Diana Gallagher

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Study Guides- Insects in amber

Gierlowska, G. (2005) *On Old Amber Collections and the Gdansk Lizard*. Bursztynowa Hossa. Gdansk.

Grimaldi, D. and Engel, M. (2005). *Evolution of the Insects*. Cambridge University Press. Cambridge.

Poinar, Jr., G.and Poinar, R. (2008) *What Bugged the Dinosaurs? Insects, Disease, and Death in the Cretaceous.* Princeton University Press. Princeton and Oxford.

Poinar, Jr., G. and Poinar, R. (1999). *The Amber Forest: A Reconstruction of a Vanished World*. Princeton University Press. Princeton.

Introduction

Entomology is a fascinating field for those who enjoy studying a group of animals that, while individually small, are the largest and most diverse group of organisms on the planet (Grimaldi and Engel 2005). They have been around for many millions of years and can be studied in the present and well into Earth's past as fossils. One material that assists in this study is amber, tree sap that has undergone millions of years of cross-polymerization to become stable. Unlike fossilization in stone, amber's properties allow an amazing level of preservation of even the minutest details of the insects contained within it.

The books used in these study guides discuss a wide variety of insects that have been preserved in different types of amber. To aid in understanding, the relative ages of amber from different areas of the world are given below. The ages are wide ranging and approximate since the age often depends on the exact mine or site from which the amber was taken.

Ambers

Dominican amber: 23 million years old to 11 thousand years old.

Mexican or Chiapas amber: 23 million years old to 11 thousand years old.

Baltic amber: 65 to 23 million years old.

Burmese amber: 100 to 65 million years old.

Canadian amber: 100 to 65 million years old.

New Jersey amber: 145 to 100 million years old.

Lebanese amber: 145 to 100 years old.

Sources for amber ages:

https://nammu.com/eng/how-old-is-amber/

https://www.sciencedirect.com/science/article/pii/S0195667112000535.

Poinar, Jr., G. and Poinar, R. (2008) *What Bugged the Dinosaurs? Insects, Disease, and Death in the Cretaceous*. Princeton University Press. Princeton and Oxford.

Level recommended: Middle School through High School.

Introduction

This book approaches its topic in a way that differs from other similar books in several ways. Just before each chapter, there is a piece that is written as a story involving dinosaurs, their environment, and the insects interacting with them. This story is not suitable for younger readers since it can be quite graphic and describes disease and death among various types of dinosaurs. Middle school would be the earliest grades for this approach and, even then, it would be advisable to be sure students are ready for this level of description.

Because dinosaurs are involved, only the oldest Cretaceous-era ambers are useful for this research. Burmese amber is the main kind that appears in this book but some Canadian amber is used as well. Other ambers are simply not old enough. Another part of the book's unusual approach is its emphasis on the pathogens and parasites that insects transmit and speculations on how these processes occurred between Cretaceous insects and dinosaurs.

Chapters

1. Fossils: A Time Capsule. This chapter provides a good introduction and explains how insects function as disease transmitters as well as how they become trapped in amber. In addition, there is a discussion about how dinosaurs end up in the fossil record and just how much we really do not know about the distant past.
2. The Cretaceous: A Time of Change. Geological change is the main topic of this chapter. The movement of continents is discussed as well as the biological changes that happen during this period. Also covered is past climate change, the development of plants, and the changes that both dinosaurs and insects underwent before and during the Cretaceous.
3. Herbivory. The chapter covers in greater detail the development of plants over time. It covers the development of flowering plants and the involvement of insects in that process. The authors speculate that dinosaurs, especially young ones, might have eaten insects as a part of their diet, whether deliberately or accidentally.
4. Dinosaurs Competing with Insects. In this chapter the discussion centers on herbivorous dinosaurs and how they might have competed with insects, possibly in the understory and lower levels of the forest (pg. 49).

