ovuliferous scales arranged around a central axis.

The fossil syninclusion identified as Mermithidae family of nematode worms such as *Mermis nigrescens* displays a long 15-20 mm, unsegmented, thread-like body (Fig. 3C). The specimen is preserved in amber alongside the winged ant insect host, which is the characteristic ecological context for these parasites (Nickle 1972). The curved, smooth posture and the lack of distinct appendages or visible segmentation align with the morphology of juvenile mermithid worms that have recently emerged from or are associated with their hosts in the fossil record.

The identification of Hymenoptera winged ant (Formicinae, *Formica*) and conifer cone scale syninclusions support ancient coexistence with possible interactions between these organisms in the Eocene environment (Kilpeläinen et al. 2009). Interactions between Hymenoptera (specifically winged ants or "alates") and the Mermithidae family of nematodes represent a highly specialized, parasitic, often lethal relationship (Laciny 2021). Mermithids infect ants during their larval stage, and the maturing nematodes (juveniles) develop within the ant's body cavity, influencing the development of the host and emerging only when the ant has reached maturity, often forcing it to behave in ways that aid the parasite (Poinar Jr 2012).

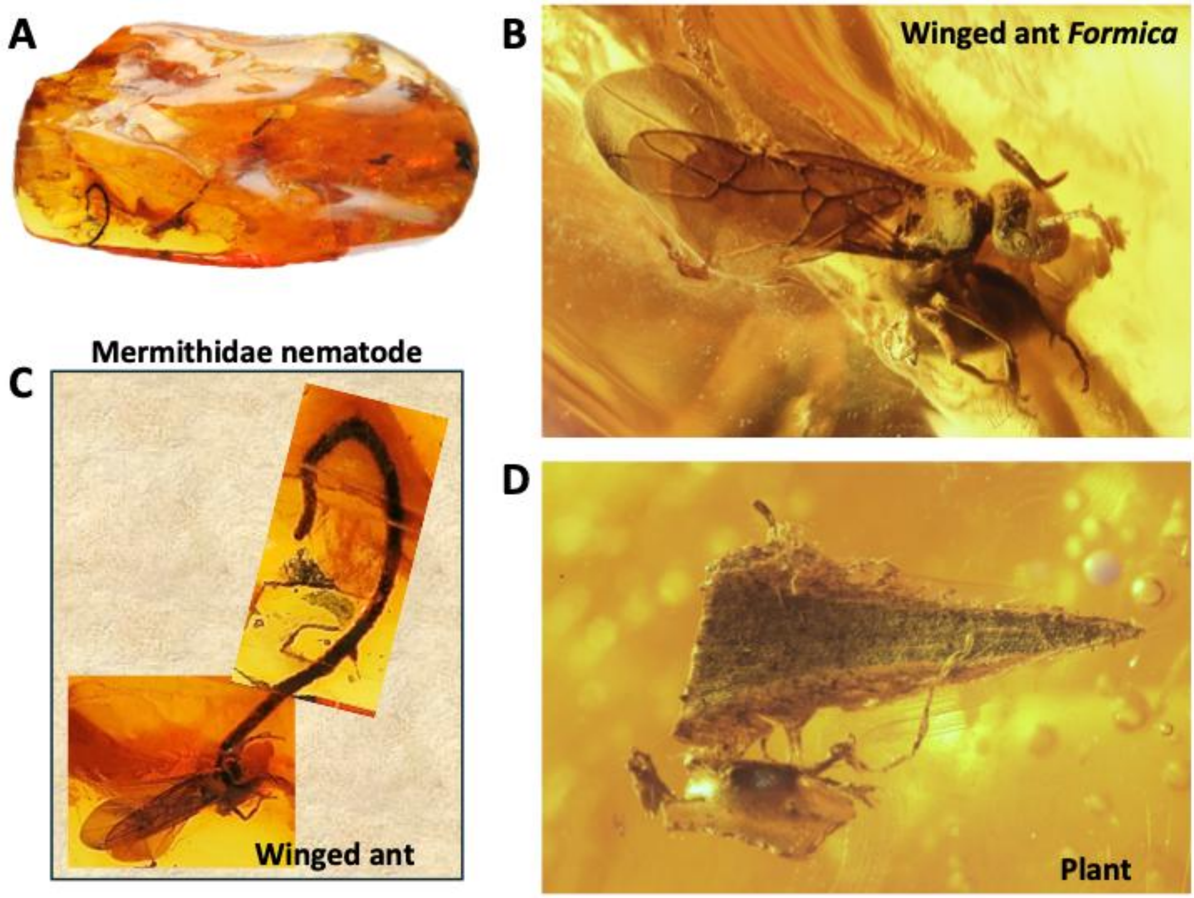

Figure 3. Conifer cone scale with winged ant and nematode syninclusions in Russian Baltic amber fossil environment (Eocene, ca. 35-48 Mya). (A) Russian Baltic amber piece (65 x 35 x 18 mm, 24 g). (B) Winged ant *Formica* sp. with ca. 5 mm. (C) Mermithidae family of nematodes (15-20 mm long) with winged ant interactions. (D) Conifer cone scale with ca. 4.5 mm.

