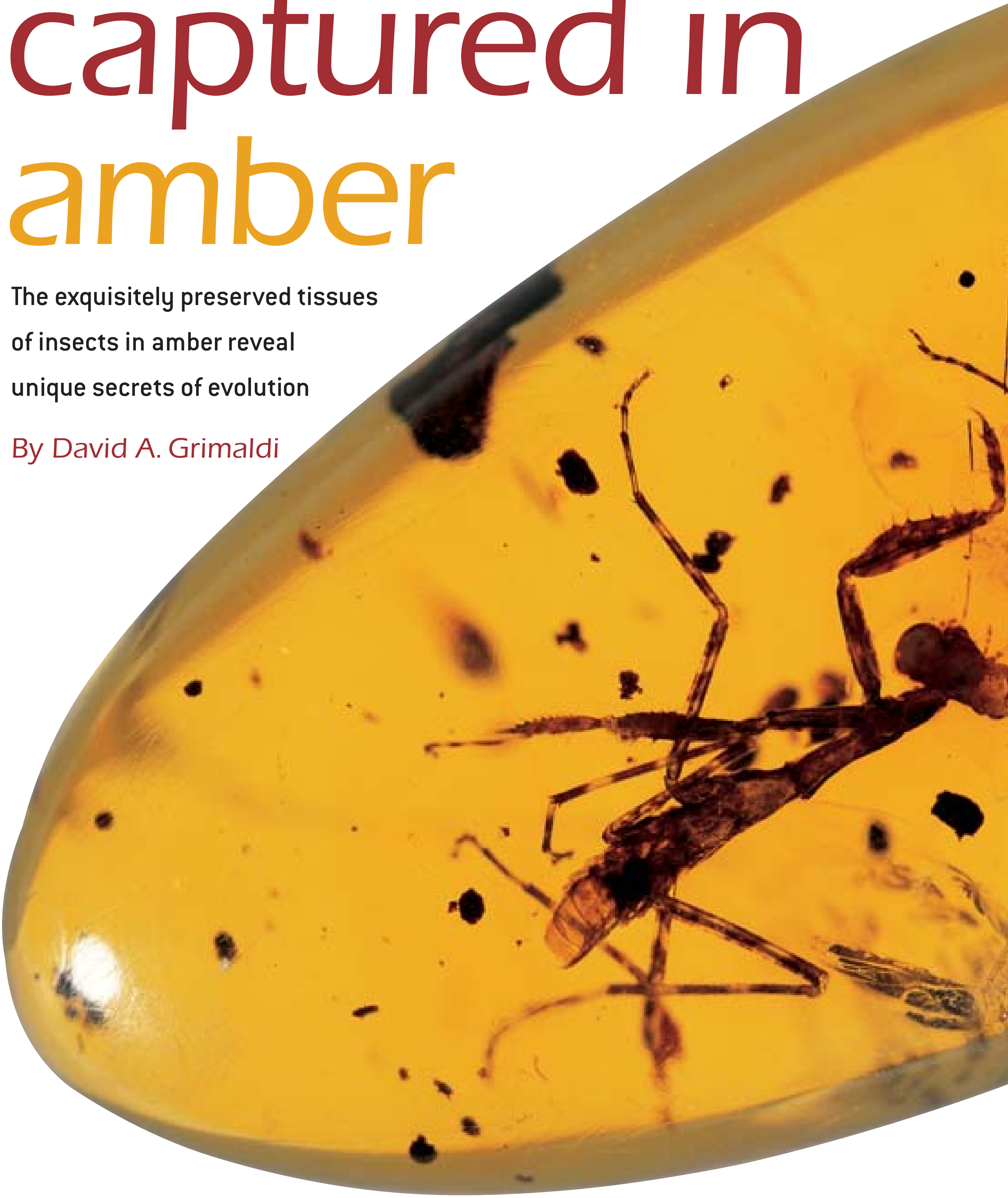
captured in amber

The exquisitely preserved tissues of insects in amber reveal unique secrets of evolution

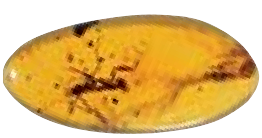
By David A. Grimaldi



Updated from the April 1996 issue

PRAYING MANTIS preserved in Dominican amber—most of which is 25 million years old—is related to cockroaches and termites. This one was probably caught while stalking prey along the trunk of a tree that exuded the amber-producing resin.

