How the Earth Turned Green
Joe Armstrong

Joe Armstrong is professor emeritus at Illinois State University. He loves to teach, and this book encapsulates most of the subjects dearest to his heart – the evolution of green plants.

This book is a rarety among all books of paleontology for the exceptionally clear description it gives of the early evolution of single celled organisms. He explains that you can't call them either animal or plant. The dividing lines are ambiguous.

The story starts about 3.8 billion years ago, after the earth had had three quarters of a billion years to cool down enough for life to get started. Nobody knows what the first organisms were, but it is clear that they were not autotrophic (able to create their own food). They made their living by exploiting the chemical energy available from controlled reactions enabled by enzymes within their own metabolism.

One learns a great many facts that seem important but that I had never seen elsewhere. First, there was no oxygen in the Earth's atmosphere at the outset. Oxygen is highly reactive, and the Earth's entire endowment was bound up in chemical combinations. Other elements such as sulfur were, however, available to fuel primitive metabolic processes.

Armstrong's opening chapter has a very good, lengthy description of the evolution of photosynthesis among red, brown and green algae. One learns to appreciate the complexity of this simple process. As part of his discussion, Armstrong discusses the evolution of scientific knowledge about photosynthesis – and many of his other subjects of interest.

Science advances by the rejection of false hypotheses. Armstrong describes what people thought, why they thought it, and why the ideas were rejected one by one until a consensus formed in support of the last one standing. Here and there throughout the book he gently ribs the Intelligent Design people. Even though the evolutionists cannot prove anything beyond doubt – science is the business of disproving, not proving – the theories that have not yet been disproven weave a thicker and thicker web of evidence in support of evolution. Conversely, the arguments that evolutionists have contrived from the inconsistencies and paradoxes within the theory of evolution seem to be disintegrating one by one the "inexplicable complexity" of life can, in fact, more and more often be explained.

He strikes a difficult balance, writing on a fairly arcane subject for educated laypeople. In the text he self-consciously points out where he uses ordinary language in place of scientific terms, but the fact is that very frequently there are no good substitutes. He is conscientious about defining new terms as he introduces them, but nonetheless the reader has to juggle quite a few at a time in order to follow the discussion. This is one of the great advantages of reading with Kindle. As I inevitably forgot a term or two, I could use the search feature to find the sentence in which it was introduced.

I am including Armstrong's chapter titles and subheads at the end of this review. They do a pretty good job of explaining what the book is about. The book is so full of useful and surprising information that I could not hope to capture it all in a review. Here is a bullet list off the top of my head.

==The only source of oxygen in the environment is photosynthesis. As the first algae started creating oxygen, they created an "oxygen crisis" as atmospheric oxygen hit a couple of percent. Oxygen is poisonous to anaerobic bacteria. Sometime prior to 2 billion years ago, they had to evolve or die.

==Photosynthesis evolved in the ocean, in an environment in which long wavelength red and short wavelength blue was stronger than the middle wavelength green light. The process came to use those colors, reflecting back the then not so useful green light. Now, on land, despite the fact that green would be a good source of energy, we are stuck with the legacy solution that evolved billions of years ago. We have a green planet.

I add as an afterthought of my own that eyes evolved well after photosynthesis. It is not by happenstance that green is in the middle of our visual spectrum. The most informative wavelengths to perceive are in the range of red to blue, and green is right between them.

==The "Cambrian revolution," in which multicellular organisms first appear in the fossil record, is an illusion. The first multicellular seaweeds had appeared more than 2 billion years ago. Their complexity evolved, ever so slowly, in the pre-Cambrian era. There is even evidence of animal life; little wormholes in sedimentary rock made by creatures that themselves could not have fossilized. The Cambrian is merely the time when multicell organisms started to include hard parts that fossilized well.

==The first vascular plant, Cooksonia by name, showed up more than half a million years ago. They appear to have evolved out of green algae. Armstrong does a thorough job of explaining all of the competing theories, which ones are favored today and why, and what might come up to disprove them.

==We learn a great deal about the evolution of sex. Early plants, and modern liverworts, mosses, ferns and horsetails, alternate between haploid and diploid "generations." The DNA double bond splits creating gametes with half of the parental DNA. The female and male gametes grow into full-blown organisms. The female creates an ovule and males create sperm that swim to the ovule and fertilize it in place. The diploid adult of the third generation grows exactly where it was fertilized.

That is a one paragraph summary of at least a chapter of text, fascinating to read. The bottom line is that ferns and mosses can only reproduce where they have water in which the sperm can swim, and cannot disperse after fertilization. A great many spores are lost in the first phase, and male gametes in the second. It is inefficient.