Grass leaf and leafy liverworts with crane flies syninclusions in Ukrainian Baltic amber fossil environment (Eocene, ca. 35-48 Mya)

The identification of plant grass leaf and leafy liverworts in the Eocene Ukrainian Baltic amber (Fig. 4A) is supported by morphological features (Figs. 4B-D).

The fossil liverwort shows a flattened, branched growth habit with overlapping scale-like appendages characteristic of leafy liverworts (Figs. 4B and 4C). The dark, carbonized appearance within the amber represents a high degree of preservation of delicate thalloid or leafy structures that are typical of bryophytes found in resinous deposits. It might be a small branch of a moss or a specialized gymnosperm twig with dense, overlapping leaves. It could also represent a fragment of a lycopod or a highly degraded fern frond that has been compressed and carbonized.

The fossil gras leaf displays a distinct linear parallel venation pattern characteristic of monocots with a long narrow blade-like shape and a tapered tip with prominent longitudinal veins typical of the Poaceae family *Gramineae* (Fig. 4D). However, it could also be a needle from a coniferous tree, such as a pine or redwood, or a narrow leaf from other monocot groups like sedges or rushes.

The inclusions identified as crane flies, putative *Tipulidae* exhibit the characteristic morphology of these family preserved in amber (Fig. 4B). They possess the notably long, slender legs, single pair of functional wings with complex venation, and the elongated, multisegmented antennae typical of crane flies. The presence of two insects in proximity within the resin is a common occurrence for swarming or mating dipterans.

Plant-insect interactions have been described in Cretaceous amber (Pérez-de la Fuente et al. 2016). Interestingly, the displayed interaction between crane flies of the family *Tipulidae* and plants varies depending on their life stages, ranging from beneficial pollination by adults to destructive root-feeding by larvae known as "leatherjackets" (Yang et al. 2022).

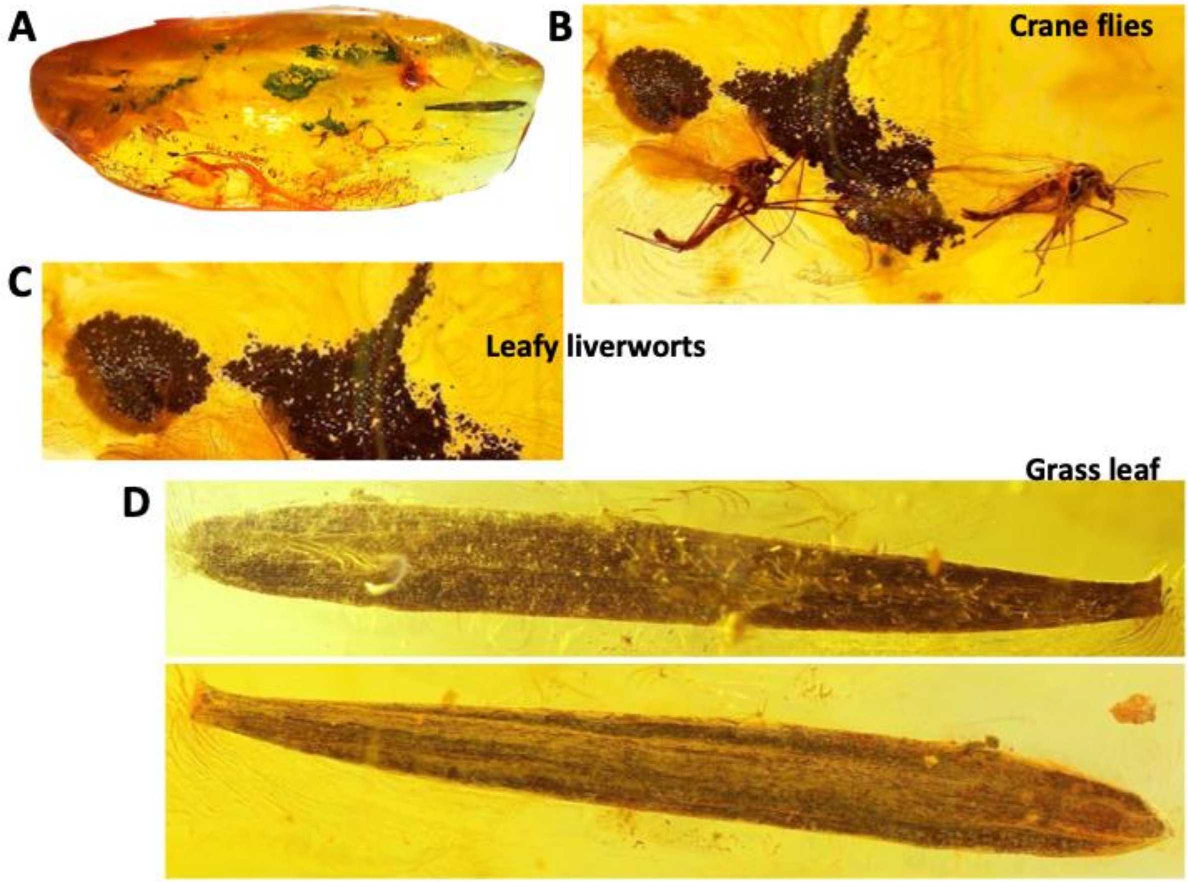

Figure 4. Grass leaf and leafy liverworts with crane flies syninclusions in Ukrainian Baltic amber fossil environment (Eocene, ca. 35-48 Mya). (A) Ukrainian Baltic amber piece (55 x 10 x 23 mm, 20 g). (B) Crane flies (ca. 1.9 mm long) with leafy liverworts. (C) Leafy liverworts. (D) Grass leaf monocot putative Poaceae family *Gramineae* (ca. 8 mm long).