5. Did Dinosaurs or Insects "Invent" Flowering Plants? This is a two-page chapter. Did dinosaurs invent flowering plants? The answer seems to be that insects were more likely to have been responsible and played a role in the evolution of plants through their feeding and transportation of material from one plant to another (pg. 56).
6. Pollination. This is a chapter that covers pollination in more detail. While insects may not have pollinated plants at the level they do today, some plants may have become dependent on insects for this (pg. 59). Bees and protobees have ended up in amber and modifications for gathering pollen can be seen (pg. 61).
7. Blights and Diseases of Cretaceous Plants. This discussion involves insects and fungal diseases. Using the American chestnut blight and Dutch elm disease as modern examples, the authors postulate that wood-boring insects and fungal parasites might have caused problems with plants in the Cretaceous and might even have been responsible for killing vital types of plants, causing issues for dinosaurs (pg. 71).
8. The Cretaceous Age: Age of Chimeras and Other Oddities. The authors point out that insects in younger ambers are usually found to be from a modern family of insects but that Cretaceous insects often are not (pg. 74). They provide the example of *Hapsomela,* an ant-like stone beetle in which both front legs had six rather than the usual five segments while the back legs had five (pg. 77). Chimeras are insects with characteristics from two or more modern families while oddities are unique (pg. 77). The example they give for an oddity is the *Strashila incredibilis*. This insect dates from around 150 million years ago and was a bit flea-like with saltatorial back legs, a proboscis for feeding on blood, and structures for gripping dinosaur feathers (pg. 77).
9. Sanitary Engineers of the Cretaceous: Anyone interested in how dinosaur dung and corpses were utilized would do well to read this chapter. Dung beetles and flies are well represented in amber and were likely kept very busy considering the amount of dung even one herbivorous dinosaur could excrete. Corpses of dinosaurs large and small would have been plentiful. The authors note "The World of the Cretaceous would have been a fetid mess without insects." (pg. 81).
10. The Case for Entomophagy among Dinosaurs: This chapter expands on the suggestion in Chapter 3 that dinosaurs ate insects as a regular part of their diet. The authors posit that eating insects may have been partially accidental as it would very likely happen when dinosaurs were eating plants (pg. 93). As for actively trying to find insects to eat, it is possible that young dinosaurs did this and rooted for grubs as well. It is speculative but termites and ants could have provided a source of bulk food for dinosaurs (pg. 98).
11. Gorging on Dinosaurs: After looking at dinosaurs eating insects, this chapter covers insects eating dinosaurs. The main question is how insects would be able to pierce the thick skin and scales covering most dinosaurs (pg. 105). Tough skin, scales, and even feathers would mean that insects would have to find spots to eat successfully. The authors believe it was likely that the area between scales would be sufficiently accessible for inset feeding (pg. 109).
12. Biting Midges: These insects can transmit malaria and filarial nematodes and the authors believe these parasites could have caused considerable suffering in afflicted dinosaurs (pg. 112).