ACTUAL SIZE



A hurricane had savaged the forest of giant *Hymenaea* trees along a Central American coastline. Yellow streams of resin oozed from mangled branches and gashed trunks, while insects bred in the wreckage. One termite happened to brush against the resin and stuck fast, ultimately becoming enveloped in its flow. Terpenes and other fragrant vapors from the resin penetrated the termite's tissues, replacing the water and killing bacteria.

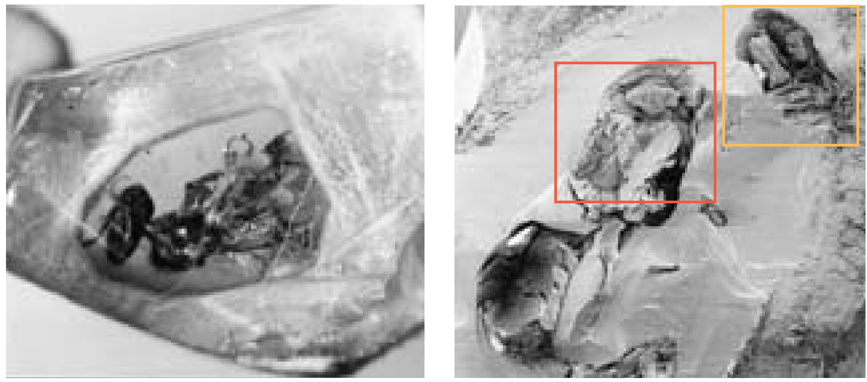
Air, along with light and heat from the sun, induced chemical reactions in the resin so that the carbon atoms in its long molecules began to link up. The chunk of hardening sap fell to the ground, one among thousands. Tides from tropical storms of a later year washed the resin fragments and rotting logs into a lagoon, where coastal sediments covered them. Twenty-five million years of subterranean pressure polymerized the resin even further, making it solid and chemically inert. Tectonic movements eventually lifted the coastline into steep mountains

ED BRIDGES *American Museum of Natural History*

ACTUAL SIZE

a

b



f

g

h

ACTUAL SIZE

DENIS FINNIN *American Museum of Natural History*

3,000 feet high, to become the island of Hispaniola in the Caribbean.

Wandering in those hills some years ago, a Dominican miner came across a small landslide that revealed a black vein of fossilized wood. Digging for hours along the seam, he unearthed a pile of nuggets and the glassy glint of amber. Within one piece lay a very large termite, wings slightly parted and legs splayed.

The amber piece with its embalmed *Mastotermes electrodominicus* found its way to the American Museum of Natural History in New York City. Entomologists have long been intrigued by these primitive insects, which share features with cockroaches and were thought to connect the latter with modern termites. Relatives of *Mastotermes* extinct for 130 million to 30 million years show up in rocks and amber around the world. One species, *M. darwiniensis,* survives to this day in Australia, an evolutionary relic.

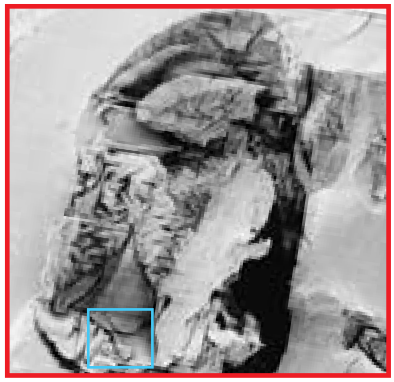
In 1992 I worked with Rob DeSalle, Ward Wheeler and John Gatesy at the museum. The Hispaniola specimen was sliced open, allowing us to extract tissues from the termite. The sample contained exquisitely preserved cells, many with even the mitochondria intact. The tissues were dehydrated, yet they had not shrunk, as one would expect with the water gone. The process by which resin "fixes" tissue so that it retains its original size is still a mystery.