Fabaceae *Hymenaea* seeds with ants, millipedes and Betsy beetle syninclusions in Dominican amber fossil environment (Oligocene-Eocene, 20-25 Mya)

The Dominican amber in a large piece shows multiple syninclusions of plants with large adult ants and larvae, small beetle and millipedes (Figs. 5A and 5B).

The inclusion identified as Betsy beetle (like *Odontotaenius disjunctus*) or Passalidae shows a morphology with a distinctly pedunculate body where the prothorax is separated from the elytra by a narrow waist with a size typical of a larvae (Fig. 5C). The head features prominent, forward-facing mandibles and a rough or tuberculate dorsal surface, while the elytra show deep longitudinal striations. The fossorial legs with thickened femora and tibiae are typical for wood-boring beetles found in amber resin. The Betsy beetle or Passalidae is a large (3.81 cm), glossy black, social beetle found in decaying logs, known for its distinct, forward-curving head horn. These beneficial, wood-recycling insects live in family colonies, communicate with over 14 distinct acoustic sounds, and are among the few beetles that actively care for their young.

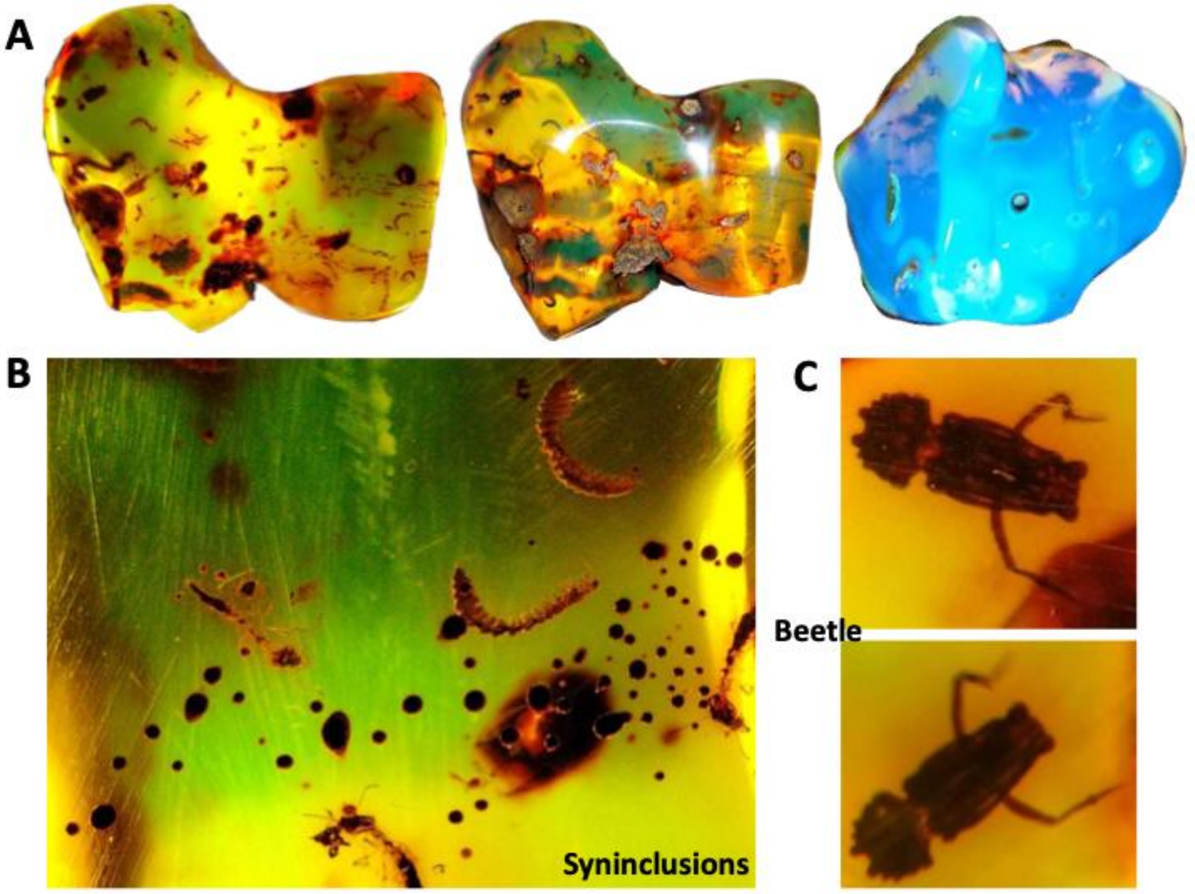

Figure 5. Fabaceae *Hymenaea* seeds with ants, millipede, beetle syninclusions in Dominican amber fossil environment (Oligocene-Eocene, 20-25 Mya). (A) Dominican amber piece (100 x 85 x 30 mm, 530 cts, 106 g). (B) Syninclusions of millipedes (putative order Polydesmida), early ants from a lineage like the Formicidae subfamily Sphecomyrma and Fabaceae *Hymenaea* seeds. (C) Betsy beetle (like *Odontotaenius disjunctus*) or Passalidae larvae (ca. 3.7 mm).