13. Sand Flies: These phlebotomine flies transmit trypanosomatid parasites. The authors wonder if dinosaurs were susceptible to visceral leishmaniasis, as humans are, and what kind of effect it would have had on dinosaur populations if they were (pg. 120).
14. Mosquitoes: Mosquitoes are very difficult to find as fossils, even in amber. At the time this book was written, only one specimen was known from the Cretaceous era (pg. 123). With the greater availability of amber from Myanmar, more specimens have been discovered. There are genera that currently attack lizards and they certainly could have transmitted malaria as well as parasitic nematodes (pg. 123).
15. Blackflies: The authors note that blackflies, a scourge even today, go back to the Jurassic era and although they are not seen to attack lizards today, they do feed on birds and mammals (pg. 129). They postulate that, if they did, filarial nematodes such as river blindness could have been transmitted (pg. 130).
16. Horseflies and Deerflies: These insects would have been able to transmit pathogens mechanically, but their main ability would have been to bite painfully (pg. 132).
17. Fleas and Lice: Fleas or flea-like insects could have been present, especially in nesting areas with debris. They do carry disease to humans, most notably the plague, but it is unknown if that was the case in the Cretaceous (pg. 138). The authors note that lice are very specific parasites and that fossil lice are rare but, as it is known that biting lice feed on birds today, it is possible that they fed on feathered dinosaurs as well (pg. 140).
18. Ticks and Mites: Although not insects, these arthropods do carry diseases. There are some ticks and mites that bite reptiles in the present and so it is likely that they bit dinosaurs too (pg. 145). Little more can be said be about them for this period.
19. Parasitic Worms: There is more evidence for the presence of parasitic worms since they occur in fossilized dinosaur coprolites (pg. 148). Snails are known to be carriers and Cretaceous-era amber from Myanmar contains a nematode near a snail, making this conjecture stronger than some others (pg. 151). Ascarid worms can become very large and can cause blockages in the intestines when they move down from the stomach. Tapeworms and flat worms could have been present as well.
20. The Discovery of Cretaceous Diseases: The authors note that amber can record even brief events and use as an example a fly that had had its abdomen bitten away while trapped in the sticky sap that became amber over millions of years (pg. 158). This recording can allow the perception of disease when all other types of evidence is long gone.
21. Diseases and the Evolution of Pathogens: The authors believe that many current vector-pathogen associations began in the Cretaceous in a complex type of coevolution (pg. 171). This allows present day researchers a way to peer back into the far past to understand how problems that still occur now began and developed.
22. Insects: The Ultimate Survivors: While dinosaurs only existed for around 180 million years, insects have been around for more than 400 million and are still in existence today. Insects are very successful at surviving and adapting to many different conditions. Their small size, high level of diversity, and quick rate of reproduction meant that they could continue through even an extinction-level event (pg. 187).

23. Extinctions and the K/T Boundary: Despite their great survival abilities, there is a gap in insect fossils that makes it harder to see the K/T boundary (pg. 196). Little is known and there are different ideas about what happened at that point.
24. Appendices: There are three appendices including a list of Cretaceous hexapods in amber, a list of key factors contributing to the survival of terrestrial animals, and the problems with evaluating the fossil record of extinction.

Questions for discussion

1. Do you think the stories that begin each chapter add to the value of the book or detract from it?
2. Much of what the authors write is speculative. Do you in general agree or disagree with their conclusions?
3. Does an analysis of diseases that cause problems for present-day lizards help with understanding Cretaceous conditions? Are lizards a useful stand-in for dinosaurs?
4. Can fossils provide enough information to answer the questions raised in the chapters of this book? What fossils might be more useful if they were to appear?
5. What can humans learn from the fossil record and studies in deep time?

Concluding thoughts

This book is very helpful for a variety of topics that might be of interest to students. Although I have approached this from the insect aspect, it could also be used for a student studying dinosaurs, ancient disease, host-vector pathogens, and questions about what survives in the fossil record. The differences between what survives in stone fossils and what survives in ambers is an excellent starting point for students who want to understand how researchers piece together information from various sources to come to a better picture of the past. One issue that does not come up in this book is that the value of Burmese amber must be balanced by the ethical problems surrounding it. Below is provided a link to an article in *Science* that discusses the issues researchers confront in finding material for their work from the mines of Myanmar.

https://www.sciencemag.org/news/2019/05/fossils-burmese-amber-offer-exquisite-view-dinosaur-times-and-ethical-minefield.

Poinar, Jr., G. and Poinar, R. (1999) The Amber Forest: A Reconstruction of a Vanished World. Princeton University Press. Princeton.

Level recommended: High School, University, Adult

Introduction

This book was written by the same authors as the book above, but it treats the material in a very different way. This book looks at the forest ecosystem as it may be understood from what has been preserved in amber. While small insects are by far the most common things found, other creatures have been caught as well. Plant material may be discovered in association with insects or on its own. A large difference is in the age of the amber being studied. This book focuses on amber that is much later in date than Burmese or Baltic amber, running from 17 million years ago to 20 million years ago, that is found exclusively in the Dominican Republic.