The dehydration was critical to the success of our experiment. After death, DNA degrades in the presence of water; the desiccation had allowed large segments of DNA to survive unaltered. We isolated snippets of the 18s and 16s ribosomal DNA genes. Mapping the sequence of bases on a DNA fragment, we compared it with corresponding sections from living termites, cockroaches and praying mantises, which constitute the group Dictyoptera.

The physical similarity between *Mastotermes* and roaches, it turned out, was a vestige of an even more ancient ancestry. The extinct and living *Mastotermes* were very closely related, both being purely termites. The two species differed by nine base pairs in a segment *c*

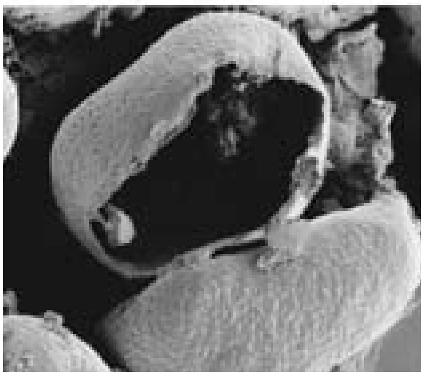
d

e

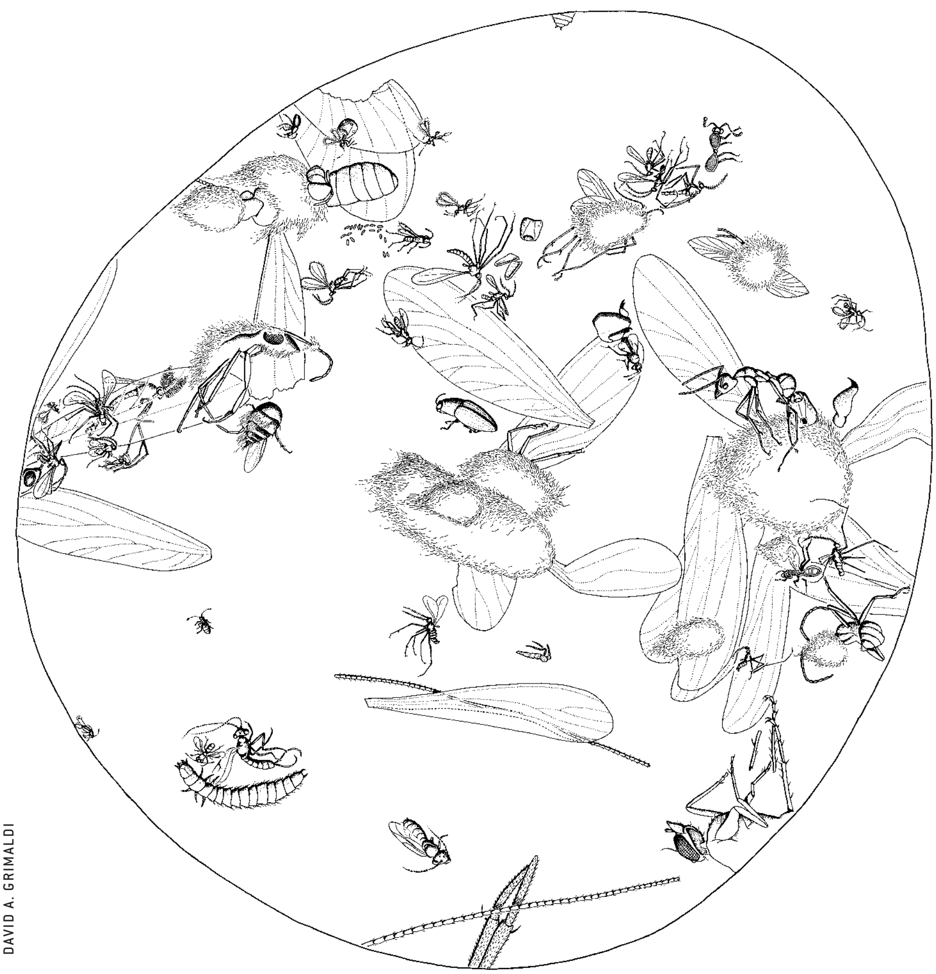


American Museum of Natural History (a–i)