The specimens identified as early ants from a lineage like the Formicidae subfamily *Sphecomyrminae* exhibit the classic morphology of an Isopteran worker preserved in amber

(Figs. 5B and 6A) (Brady et al. 2006). Key features include a moniliform beaded antenna, a soft-bodied appearance with a broad waist, lack of a petiole and a distinct rounded head capsule with strong mandibles (Fig. 6A). The presence of multiple individuals in one piece of amber is common for social insects like ants. The ants were identified with syninclusions of Fabaceae *Hymenaea* seeds (Figs. 5B and 6A). Commonly known as Jatobá or West Indian locust, are large (approximately 5 g), thick-coated and brown, often containing high amounts of viscous polysaccharide xyloglucan used in industry (Calvillo-Canadell et al. 2010). They are found in dry, indehiscent pods in which ants are attracted by its sweet sap.

The fossil millipedes of the putative order Polydesmida (flat-backed millipedes) display the characteristic morphology of a flat-backed millipede, including a segmented body with distinct lateral extensions known as paranota (Figs. 5B and 6B). The presence of two pairs of legs per body ring (diplosegments) is visible in the ventral and lateral views, which is a defining trait of millipedes. The flattened, broad appearance of the segments and the overall body proportions are consistent with members of the order Polydesmida preserved in amber (Riquelme et al. 2021).

The interaction between Betsy beetles (Passalidae), early ants (Formicidae), and Polydesmid millipedes (Polydesmida) is primarily driven by the context of decomposing woody debris such as Fabaceae *Hymenaea* seeds, where these arthropods compete for resources, act as predators, or share microhabitats where they are all essential but often antagonistic key players in forest floor ecology (Sánchez-Piñero and Gómez 1995, Warren and Bradford 2012).

Figure 6. Arthropod syninclusions in the Dominican amber fossil environment. (A) Early ants from a lineage like the Formicidae subfamily Sphecomyrma (ca. 6.0 – 6.5 mm long). (B) Millipedes (putative order Polydesmida) with ca. 7.0 - 7.5 mm long.

Petrified palm wood with mollusk holes in London Clay Formation environment (Eocene, 34-56 Mya)

Fossil palm wood with Teredo (*Teredolites longissimus*) marine mollusk holes were found in Eocene London Clay Formation environment (Fig. 7). The association between petrified palm wood (often classified as *Palmoxylon*) and mollusks represents direct close interactions with marine or coastal organisms (Ruiz et al. 2020). These interactions illustrate how these plants once thrived along ancient volatile coastlines during the Eocene epoch.