Chapters

1. Prologue and Introduction: The Prologue discusses a small stingless bee that was found in Dominican amber. The authors try to surmise how it had lived and then dies in the sap that became amber. They also map out the ways in which tree sap becomes amber and then is mined. The Introduction follows the early movement of continents over millions of years and dates the emergence of the surface of the island that is now, in part, the Dominican Republic at about 65 million years ago. Plants and animals arrived over time including the algarrobo tree, which is the tree on the island that produced the sap that became amber (pg. 4). The authors note that amber preserves plant and animal associations that would otherwise be lost and, although a complete picture is not possible, it can preserve a moment in time (pg. 8). It may also be possible to infer indirectly the presence of plants or animals by finding another organism that is associated with it (pg. 10). An example is that figs are believed to be present, even though they have not been found, because fig wasps are caught in the amber and fig wasps can only eat and reproduce in figs (pg. 10).
2. The Amber Forest: This is by far the longest chapter in the book. There is evidence in amber of the landscape that existed in this tropical forest. Trees such as the algarrobo, cativo, and nazareno were dominant along with palms and figs (pg. 21). Fig wasps were mentioned but palm specific insects were also found. The understory layer was composed of acacias, mimosas, lianas, and other vines (pg. 23). Seeds, buds, and plant hairs are all found in amber. The authors discuss the indirect evidence for the presence of epiphytic bromeliads, such as the presence of stalk-winger damselflies, butterflies, and orchid bees (pg. 34). Social insects are discussed at length because they are important to understanding the structure of the ancient forest (pg. 97).
3. Reconstruction of the Amber Forest: It is in this chapter that the authors attempt to put it all together and show what the tropical forests looked like between 15 and 45 million years ago. The important features that they use to classify the forest are temperature, rainfall, latitude, and altitude. They were able to determine that biodiversity was greater millions of years ago than it is today. The example the authors use is that of tropical bees

that are found in great numbers in amber but are now extinct (pg. 183). A large portion of the chapter is devoted to discussing what possible larger animals existed in the forest. Insects and some small creatures have left their traces but there are other animals that were possibly or even very likely present. Small insectivores called Solenodons, sloths, monkeys, bats, turtles, and birds are the animals that likely coexisted with the insects from amber (pg.176). The authors use this chapter to argue for behavioral fixity. This is a principle that states that the predator-prey, host-parasite, and other symbiotic relationships continue today largely as they did over the long term (pg.188). It is this long-term stability that allows an analysis of a long-gone forest on the basis of relationships that can still be observed.

4. Amber Today: In this short chapter, the authors provide suggestions for those who would like to find and examine amber specimens today. They advise on processing the amber to allow a good view of the inclusions inside. In addition, they warn against fake amber and give some suggestions on avoiding it. In the end, they even touch on DNA in amber and why its extraction, Jurassic Park notwithstanding, is problematic (pg.195).
5. Appendices and References: The main appendix covers the frequency of specific organisms in Dominican amber.

Questions for discussion

1. How does understanding the ancient ecosystem help researchers reconstruct a lost world?
2. Are the arguments made by the authors for using indirect evidence to infer the presence of unseen species convincing?
3. Aquatic insects and stages of insects are rare. How important is the tank bromeliad discussed on pages 87 to 96?
4. The authors argue for a concept known as behavioral fixity. Do you accept that this is true?
5. Why do you think tropical stingless bees became extinct on the island? The authors suggest disease, inbreeding, or climate change. Which of these or combination of these makes the most sense?

Concluding thoughts

This book is of particular interest in that it covers the general ecosystem of ancient worlds as reflected in the survivals in amber. Not only insects, but other arthropods, birds, and even the occasional tuft of mammal hair is addressed. Students interested in not only what survives in the fossil record but also how that information can be used to reconstruct the unseen forest and its members will find this a valuable resource.

