Chapter 9

The Historical Development of the Idea of Evolution

9.1 Myths about evolution theory

The word 'evolution' literally means continuous change. Before we proceed into this topic, let's clear up some major misconceptions, and myths concerning the idea of evolution.

Myth No.1 – The theory of evolution was first contemplated by Charles Darwin.

As we will see in this chapter, many earlier naturalists, including the ancient Greeks, considered a natural evolution of life on Earth.

Myth No.2 – Charles Darwin developed the theory of evolution.

He didn't 'develop' the theory. He discovered the theory, then described his discovery. The point I am making here is that scientific theories seek to describe reality by seeing patterns in its organization. Charles Darwin and Alfred Russel Wallace both independently discovered a theory of evolution within a few years of each other. And if they hadn't discovered it, then someone else would have. Although naturalists tended to ponder the idea in their lifetimes, the time for the theory's discovery wasn't right until the middle 1800s.

Myth No. 3 – Evolution is a unique and separate biological process.

There is no such thing as an evolutionary process. There is no separate biological phenomenon called 'evolution.' You cannot go out into nature or into the laboratory and observe evolution 'happening.' There is no technique with which to detect the evolutionary phenomenon because evolution doesn't 'happen.' Life happens.

The term, 'evolution,' is a label that biologists use to describe a result. I repeat RESULT. Evolution theory is a synthesis of modern genetics theory and modern ecology theory. Genetics describes how information is managed in living systems. Ecology describes how living things experience their lives. The living individual experiences life as a stream of complex circumstances that change from moment-to-moment. We can observe those experiences. If the genetic information describing a type of living thing changes from one generation to the next, then that change would represent an 'evolutionary result.' Evolution doesn't 'happen.' Life happens.

Myth No. 4 – Evolution theory predicts that humans evolved from apes.

Two problems here. First, the theory has no capacity to interpret itself. All the theory does is provide a framework for inquiry into such interesting questions as the evolution (or not) of humans (and all other kinds of living things). The theory provides a tool by which investigators may consider their observations. Predictions about the evolutionary history of humans (for instance) represent interpretations of the theory. If such interpretations are unpopular, then this does not necessarily reflect poorly on the theory itself, but rather on its interpretation and implementation.

Second, the idea that humans evolved from apes is a popular misconception and gross misinterpretation of the theory. This myth misunderstands the structure of evolutionary lines and the notion of common ancestors. If humans 'evolved' from different types, our ancestors were certainly NOT apes.

Myth No. 5 – Living things adapt to their environment

(NOTE: There is a phenomenon called 'physiological adaptation', but that is not the same as evolutionary adaptation.) There is absolutely NO WAY that any living thing can evolutionarily adapt to its environment. This myth was promoted by a scientist named Lamarck whom you will read about later. Unfortunately, most people have it in their head that evolution works because living things adapt to their environment. In reality, an individual copes (or not) with its environment. Individuals don't adapt.

This notion also implies that evolution is some kind of **response** to environmental conditions. You may perspire on a hot day but you cannot evolve a sunshade in response to the burning sun. An evolutionary result does not occur as a response to the environment but as a consequence of the environment.

Myth No. 6 – Survival of the fittest

In my view, this expression should be stricken from all evolutionary literature. It is a tautology that means nothing more than 'survival of the survivors.' It's like saying the finishers are the runners who finish the race. So tell me something I DON'T know. But more dangerously, this expression implies that genetic fitness can be somehow predicted BEFORE the individual's life – which it cannot. The term 'fitness' implies that a trait or gene accumulates primarily, if not exclusively as a result of non-random environmental tests. Life is far more rich and complicated to be reduced down to this expression.

Myth No. 7 – Only the strong survive.

He who turns and runs away lives to fight (or eat) another day.

Myth No. 8 – Evolutionary biologists 'believe' in evolution

I shall remind you that the scientific enterprise is not in the 'belief' business. Science's primary mission is to understand the reality of how things work. This is purely an intellectual activity and does not require the operation of any faith or belief system. I use a broom to sweep out my garage because it's the best tool for dealing with the reality of grunge on my garage floor. But I don't 'believe' in brooms. I consider the reality of the broom in terms of my dirty garage floor.

Scientists seek the best tools to help them comprehend the reality of the world in which they live. To the extent that a theory is useful, it will be used. To the extent that a theory is not useful it won't be used. Scientific theories are the tools for scientists like wrenches are the tools of mechanics. We use tools in our lives where they are most appropriate but we are not required to 'believe' in them.