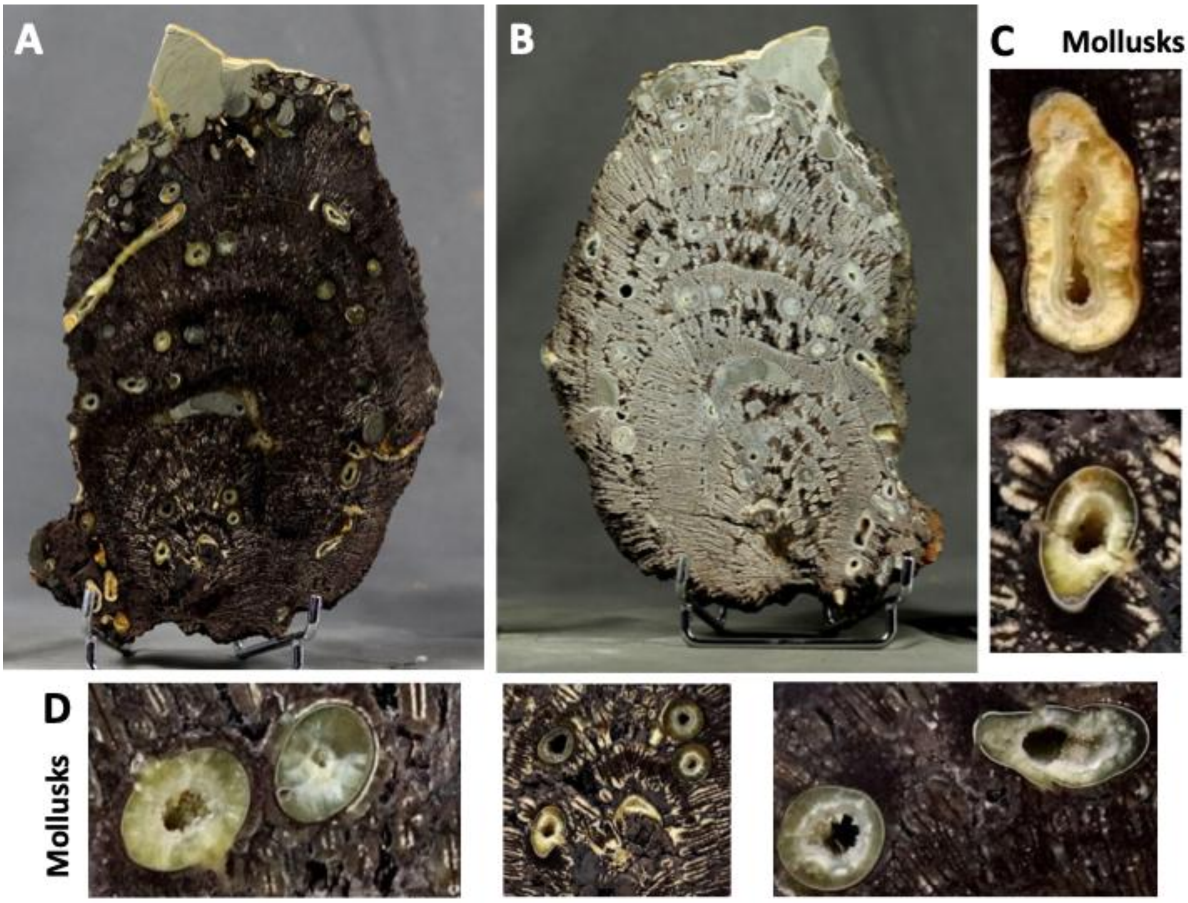

Figure 7. Petrified palm wood with mollusk holes in London Clay Formation environment (Eocene, 34-56 Mya). (A, B) Petrified palm wood with (A) polished and (B) natural sides (220 x 140 x 20 mm, 1.08 Kg). (C, D) Teredo (*Teredolites longissimus*) mollusk holes.

Opalized fossil plants in Ethiopian Welo opal environment (Miocene, ca. 15 Mya)

Opal is a liquid silica, which solidifies over millions of years (Fig. 8A). In some rare cases, biological remains such as plant roots, wood, cones, and leaves are incorporated into the silica, as agglomerated fossil plant remains identified here and reported before in the Ethiopian opal (Rondeau et al. 2012) (Fig. 8B). Opalized fossil plant remains form when silica-rich groundwater replaces organic material with opal over millions of years.

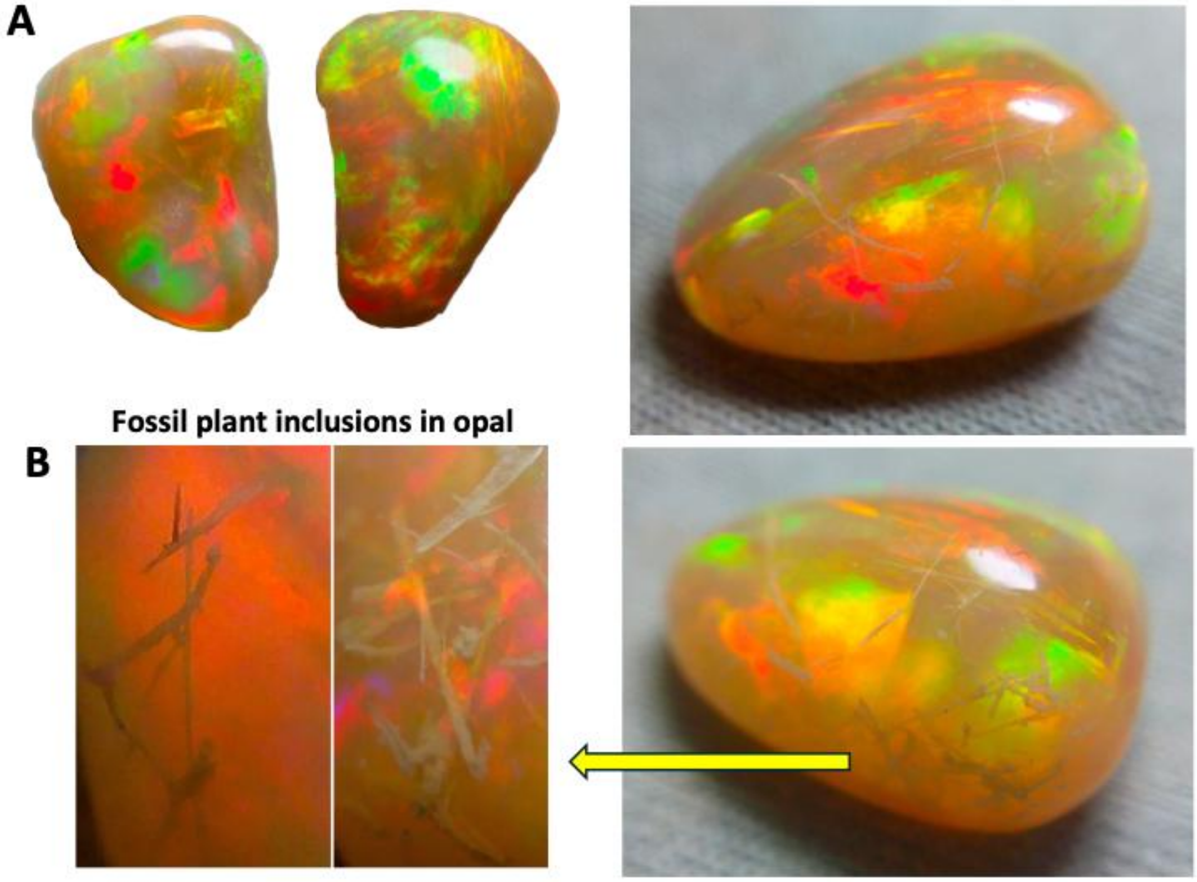

Figure 8. Opalized fossil plants in Ethiopian Welo opal environment (Miocene, ca. 15 Mya). (A) Ethiopian Welo hydrophane precious opal (12.5 x 9 x 7 mm, 0.69 g, 3.45 cts). (B) Fossil plant remains inclusions in opal.