==Coniferous trees are more efficient with their pollen. Nevertheless, it is windborne and a great deal is lost. The system works when a forest is more or less a monoculture. When there are dozens of different tree species competing, other means are better.

And that is the advantage of flowering plants, we find out in the last couple of chapters. The plant embryo fertilized and packaged in a seed. Instead of the haploid gametes having to find each other in the open, unprotected environment, the whole sexual businesses is taken care of within the reproductive organs of the flower. The seed contains an embryo, ready to go. It can be dispersed widely by animals and any number of vectors, and it can last a long time for sprouting. Flowers are evolutionarily successful. That's why we see so many of them.

Armstrong does a pretty good job of relating plant evolution to animal evolution. They go together. Animals could not invade land until there was something to eat. Conversely, however, plants have come to depend more and more on animals in their own reproductive processes. One of his early chapters has an interesting piece on the fertility of the open oceans. Basically, kind of sterile. They get a lot of sunlight, but there is not much raw material for photosynthetic bacteria to work with. Going up the food chain, it takes an awful lot of open ocean to support a single top predator like a swordfish. Far and away the most productive parts of the ocean are along the shores, where erosion brings minerals down via rivers to where seaweeds can use them.

Anybody with an interest in animal evolution owes it to themselves to look at the other side of the story – plant evolution. You can't have one without the other, and you can't understand one without the other.

The book is rich with diagrams, many of them showing the relationships and evolutionary paths among fossil organisms. He often explains alternative possible paths.

One thing that becomes clear is that the old Linnaean classification system of kingdom, phylum, class, order, family, genus and species is outdated. The real world is not that orderly. A diagram of the Linnaean system would be as regular and orderly as a monkey puzzle tree. Real life is as disorderly as a contorted willow or a bristlecone pine.

A better concept to use is nested clades. A clade is a group of organisms with a common ancestor. Human beings belong to the clades of anthropoids, great apes, monkeys, primates, and mammals in that order. The problem with clades is that they can stack to an infinite depth. There isn't a clean convention for nomenclature, such as the Linnaean genus and species. Armstrong explains all this quite clearly, and then goes on to use Linnaean terms quite frequently because that's what his readers will be familiar with.

Chapter titles

1. A Green World Wherein a discussion of “plant” and “plant kingdom” introduces the science of taxonomy and classification, and the nature of science is illustrated by explaining how we know the age of the Earth and why biologists care about elements from stars and molecules from space.

2. Small Green Beginnings Wherein the discovery of microorganisms, their amazing numbers, and the places they live are explored; evidence of ancient life is examined; and the nature of metabolisms and the origin of their complexity is explained.

3. Cellular Collaborations Wherein the diversity of unicellular organisms is explored, chloroplasts and mitochondria are obtained via symbiotic interactions between cells, and other features such as nuclei and sex are examined to determine what can be learned of their origins and functions.

4. A Big Blue Marble Wherein algae are introduced, ocean ecology is explained, and phytoplankton diversity is explored.

5. Down by the Sea (-weeds) Wherein coastal environments are contrasted to oceanic environments, and organisms adapt to the new challenges presented by living on coasts by becoming anchored, larger, and multicellular, which in the case of green organisms results in those algae called seaweeds.

6. The Great Invasion Wherein the challenges and colonization of the terrestrial environment are examined so as to understand the adaptations of land plants, especially their life cycle.

7. The Pioneer Spirit Wherein liverworts, hornworts, and mosses are examined to demonstrate their adaptations to terrestrial life and their relationships to each other and vascular plants.

8. Back to the Devonian Wherein a field trip to the Devonian introduces early vascular plants and examines how, from such small beginnings, xylem and new ways of branching helped plants produce leaves and roots and grow into trees, Earth’s first forests.

9. Seeds to Success Wherein the nature of seeds, their impact on the land plant life cycle, their history, and the diversity of seed plants is investigated.

10. A Cretaceous Takeover Wherein the quite singular ecological dominance and species diversity of the flowering plants are examined in light of their novel features and their gymnospermous ancestry.

11. All Flesh Is Grass Wherein the development of modern vegetation and recent interactions, like agriculture, and their impact on both plants and humans are examined.

I add in summary that Armstrong addresses climate change with the same deft touch as every other topic in the book. It would be presumptious of scientists to forecast exactly what will come of increased levels of CO2 in the atmosphere. To predict disaster seems out of place, given the extreme variations in climate that life has endured in the past. Nevertheless, it is foolish to tinker needlessly with systems that we so patently do not understand. We should exercise restraint in generating CO2, in making changes to the chemistry of the land and the oceans, and in moving species about. We should have a bit of humility. Not one ofhumanity's strong points.