Gierlowska, G. (2005) ***On Old Amber Collections and the Gdansk Lizard*****. Bursztynowa Hossa. Gdansk.**

Level recommended: Adult, General Interest

Introduction

Among the books on this list, this one appeals most to the general population. It treats the material in a more basic way and covers as much art and history as it does scientific information. It would be a good general starting point for studying amber and amber collections and provides methods for determining whether amber in jewelry and carvings is natural or treated. Many people reading this book might find that they own amber jewelry that has been pressed, colored, or heated to change its appearance.

Chapters

1. What is Amber? In this opening chapter, the author provides an overview of the scientific, historical, and decorative uses of amber, specifically Baltic amber. The author covers, in some detail, the different colors and appearances of amber as well as how it can be processed for jewelry, decorative items, and even therapeutic uses (pg. 41). The wealth of photos of amber would make this a useful reference for anyone wanting to identify an amber piece. Most of the suggestions concerning therapeutic uses of amber should be treated more as a curiosity rather than as actual medical advice, although there are photos of several Russian products that incorporate amber (pg. 43).
2. Old Amber Collections- Gdansk Collections of Objets de Vertu: This chapter is an amazing look at some beautifully carved and assembled works of art made of or involving amber. For thousands of years, humans have collected and worked amber on account of its properties. The pieces photographed for this book come from eras including the ancient, medieval, baroque, and modern among others. Intricately carved cameos, statuettes of solid amber, and elaborate boxes covered with plaques of different colors of amber are just some of the pieces. The largest is the Amber Room, an entire room covered in amber. It is thought to have been lost or destroyed during the Second World War, but its fate is not known. It has been reconstructed by Russian craftsmen (pg. 51). The author provides an overview of some early collectors and researchers who studied amber as well as the museums for which they worked.
3. The Gdansk Lizard in Baltic Amber (Succinite) and Other Lizards in Gdansk Collections- This is largely the basis upon which this book was written. The author has provided many photographs and descriptions of this lizard, which is a spectacular specimen, although not a complete animal. Lizards are usually large enough to escape the sticky resin that becomes amber, so they are rare finds. This lizard was found in the late 1990s and was identified as being of the Lacertidae family (pg. 82). The lizard became very well known in Poland through the efforts of scientists and the press and has been the subject of journal articles (pg. 86). It was even considered important enough to give a catalogue of its exhibition to Pope John Paul II (pg. 85).

4. A Look at the Author's Collections of Inclusions (in photography) - This section consists almost entirely of very clear photographs of the author's collection of insects in Baltic amber. Because Gdansk is on an old Baltic beach, the author has been able to find all of these specimens herself. They include mating gnats, planthopper nymphs, plant material, and swarms of many insects. The one drawback to this section is that the author does not label the photographs to indicate the name or type of insect in the picture. This would be a challenge for those who are interested in entomology and wanted to see how many insects would be identified and to what level of detail.

Questions for discussion

1. Why have humans always used and worked amber? What makes it an attractive material?
2. How might a lizard become stuck in the sap that becomes amber?
3. Would you take medicine or use a product that included amber among its ingredients?
4. The author's collection of insects in amber is made up entirely of Baltic amber, meaning it is approximately 40 to 50 million years old. What can the insects tell researchers about that period?
5. How much do you think was lost during and after the Second World War from the collections and museums described by the author?

Concluding thoughts

In this book, the author's love for and knowledge of amber comes through very clearly. For a short book, it is filled with many excellent photographs that provide great detail in terms of the insects and lizard they depict. Readers who wish to delve deeply into insect identification and ancient environments might do well to find a different resource but for the many who want an overview of the history, uses, and scientific importance of amber, this book is an excellent choice.

Grimaldi, D. and Engle, M. (2005) *Evolution of the Insects*. Cambridge University Press. Cambridge.