Fossil pinecone in German Rhine environment (Pleistocene, 0.0117-2.58 Mya)

Fossil pinecone of *Picea abies* (Norway spruce) was found in a gravel quarry on the Rhine in Germany (Fig. 9A). These fossil cones are found very rarely in this state of preservation, as they are very brittle and usually break between gravel and larger stones. The identification of fossil records of *P. abies* during the Pleistocene demonstrate that this species was present in Europe during interstadial (warmer) periods, surviving in refugia in southern and central Europe during colder glacial stages (Holyoak 1983).

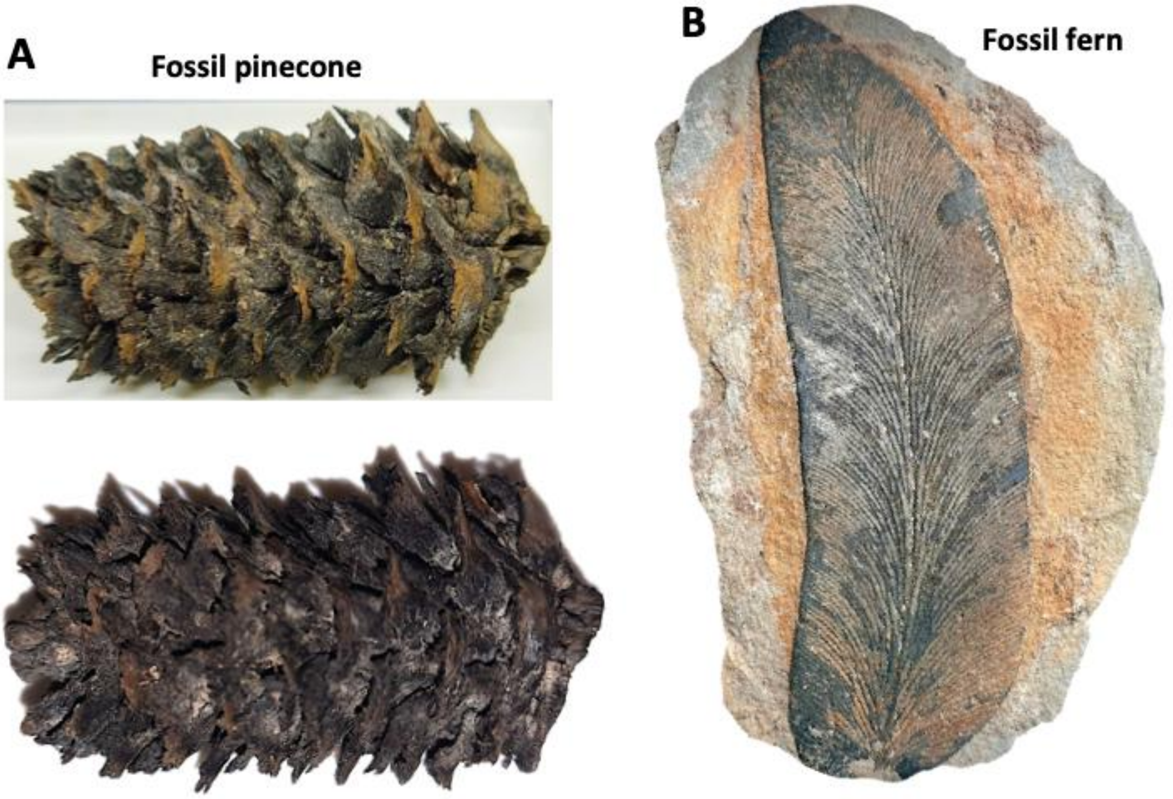

Figure 9. Fossil stones with ancient methods of plant reproduction and adaptation. (A) Fossil pinecone in German Rhine environment (Pleistocene, 0.0117-2.58 Mya). The fossil (55 x 28 x 25 mm) shows high-quality well-preserved details under natural conditions. (B) Fossil fern, *Macroneuropteris scheuchzeri*, from Late Carboniferous (Pennsylvanian) period (299-359 Mya). The fossil (70 x 42 mm) shows a well preserved 3-D fern. Pinecones are the seed-bearing woody organs of conifer trees (gymnosperms), while ferns are vascular, non-flowering plants that reproduce via spores.

Fossil fern in Pennsylvanian environment (Carboniferous, 299-359 Mya)

The fossil seed fern, *Macroneuropteris* scheuchzeri, is a well-known species of arborescent Medullosales seed fern from the Late Carboniferous (Pennsylvanian) period identified in Moscovian/Desmoinesian age strata of Mazon Creek, Grundy County, Illinois, USA (Fig. 9B). Pecopteris is a genus of seed ferns, an extinct group of ferns that reproduced from seeds as opposed to the sporophyte reproduction of most modern ferns (Cleal and Zodrow 1990).

Fossil leaves in Australian environment (Permian, 251-260 Mya)

The fossil specimens are preserved leaves of *Glossopteris browniana* (Brongniart 1892) from the Late Permian period (Fig. 10). The plant inclusion is well preserved with distinguished by its broad, tongue-shaped leaves with prominent venation patterns with its characteristic ribbed texture, indicating the vascular structure that supported the leaf's function in photosynthesis (McLoughlin 2011).