Myth No. 8 – Humans will evolve into creatures with bigger heads and weak bodies because we need bigger brains and we don't need strong bodies.

This is the 'space alien' misconception. UFO advocates demonstrate an intense misunderstanding of evolution theory when they offer illustrations of aliens from other worlds. Such ideas reflect a Lamarckian view of evolution, or 'evolution-by-necessity.' Directional changes like these can only happen after many, many generations in which women continuously prefer skinny, big-headed guys. It could happen, but it's not happening on MY college campus, that's for sure.

Myth No 9 – The Planet of the Apes phenomenon

The movie, Planet of the Apes, assumes that should humans suddenly disappear from the Earth, apes (Chimpanzees? Gorillas?) will evolve into a technological species. What a crock! The trouble is that most people learn about evolution theory from Hollywood producers and NOT scientists. Here is the problem. Evolution theory is inherently incapable of making predictions about the future evolutionary trends of any type of living thing. This is because the system described by the theory is a dynamical (or chaotic) system. Life occurs in a dynamical environment such that not all situations can be predicted.

If we were to correctly consult the theory in an attempt to predict the evolutionary outcome of apes in a human-free world, the odds would overwhelmingly favor that the apes would remain unchanged. Of course, then the movie would be pretty boring, no?

Myth No. 10 – The main purpose of an individual's life is to reproduce

Actually, the primary mission of a living individual is to maintain the living state – which means, to stay alive. Reproduction is an inconvenience imposed upon individuals at the behest of the type (species). Human beings first experience the internal 'need' to seek reproductive opportunities at puberty. This behavior modification is done chemically with the release of hormones into our blood. As a result, we find ourselves spending too much money on entertainment, clothes and cars in an effort to attract a mate. And the outcome of reproductive success is a huge burden on the parents as they must devote limited and hard-to-acquire resources to caring for their young.

In short, reproduction is harmful to the individual. When the individual reaches sexual maturity, the species exploits the individual by turning them into a genetic messenger.

Myth No. 11 – A species is alive

Not true. The word, 'species,' means a particular type. It is a label applied to a description of a particular type. Think of a species like a specification sheet, a body of information that describes how to build, operate and maintain a particular type of living thing. The key point here is that living things do not define the species. Instead the species defines the living things. In any case, the information is not alive. But its manifestation is.

The information that describes the type is contained within the DNA in all of the living individuals of that type. When we say, 'a species evolves,' this means that the information that describes the type changes from one generation to the next.

Although the information codebase itself is not alive, it can only execute within the living cells of a living individual. And since individuals live for just a short time, the genetic information describing the type must be repeatedly instantiated into generation-after-generation of new individuals. While the information describing the type is executing inside living individuals of its own construction, the species is extant (with living representatives). When the information no longer executes, the species is extinct.

Myth No.12 – Evolution theory contemplates the spontaneous origin of life on Earth

Another widely accepted but misinformed notion. Evolution theory is not concerned about the origin of life. Life Origin theory is concerned about the origin of life on Earth. The main tools for life origin theory are biochemistry and molecular biology. Evolution theory is a framework for understanding how species may go through changes. Its main tools are a synthesis of genetics theory and ecological theory.

Myth No. 13 – It's just a theory

Often this statement is considered a sufficient dissenting argument. But it really is an expression of ignorance about how science works. I remind you that everything we understand about how things work in this world is 'theoretical.' Architects consult architectural theory. Structural engineers designing a bridge consult structural engineering theory. Medical doctors consult medical theory. Repeat, scientific theories are discoveries of how reality is organized. To the extent a theory is useful it will be used. To the extent a theory is not useful it won't be used. Given the power and utility of the theories that form the foundation of modern, technological civilization, a statement like the one above reflects a failure to understand this.

9.2 Introduction

The purpose of this chapter is to describe the historical origins of the modern theory of evolution. I will present a chronicle of how two main ideas of evolution came about. The first idea is the notion that life on Earth experienced evolutionary changes. The second idea concerns the development of a cohesive, scientific explanation as to *how* evolutionary changes occurred. In order to get to these ideas, naturalists first had to use empirical methods to solve the riddle of the fossils and the riddle of the rocks. In the 1700s, once fossils were accepted as the impressions of once-living organisms, there was little doubt that life went through many changes during its occupation of Earth. But how? Further work by geologists placed fossils on a time line that showed the different stages of life's history on Earth. And it was an old, old planet. Then, world travel, the recognition of millions of closely related species well suited for their environment, and the discovery of stressful ecological forces led Charles Darwin and Alfred Russel Wallace to a natural explanation of evolution in the mid 1800s.