Level recommended: Advanced University, Advanced Adult

Introduction

This is the most advanced of the books on this list and, at 755 pages, also the longest. It is an excellent reference for those interested in entomology, evolutionary history, and the development of diversity in early insects. Other books on this list might be better for those who are not comfortable with scientific terminology, although the first two chapters are accessible and the photography in the book is wonderful and clearly illustrates the text.

Chapters

1. Diversity and Evolution: Introduction- This chapter details the history of the development and study of insects. Insects are incredibly diverse and date back 400 million years. The question of how many species of insects there are is addressed with large and colorful tables and pie charts. The chapter also covers the big names in the history of entomology, including Linnaeus, Cuvier, Lyell, Wallace, and Darwin.
2. Fossil Insects- In this chapter there is a very useful discussion about fossilization and other types of preservation including trace fossils such as fossilized wood with insect galleries and frass. In the discussion, the authors describe amber with inclusions and detail how it can be used for study (pg. 60). They include wonderfully clear photographs as well as scanning electron microscope pictures of insects. The question of DNA in insects in amber is addressed but mostly to indicate that it is generally too degraded to be of any use (pg.60). The major insect groups are covered as well as the major geological periods are laid out in detail and are very helpful for anyone who wants a good grounding in those areas (pg. 65). Charts and tables are very well done and are useful for orienting fossils and amber in time and space.
3. Arthropods and the Origin of Insects- This is a detailed chapter that discusses the origin of insects and the way scientists learn about such deep time. The most useful chart is the one that sets out the Phylum Arthropoda in great detail (pg. 99). The authors provide examples in amber of some of the earliest insects such as Collembolans and Diplurans.
4. The Insects- This is really the introductory chapter for the main chapters in the book. It covers the morphology and structure of insects. There are sections on the head of an insects, the thorax, and the abdomen. Some discussion of eyes, legs, wings, and reproduction happens in relation to each insect structure, but more will be done in the chapters on specific groups of insects. The development of classification is provided along with some information about how relationships were worked out up through the nineteenth century. The authors arrive at the most recent chart of classification and show how a phylogenic chart is set up and used (pg. 146 and 147).
5. Earliest Insects- The earliest insects, such as bristletails and silverfish, are discussed. There is an example provided of the oldest insect in early Devonian chert from Scotland (pg. 153).

6. Insects Take to the Skies- This chapter focuses on flight and how it developed in insects. Other questions are when and why flight developed (pg. 158). The authors characterize this as a conundrum and describe the evidence for the development of flight. Some of the insect orders they discuss in this chapter are Ephemeroptera and Odonatoptera. For each order, there are impressive charts and phylogenies as well as schematics of wings and mouthparts. Some very clear pictures of these insects in stone and amber are included in this chapter.
7. Polyneoptera- The authors cover the Neoptera including Blattaria (cockroaches), Phasmatodea (walking sticks), Plecoptera (stoneflies), Embiodea (webspinners), Ortoptera (grasshoppers), and Dermaptera (earwigs) (pg. 190). A useful part of the discussion is an overview of the immature forms of all of these groups.
8. The Paraneopteran Orders- The Psocoptera are the main topic for this chapter. These include bark lice and thrips. Scale insects, human lice, and the sucking insects, known as the hemipterans are covered as well.
9. The Holometabola- The discussion in this chapter centers around the insects that undergo a complete metamorphosis. The following chapters will feature other insect orders that are holometabolous. In this chapter, the authors cover the orders Neuroptera, the lacewings and antlions, the Raphidoptera, which are snakeflies, and the Megaloptera or alderflies and dobsonflies.
10. Coleoptera and Strepsiptera- While Strepsiptera is a very small group, the Coleoptera are arguably the order with the largest number of species. Beetles come in a huge variety of sizes, colors, shapes, and habits. Their wings and bodies are heavily sclerotized and so preserve very well in the fossil record. There are many fossil and amber specimens shown in this chapter. The strepsiptera, on the other hand, are much harder to find and are considered a very odd order (pg. 399). The females live permanently in their host and never change from their larval form. They are essentially parasitic. The males are free living and fly to find the females, which protrude from the host to allow mating (pg. 399). Amber specimens exist but are very rare.
11. Hymenoptera: Ants, Bees, and Other Wasps- These are among the best-known insects and fall within the group of social insects. The authors break down these large groups into sub-groups and discuss in detail parasitoid wasps, a large number of types of ants, and many different bees. Examples of extinct bees in amber cover the earliest bee found in New Jersey amber, through the extinct bees found in profusion in Dominican amber, as well as a more general overview of eusocial insects (pg. 467).
12. Panorpida: Antliophora and Amphiesmenoptera- This chapter covers the scorpionflies, fleas, and true flies. The authors provide a detailed analysis of wing types and venation. There are few photos of examples in amber, because many of these kinds of insects do not live in areas where amber preservation is common. The exception to this is some flies and many midges (pg. 500). Midges and crane flies end up in amber often, sometimes in swarms, but mosquitoes are rarer (pg.507). The authors provide several complex phylogenetic trees for those who are interested in the development of flies from the Jurassic to the present (pg. 519).