These fossils provide a glimpse into the plant life in the coal-forming swampy forests that dominated the ancient supercontinent Gondwana before the Permian-Triassic extinction event. The plant material in these coal-rich deposits played a vital role in the formation of coal beds that are still significant in modern energy production. *Glossopteris* was a seed-bearing plant and a significant component of the Permian forests, which were composed of dense vegetation that contributed to Earth’s changing climate and ecosystems (McLoughlin 1990).

Figure 10. Limestone with Australian fossil leaves. Fossil leaves of extinct *Glossopteris browniana* (Brongniart 1892) from Australian environment in the Late Permian period (251-260 Mya; 128 x 106 x 18 mm).

Fossil grasshopper and plant thalloid liverworts in Brazilian environment (Permian, 251-260 Mya)

The fossiliferous limestone is from Cretaceous Aptian period (ca. 92-113 Mya) Crato Formation in Northeastern Brazil (Fig. 11A). The specimen shows a small thalloid liverworts with lobate outline and a stalked region bearing a dense cluster of tiny, round, closely spaced dark bodies with a flattened thallus and stalked reproductive receptacles or aggregated sporogenous structures (Fig. 11B) (Gerrienne et al. 2024). The dark dots resemble spores or sporangia preserved as condensed organic or mineralized particles, which is commonly seen in fossil liverworts and other bryophytes. Modern species include *Cyathodium cavernarum* found in the Cerrado and Atlantic Forest and *Noteroclada confluens*.

The grasshopper shows a narrow, elongate body with a clearly preserved forewing bearing parallel longitudinal venation and a large, robust hind leg with an enlarged femur (Fig. 11C). The classic adaptations for jumping seen in grasshoppers (Caelifera). The overall body proportions and wing venation pattern match typical Orthopteran compression fossils rather than winged beetles or flies.

Grasshoppers possess chewing mouthparts designed to tear and ingest plant tissues. While they prefer vascular plants, they are opportunistic feeders and can consume thalloid liverworts, which form part of the ground-level vegetation in damp habitats where some grasshopper species reside (Joern 1979). Thalloid liverworts accumulate heavy metals directly absorved from the atmosphere, water, and substrate through their entire thallus surface (Fasani et al. 2022). Therefore, the consumption of Thalloid liverworts by grasshoppers may have physiological and behavioral impacts (Prakash Devkota and Schmidt 2000).