The modern form of evolution theory is based on two powerful insights, which are: 1)the idea of *natural selection*, an ecological explanation discovered by Charles Darwin and Alfred Russel Wallace; and 2) the science of *genetics*, based upon the work done by Gregor Mendel. Natural selection describes how ecological stress acts in unique ways on unique individuals. Some individuals can cope with ecological stress better than others can. To the extent that an individual's suite of traits helps it survive long enough to reproduce, those traits will get passed on to the next generation. But what produces a unique individual and how does it pass on its attributes? Mendelian genetics answers these questions. Each trait is manufactured by the individual according to a recipe in its genes. The genes reside as bits of DNA code in the individual's cells. These recipes are passed on to the next generation as offspring inherit copies of their parents' genes. And so, modern evolution theory sees evolutionary results as an outcome of ecological forces acting on inheritable genetic variety.

Today, modern evolution theory helps us explain three main things about life on Earth, which are: 1) why there are so many different species on Earth; 2) how adaptations develop; and 3) the history of life on Earth including the many extinct species that came and went.

The theory of evolution, as we now understand it, is one of the most powerful and enlightening ideas ever developed by science. It was no trivial hunch hastily scribbled on a cocktail napkin. Evolution theory not only is a *tour-de-force* in the development of human thinking about the world, it also is a heroic demonstration of the struggle of indomitable human reason against restrictions imposed by severe religious doctrine. As you will see in this chapter, the ideas of evolution were not unique to one man, but appeared independently many times and in many forms over at least 2000 years of history. But earlier evolutionary ideas did not lead to a workable theory. The problem lay in evolution's unforeseen complexity and our own scientific ignorance. Until 150 years ago, we simply did not have enough information about the workings of our physical and biological world to bring together such a theory. But this situation changed as humans accumulated more knowledge about the Earth and nature. The big turning point came in the early 1800s, as progress in such far-flung fields as geology, natural history, geography and economics led two naturalists to a revolutionary new explanation of life on Earth. No one could have predicted the magnitude and scale of evolution theory's impact on science and human culture.

How did the theory develop? Did Charles Darwin, in a moment of enlightened inspiration, simply declare the theory of evolution, and that was that? It turns out that the theory of evolution itself emerged following the lengthy evolution of human understandings about nature. It wasn't the product of a single man, but of dozens and dozens of natural philosophers who, for thousands of years and at great personal risk, cleared the path for the theory's inevitable discovery.

9.3 Early on, the ancient Greeks considered that life evolved into different forms.

Long ago, ancient Greek philosopher, Anaximander (ca. 611-547 BC), proposed that the Earth had gone through many changes in its history. As a consequence, life took on many different forms during each new stage of the Earth's development. For example, Anaximander believed that fish dominated the early Earth when there was little land. As the continents appeared, some of the fish left the sea and changed to become more suited for a life on dry land. According to Anaximander, humans resided as quiescent parasites inside these land fish much like a modern day astronaut lives inside a space suit. Once the changing world could support them, humans awoke and cast off their fish skin.

Empedocles (ca 492 BC - ca 432 BC) was one of the greatest of the ancient Greek philosophers. More than 2200 years ago, he discovered the fundamental ideas of life that now support the modern theory of evolution — 1) variety amongst individuals; 2) competition; and 3) reproduction and inheritance. Empedocles saw the diversity in modern animals as a consequence of differentially endowed individuals competing with one another, and passing their attributes to their offspring.

According to Empedocles, life went through a peculiar kind of evolution. He viewed life on Earth originally as a disorganized assemblage of unattached arms, heads and other body parts. Later, these free-floating parts became attached to each other in bizarre combinations — for example, a human head on an ox body. Some of these freak animals died off, as they were unable to compete with other more richly endowed animals.

Empedocles also understood the importance of reproduction and inheritance in the continuance and evolution of life. He remarked that, considering the difficulties of survival, the kinds of animals alive today must possess special courage or other features that help them survive and reproduce themselves. In so doing, each parent passes some of their own traits to their offspring.