i



SCANNING ELECTRON MICROGRAPHS of a stingless bee, *Proplebeia dominicana,* attest to the astonishing preservation of tissues in amber. The polished piece (*a*) is sawed to within a hair's breadth of the insect, cleaned and gently pried open. The left half of the specimen (*b*) contains parts of the head (*top*), thorax (*middle*) and abdomen (*bottom*). Within the head (*c*) lie the brain (*top middle*) and the long muscles used for sucking (*left*), along with the bee's small tongue (*bottom*). The scales on the tongue (*d*) are each about 10 microns long. The thorax (*e*) contains folded air sacs and, among other structures, a small bundle of muscles (*f*), each fiber of which is about 15 microns thick. The right half of the specimen (*g*) holds another part of the abdomen (*lower right*), along with pollen grains (*h*) that the bee had ingested. A single grain (*i*), viewed here from a different angle, is about 30 microns across. Stingless bees are common in Dominican amber: while harvesting the resin to construct their nests, the bees were often trapped instead.



DAVID A. GRIMALDI

MENAGERIE IN AMBER (*far left*) contains 62 whole and partial insects, all within a piece just 2.8 centimeters across. A map of the specimen (*left*), drawn by the author, depicts insects belonging to five orders and 14 families. Among them are several gall midges, ants, adult and larval beetles, and parasitoid wasps—including one that has just deposited her eggs (*top left*). Termite wings and antennae float across the scene; parts of three termites are sticking out of fuzzy mold. (Some of the insects were probably only partially trapped at first. The exposed parts decomposed, became moldy and were then covered by another layer of resin.)

of the 16s gene with 100 base pairs. The extinct DNA enabled us to reconstruct the evolutionary tree for the group and helped to clarify the relation of *M. darwiniensis* to other termites.

Since that study, DNA has been reported from a *Drosophila* fruit fly, a stingless bee, a wood gnat, a fungus gnat, and tree leaf and chrysomelid beetles, all preserved in Dominican amber. Raul J. Cano and his colleagues at California Polytechnic State University reported sequenced DNA from a weevil in Lebanese amber; at 125 million years old it would be the most ancient DNA known.

Thorough work on putatively ancient DNA from amber was done in 1998 at the University of Illinois and the Natural History Museum in London. Ancient DNA was not recovered from any specimens, though, suggesting that DNA in earlier reports may have been contaminated by DNA from living insects being studied simultaneously in laboratories. Nevertheless, the tissue preservation observed continues to astound. In 2001, working with Lynn Margulis and Michael Dolan of the University of Massachusetts at Amherst, my laboratory unearthed microscopic remains of symbiotic protists and bacteria-like spirochetes in the gut of an extinct termite. Modern termites require such microbes to digest cellulose. Our work proves that ancient relatives were similarly dependent.

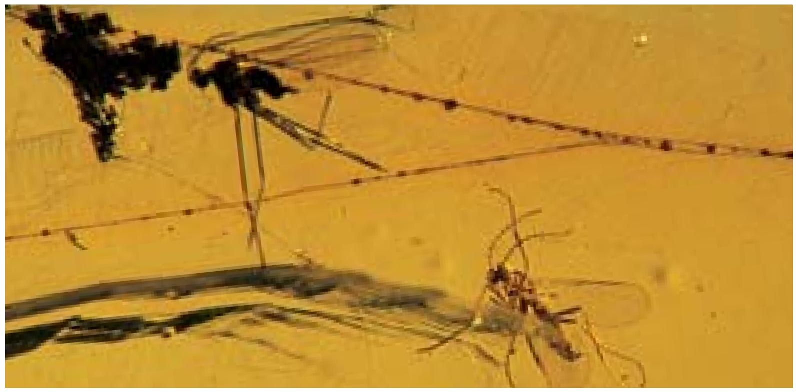
Right now amber from the Cretaceous period of 140 million to 65 million years ago is attracting scientists' attention. Dinosaurs died out at the end of this period; more important, the landscape transformed during its tenure. Flowering plants blossomed onto the scene. Many modern groups of insects evolved: ants, termites, bees, moths, butterflies, beetles and other creatures associated with flowering plants.