13. Amphiesmenoptera: The Caddisflies and Lepidoptera- Caddisflies, or Trichopters, are very interesting for the habits of their aquatic larvae. These larvae build cases for themselves from the surrounding debris and these cases sometimes show up in the fossil record. The authors do not spend a great deal of time on this group and only provide one picture of a caddisfly in 90-million-year-old New Jersey amber (pg. 554). They spend considerably more time on the Lepidoptera. More butterflies and moths end up in the fossil record and in amber than might at first be thought. Some caterpillars and immatures end up in amber, often Dominican and Baltic ambers, as well as some adults (pg. 581). Such details as coloration, wing scales, and even the damage done to plants by specific Lepidopteran larvae are found in amber of various ages (pg. 572). All of these elements allow the authors a much greater understanding of development than would otherwise be available.
14. Insects Become Modern: The Cretaceous and Tertiary Periods- The periods covered in this chapter saw the "most profound biological episode in the history of life" (pg. 608). Flowering plants radiated and insects were right there with them. Insects consumed these angiosperms and pollination became important for plants and insects alike. This is a wonderful example of co-evolution. A photograph of early flowers in 90-million-year-old amber from New Jersey provides information about the development of pollination (pg. 613). The authors also discuss mammalian radiations and the effect this had on insect development and spread (pg. 638). The extinctions at the K/T boundary are also addressed (pg. 635).
15. Epilogue: Why So Many Insect Species?- This question was posed at the very beginning of the book and, in this chapter, the authors revisit it. Among the reasons for the diversity and success of insects, the authors cite their exoskeleton, their ability to fly, and the development of their immature stages (pg. 646). They also look to the future of insects and the effects that could happen to humans and animals if extinctions occur (pg. 650).
16. Glossary and References

Questions for discussion

1. The authors discuss recovering useable DNA from insects in amber. Is this an avenue of study that should be pursued or is it likely a dead end? How much has it been influenced by popular culture?
2. How do the different types of preservation add to the understanding of the fossil record?
3. Why do you think the authors present the mass extinction at the K/T boundary (pg. 636) as having a minor impact on insects? Do you agree with their assessment?
4. Do you agree with the authors' final thoughts on the future of insect species and their capacity to survive human-made threats?

Concluding thoughts

Professional and amateur entomologists at all stages of their studies will find this book an invaluable reference volume. In addition to the stellar photographs of insects in amber and as conventional fossils, there are modern SEM images of current insects as well as descriptive anatomical drawings, classification tables, and phylogenic charts. It has far too much information to allow comprehensive summaries of the chapters and covers a wide variety of topics that will interest anyone who wants to know more about entomology, fossilization, and classification.