Aristotle (384-322 BC) delivered a mixed bag of ideas to the understanding of life on Earth. First, he organized animals into a hierarchical classification scheme. According to Aristotle's classification, humans were at the top of the hierarchy. Below humans, were other live-bearing animals, followed by egg-layers. At the bottom of the scale were the vermin that arose spontaneously from the mud and filth. Aristotle's hierarchy reinforced the belief that humans enjoyed a special authority over all other life forms, that all non-human life was naturally subordinate to humans and less important. The notion of such a hierarchy also led to the development of the 'evolutionary ladder' idea of the 1800s. This unfortunate and wrong-headed evolutionary model continues to confuse, misinform and interfere with our understanding of evolution. More about this problem in chapter ?. Remember that Aristotle was a pioneer and though his hierarchy idea now is not supported, he did have remarkable intuition on the natural selection of favorable traits.

Aristotle's clever insights into the workings of animals in their natural world led him to make some very prophetic statements about the preservation or disappearance of certain anatomical characteristics. He recognized in animals that some features of their anatomy were beneficial — for example, the presence of sharp incisor teeth for cutting, and flat molars for grinding. But he suggested that such features do not appear for any predestined purpose. Instead, after having appeared, an anatomical feature either is useful or not. If the feature is useful, then it is preserved. If a new feature is not useful, then it will perish. Unknown to Aristotle at the time, he had predicted a natural mechanism for shaping the anatomies of animals. This understated yet powerful idea was rediscovered and extended by European naturalists more than 2000 years later. Unbeknownst to Aristotle (or anyone else), he had flirted with the concept of evolution by natural selection.

Given these ideas of more than 2000 years ago, it seems that the formative notions about the changeability of living things inevitably inspire people who think about life and nature.

9.4 During the Middle Ages, the church suppressed ideas about evolution

Despite that in ancient times there was an emerging interest in the history of the earth and life, an orderly explanation of everything was not immediately forthcoming. And nearly all efforts to understand how natural processes shaped the planet and life were suspended during the Middle Ages. During that time, the teachings of Aristotle were solidified by the church and dominated western scientific thought on the idea. Throughout the 1000-year stretch of the Middle Ages, very little progress was made.

With the Renaissance in Europe, interest again stirred regarding the history of Earth and life. But the church continued to persecute philosophers whose explanations strayed too far from Christian religious doctrine. According to the Bible, the Earth was created by God in seven days and was placed at the center of the Universe. Various theologians, beginning in the 4th century and continuing through the 1600s, estimated that the Earth was a mere 5000 to 8000 years old. In this short time span, there was one great catastrophe, the Great Flood. This flood was brought

Panel 9.1 Fossils were important stimulators of evolution ideas, which made them controversial

Our scientific understanding of the Earth's history grew from a natural explanation of fossils. The fossils in the rocks revealed two revolutionary understandings:

1) The rocks of the Earth formed in a definite sequence of successive geologic ages.
2) Life appeared on Earth in many forms and in a definite sequence of successive stages.

The study of fossils began in Ancient Greece. Xenophanes (576-490 BC) was the first natural philosopher to use fossils to support his ideas about a changing Earth. He observed the impressions of seashells and fish far inland and in the mountains. This led to his explanation that the dry land and sea had changed places many times in the past, and would do so again. Similar findings were reported more than a hundred years later by Xanthus the Lydian and Herodotus.

Aristotle, for all his great contributions, also was source of peculiar ideas. He thought celestial influences caused fossils to form deep in the rocks.

Following the thousand years of the Middle Ages, Renaissance scientists again took up the study of fossils. But this was done at great personal peril, for the church still was a formidable political power. Nevertheless, the church could not completely ignore fossils. Some explanation was needed. So, theologians offered creative interpretations of the fossils keeping them consistent with religious thought. I will list some examples below:

1) Fossils grew inside the rocks from seeds.
2) Fossils were unsuccessful creations cast aside by God.
3) Fossils are tricks of the Devil intended to deceive humans about the true history of Earth.
4) Fossils were 'sports of nature', just whimsical, nonsensical and irrelevant creations of nature.
5) Some fossils were the remains of poor human sinners killed during the Great Flood.
6) Fossils are remains of organisms whose kind are still alive somewhere on Earth, but have not yet been discovered by humans.
7) Many fossils are strange and unlike things alive today. But they could not be the remains of once-living organisms. If they were, it would mean that Noah and God were unsuccessful in preserving representatives of all living things during the Great Flood. And this is a direct affront to the Christian model of a loving and benevolent God.