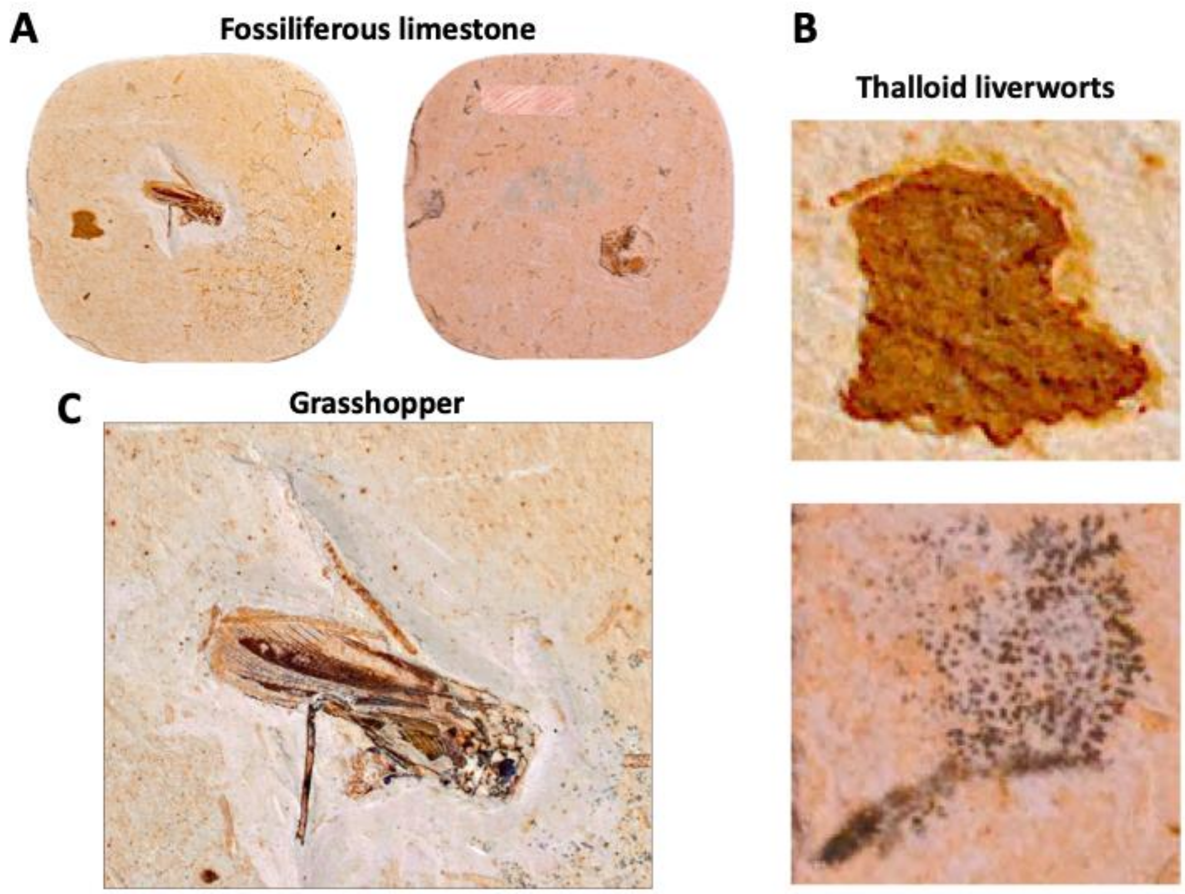

Figure 11. Brazilian fossil grasshopper with plant Thalloid liverworts. Fossil limestone with syninclusions of a grasshopper and plant remains from Cretaceous Aptian period (ca. 92-113 Mya), Crato Formation, Araripe Basin, Northeastern Brazil, 100 x 100 x 20 mm, KGJ Collection reference J6 (Fig. 11).

Conclusions

The results of the study approached ecosystem representations from different regions (East to West, Australia, Myanmar, Russia, Ethiopia, Ukraine, Germany, UK, Brazil, Dominican Republic, Illinois-USA) and epochs (ancient to recent, ca. 0.01 to 359 Mya, Pleistocene, Miocene, Oligocene, Eocene, Cretaceous, Permian, Carboniferous) with coexistence of plants with different organisms with or without ecological interactions (Fig. 12). These representations illustrate the diversity in plant fossil environment.

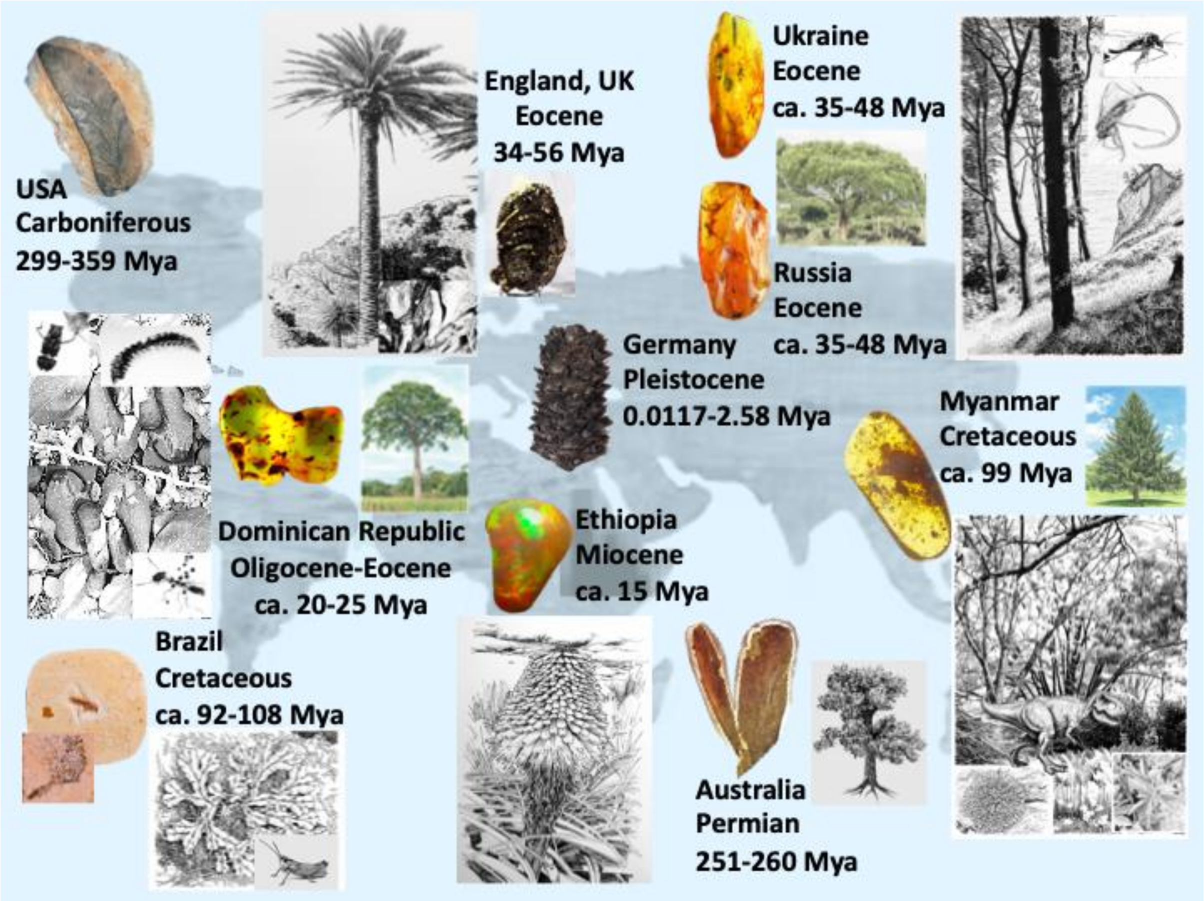

Figure 12. Conclusions of the study: Graphical representation of the diversity in plant fossil environment. Represented fossils were approached in the study. Drawings of fossil plants with identified syninclusions are shown. Plant color drawings illustrate the tree amber origins.

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