One of the most important deposits of Cretaceous amber, from 94 million to 90 million years old, was discovered in central New Jersey in 1992. This trove has yielded some extraordinary fossils. Among the startling finds is a bird feather—the oldest terrestrial record of a bird in North America—and the oldest definitive bee and ants. In addition, we have uncovered the only flower in Cretaceous amber, a small inflorescence of the most primitive known oak.

The New Jersey amber has yielded the oldest fossil tardigrade—a minute animal closely related to arthropods—and it is extremely similar to modern species, indicating that remarkably little has changed in 90 million years. Other significant finds include 100-million-year-old amber from northern Myanmar (Burma) that contains diverse organisms. We are eager to learn more. SA

CAUGHT IN THE ACT

INSECT TABLEAUX sealed in Dominican amber have demonstrated that some familiar behaviors are at least 25 million years old.



STRANDS OF A SPIDER'S WEB snag one of two delicate gall midges, in the family Cecidomyiidae.

THREE ANTS ATTACK a nymphal praying mantis, evidence of cooperative hunting—or, possibly, defense—among ants.

DAVID A. GRIMALDI (*top*); JACKIE BECKETT *American Museum of Natural History* (*bottom*)

LOVE AND DEATH unite two mating gall midges, providing specimens of both sexes. The female would have laid about 100 eggs, the larvae of which feed on fungi.

LAYING EGGS as it dies, a moth demonstrates a reflexive action observed in many insects. Larvae of this moth (family unknown, probably Tineoid) are thought to have fed on hard, woody bracket fungi that infected *Hymenaea* trees.

QUEEN ANT of the genus *Acropyga* carries a scale insect in her jaws, in an exceptional example of symbiosis. Some ants tend colonies of such insects, from which they harvest a sugary secretion called honeydew. (Some modern-day relatives of scale insects are common garden pests, such as whiteflies.) As the queen departs her old colony, she takes a scale insect along on her nuptial flight to start her new nest.

MITE CLINGS to the abdomen of a chironomid midge. These midges live in water or very damp soil during their larval stages, picking up the mites.

BITING MIDGE (family Ceratopogonidae) is bloated after a blood meal. Popular culture holds that blood from similar midges in Cretaceous amber was ingested from dinosaurs. This midge, however, lived 40 million years after the dinosaurs had vanished.