During the lessening but still powerful hegemony of the church, Renaissance scientists wagered more natural explanations about the fossils in the rocks. The great Leonardo da Vinci (1452-1519) suggested how fossils could be formed under natural processes. He noted that the remains of shelled marine life (like clams and snails) could be preserved in the sediments of shallow seas near land. He also stated that the sea and the land undergo changes such that old sea bottoms emerge above sea level, revealing their storehouse of preserved shells. Interesting. But Leonardo da Vinci, like the ancient Greeks who far preceded him, had little impact in changing accepted beliefs about fossils.

After Leonardo da Vinci, other scientists became bolder regarding Earth's history and the meaning of fossils — and the church made them pay heavily for it. For example, in 1580 Bernard Palissy suggested that some fossils indicated many species of plants that are not alive today. The church denounced him as a heretic. Later, Italian scientist, Giordano Bruno, was burned at the stake in 1600 for his heretical views. He claimed that there never was a Great Flood, but that the positions of the land and sea had changed many times.

Clearly, the fierce political fortress of the Christian church of Medieval and Renaissance Europe did not value independent thought. This oppressive political climate changed with the appearance of the modern age starting in the 1600s. As naturalists more closely examined of the growing collection of fossils, the Church's view eventually was rejected.

In 1695, Nicholas Steno presented detailed and persuasive analyses of the anatomy of fossils. His impressive work made it unreasonable to argue against the organic origin of fossils. Eventually, the modern understanding of fossils became widely accepted. The evidence persuasively indicates that fossils are impressions in the rocks made by organisms that lived long ago. The acceptance of this important idea was necessary for a complete understanding of the Earth and life.

to Earth by God to punish humankind for its sinful ways. The biblical figure, Noah, recognized as the only righteous man on Earth, was instructed by God to build a large boat (the ark) and to place two of each kind of living thing on it. When Noah finished this task, the Great Flood sterilized the Earth and only the passengers on Noah's ark survived to repopulate the planet, hopefully in a more obedient way.

During this period, the church saw inquires into the natural development of the Earth and life as challenges to this fundamental doctrine. When philosophers argued favorably for a more natural explanation of the Earth, the church confronted such challenges — sometimes with deadly consequences. Eventually, the church lost its tight grip on human thought as greater numbers of educated people embraced more sophisticated views of nature. Surprisingly, the trail to modern evolutionary theory was cleared largely by new developments in geology and a final understanding of the meaning of fossils.

9.5 The acceptance of fossils meant that evolutionary changes actually happened

In the early 1700s, natural philosophers continued their struggle against the Catholic Church's constraints on human reason, creating an Age of Enlightenment. By the early 1700s, the collection of fossils continued to grow, as did doubts about the church's explanation for them. The work of Nicholas Steno in 1695 convinced many that fossils are indeed impressions of organisms that lived long ago (see Panel 9.?). The realization that many fossils are impressions made by organisms now extinct led to two possible explanations: 1) many species, once part of the special creation, had disappeared; or 2) species change through time. In any case, religious naturalists were confronted with a difficult crossroads. How could they reconcile the growing body of evidence with their traditional religious views? Perhaps the most outspoken objector of the age was naturalist, John Ray. He argued that species do not change and that no benevolent and wise creator would cast aside his creations in such abundance. In the waning tradition of religious naturalists, Ray chose to protect his spiritual belief system by rejecting the organic origin of fossils despite overwhelming evidence to the contrary. No rational argument can dislodge a belief.

Based upon a growing acceptance of the validity of fossils, eighteenth-century naturalists had enough evidence to advance the idea that evolutionary change actually happened. The evolutionism of the 1700s proposed that species did in fact change through time, but this idea was beset with certain shortcomings. For example, despite the abundance of fossils, there was no clear geological theory that would allow the fossils to be arranged along a time line. It was crucial to any fossil-based theory of evolution that it be able to determine when certain life forms appeared in relation to others.

How was the idea of evolution received? In a demonstration of their own adaptability, religious naturalists adopted the general concept of evolution with the proviso that God was still involved. According to this view, evolution was a process that unfolded according to a predetermined script. God was cast in the role of supreme Designer. Since there was not yet a theory describing a natural means for creating and changing a species, a Designer must exist. As proof of the Designer's love and benevolence, each species possessed a suite of traits that enabled it to cope with its environment. Like a watchmaker gracefully crafting a fine timepiece, God has designed useful adaptations for all living things. As we will see below, the advance of modern geology helped support later, naturally-driven versions of evolution.