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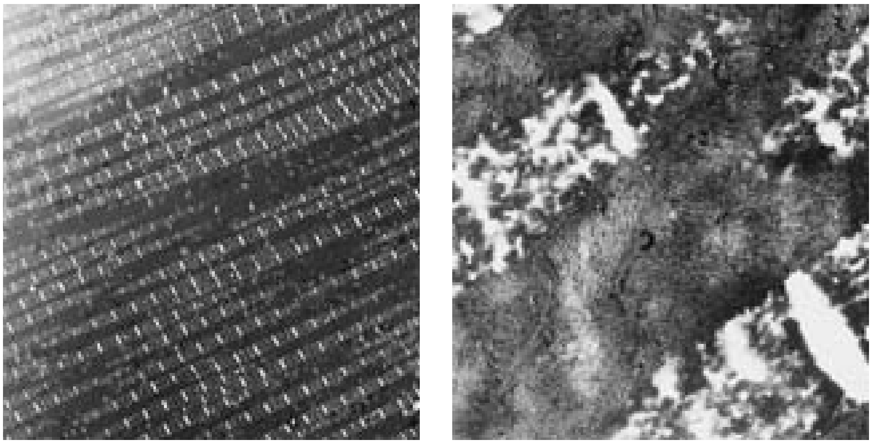
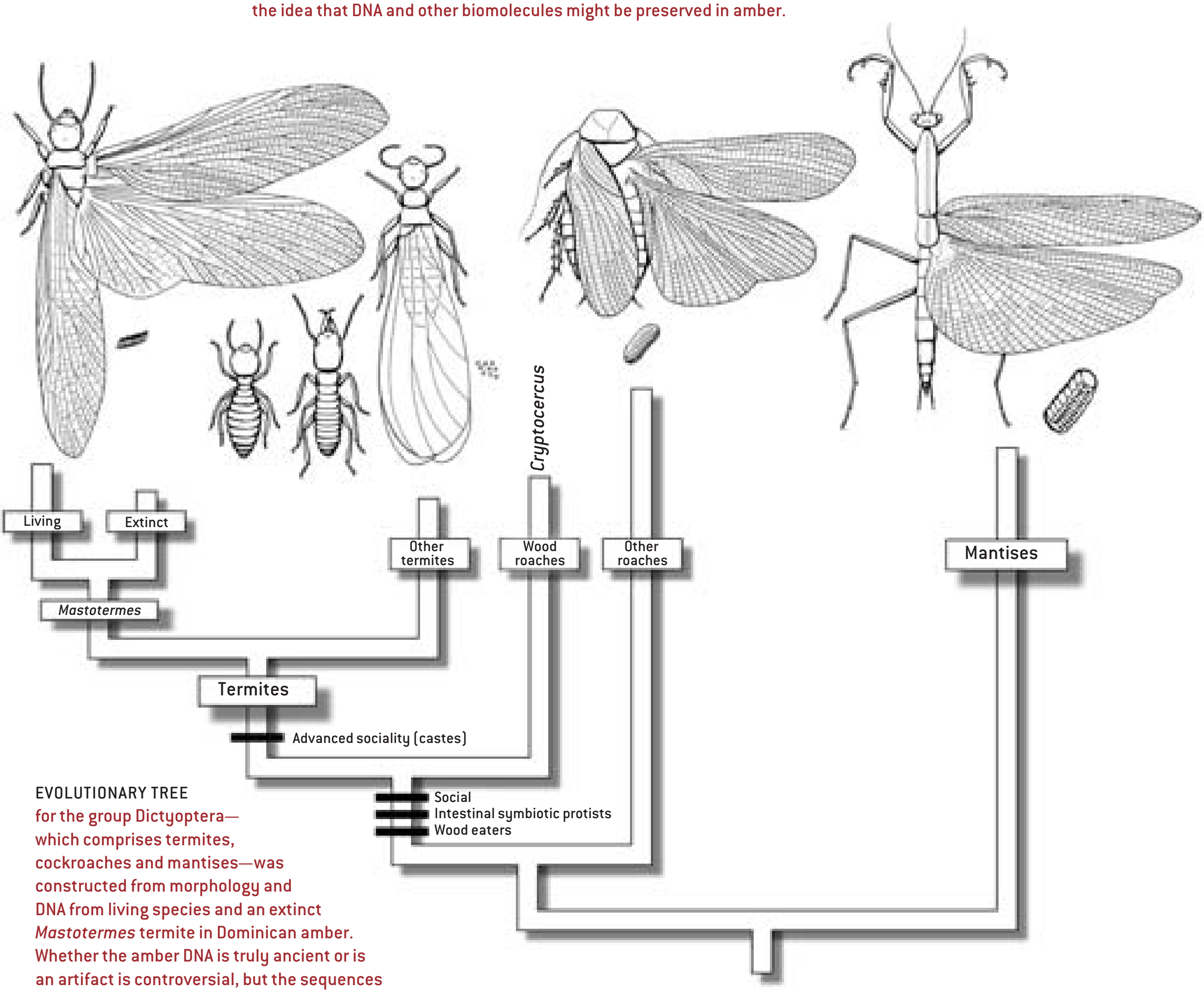
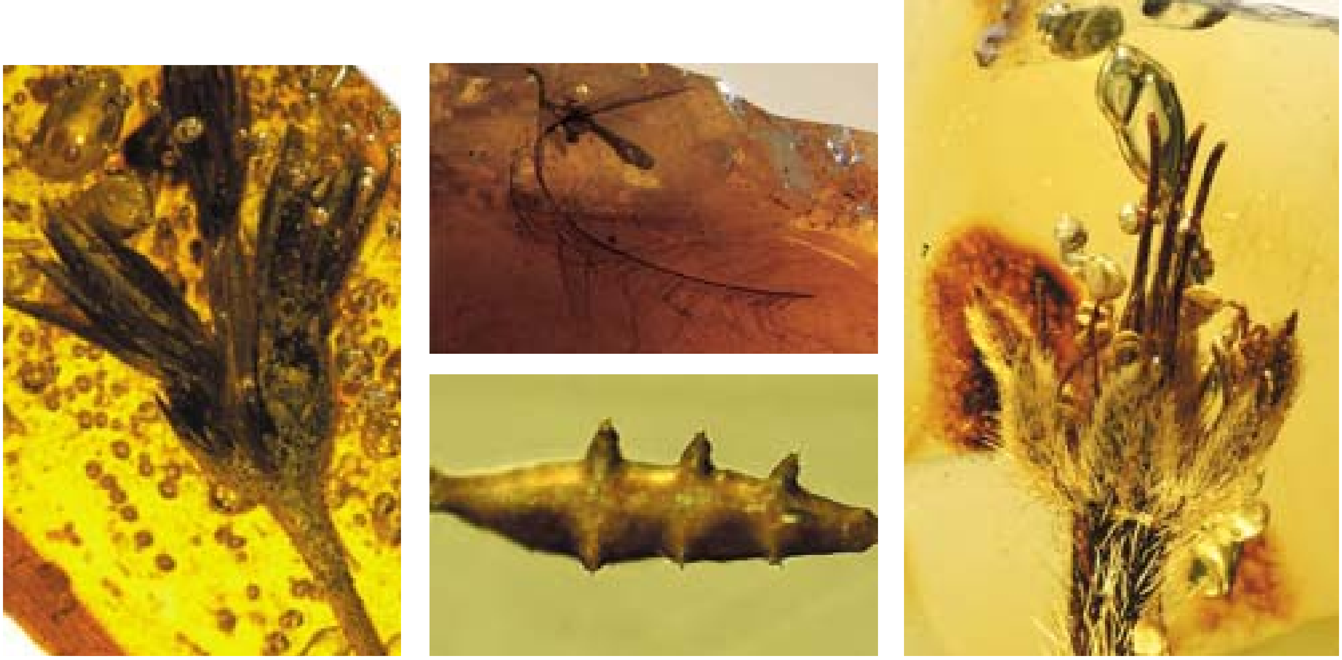


FLIGHT MUSCLES of a fossilized stingless bee (*left*) are magnified to reveal banded muscle fibers. Each fiber is up to one micron across. Between the strands are packed the folded membranes of mitochondria, which, when sliced through, look like fingerprints (*right*). Such preservation led to the idea that DNA and other biomolecules might be preserved in amber.

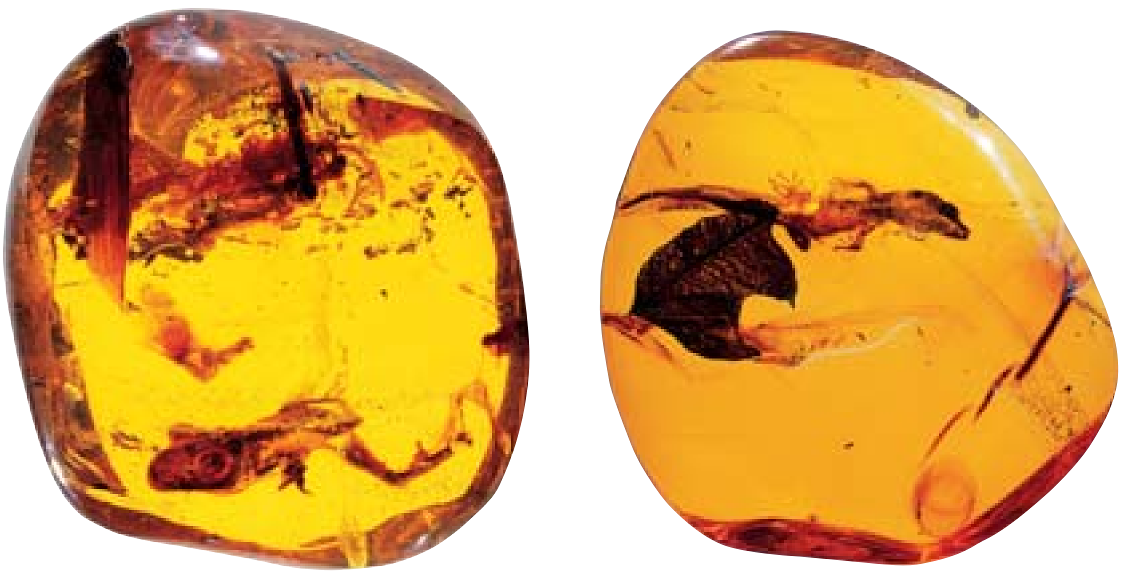


EVOLUTIONARY TREE for the group Dictyoptera—which comprises termites, cockroaches and mantises—was constructed from morphology and DNA from living species and an extinct *Mastotermes* termite in Dominican amber. Whether the amber DNA is truly ancient or is an artifact is controversial, but the sequences do indicate that the extinct species is closely related to the one living species of *Mastotermes,* in Australia. *Mastotermes* is the most primitive living genus of termites. (The illustration is by the author.)

STEPHEN DOBERSTEIN AND MICHAEL DELANNOY *Johns Hopkins University* (*micrographs*); DAVID A. GRIMALDI (*drawings*)



NEW JERSEY AMBER, between 94 million and 90 million years old, has yielded many of the most exciting fossils. Among the most beautifully preserved is a cluster of oaklike flowers (*left*) found in 1994 and an as yet unidentified flower discovered in 2003 (*right*). The feather (*top center*) is the oldest record of a terrestrial bird in North America. The amber also contains the oldest specimens of several insect families and of mushrooms, as well as the oldest true member of the phylum Tardigrada (*bottom center*). Tardigrades are minute creatures (this one is barely one millimeter long) that are the closest relatives of arthropods and can remain dormant under extreme conditions. This tardigrade is remarkably similar to a widespread, living species, indicating that scarcely any change has occurred in this lineage for 90 million years.



ELEUTHERODACTYLUS FROG (*left*) and *Sphaerodactylus* gecko (*right*) are trapped in pieces of Dominican amber 5.8 and 4.3 centimeters in size, respectively. Poised above the frog is the decayed carcass of another one, surrounded by fly larvae. The gecko's back is broken, perhaps because it struggled to escape from the resin; the leaf adjoining it has been chewed, most likely by a leaf-cutter bee. Dominican amber is renowned for the variety of life it embalms, including these rare vertebrates.

DAVID A. GRIMALDI (*top*); JACKIE BECKETT *American Museum of Natural History* (*bottom*)

THE AUTHOR

DAVID A. GRIMALDI is curator of invertebrate zoology at the American Museum of Natural History in New York City. He obtained his Ph.D. in 1986 from Cornell University, where he is now adjunct professor of entomology. He is also adjunct professor of ecology and evolutionary biology at the City University of New York and at Columbia University. Grimaldi's main interests are systematics, paleontology and biogeography, the science of why life-forms are where they are. Trained also as an artist, he is known in scientific circles for his illustrations. Grimaldi is author of *Amber: Window to the Past* (Harry N. Abrams, 1996) and, with Michael S. Engel, *Evolution of the Insects* (Cambridge University Press, 2004).