Panel 9.2 Descartes popularized the notion of a mechanical Universe

In the middle 1600s, French philosopher, Rene Descartes, advocated a view of evolution that blended divine forethought with natural processes. According to Descartes's ***mechanical philosophy***, God's exertions in the development of the Universe were most intense at the time of creation. While He was creating the Universe, God established all the laws that governed how it would work – keeping in mind that His objective was the eventual appearance of humans on Earth. So, once created, the Universe unavoidably and on its own created Earth, life and humans through what otherwise appeared to be natural processes. Descartes argued that we are the result not of special creation, but of meticulous planning by a clever and patient God. This 'autopilot' approach raised serious objections by theologians as it implied that, once set in motion, God could then concern Himself with matters other than the day-to-day affairs of humans, His most special creation. Although Descartes's idea was imaginative, it lacked sufficient empirical evidence. With time, evidence continued to accumulate.

The difficulty with any history of *life* was that it needed to be consistent with the *physical* history of the Earth. Until this time, the various Earth histories were based upon biblical accounts or other forms of creation and catastrophism. Unfortunately, all such theories were advocated without the benefit of solid empirical evidence. In the late 1700s and early 1800s, the notion of an ancient and ever-changing Earth (and not a catastrophic one) began to capture the imagination of scientists.

One of the distinguished scientists of this period was the French naturalist, Georges Louis Leclerc, Compte de Buffon (1707-1788). He was a prodigious writer and prepared a 44-volume treatise of the natural world entitled, *Natural History*. In it, he promoted the idea of a gradually changing Earth shaped by natural forces, and not necessarily by the acts of God. But later, under pressure from the church, Buffon retracted statements that departed from orthodoxy. Nonetheless, Buffon inspired a new generation of geologists who advanced and refined his ideas.

9.6 Hutton demonstrated that there was time available for small evolutionary changes to accumulate

One important scientist of the Enlightenment tradition was Scottish geologist, James Hutton (1726-1797). Hutton firmly established the field of modern geology with the publication in 1795 of his two-volume, *Theory of the Earth, with Proofs and Illustrations*. His geological theory was revolutionary and controversial. It directly challenged prevailing Earth theories that unsuccessfully tried to reconcile geological observations with the Biblical account of creation. Although Hutton believed that God had designed the Universe and Earth, he departed from the literal Christian view of creation. As we have seen before, disagreements with the church were very risky adventures. So, what drove Hutton down this hazardous road?

It turns out that the rebelliously empirical Hutton refused to ignore the overwhelming body of evidence that simply did not fit the creationist story. Instead of a planet shaped by catastrophes, Hutton reasoned that the Earth constantly undergoes small changes. Observable geological processes such as volcanoes, earthquakes, erosion and sedimentation bring about these changes. Over long periods of time, these small changes add up to big changes such as mountain-building and mountain erosion. For example, Hutton and others observed that erosional forces steadily washed away mountains, depositing the eroded sediment in the sea. Periodic variations in rainfall meant that sediments would be laid down on the sea bottom in a series of layers. Over time, pressure and heat would solidify the layers of mud, forming rock. Occasionally, the ancient beds of sediments would be slowly lifted up out of the sea to form new mountains. Then the whole process would begin again. And so, Hutton described the Earth as an ancient planet in a perpetual state of decay and rebirth.

Hutton's contentious theory was successful largely because his focus was narrow and his ideas were well bolstered by a corpus of empirical evidence that was sufficient and reasonable. Although he did not specifically concern himself with the concept of evolution, his theory indicated that the Earth is ancient — far older than 8000 years. Thus, Hutton provided evolutionary biologists one important concept: the immense time needed for evolution was available. Instead of a young Earth only 4000 years old, the Earth could be millions of years old. This greater availability of time made the idea of a natural evolution of life much more reasonable.

9.7 William Smith's work made it possible to arrange fossils on a time line

Until now, the evidence for evolution was limited simply to the recognition of unusual fossils in the rocks. Their appearance alone naturally led scientists to consider that life may have undergone changes leading to its present assemblage. But there was no way to trace the thread of these changes. Finding a fossil here and a fossil there kept curiosity high but did not lead to an organizing principle about the evolution of life. If life did experience large-scale evolutionary changes, it should be possible to follow its progress in the rocks. William Smith discovered the key to this mystery.

William Smith, an English canal-builder in the late 1700s and early 1800s, established the notion of *faunal succession*. According to Smith, fossils occur in the rocks in a definite and orderly sequence. During his studies of fossils and rocks in Great Britain, he recognized a pattern of succession. Certain types of fossils always seemed to occur in a consistent sequence in relation to other types of fossils as if laid down one-after-the-other. This pattern repeated itself at many distant locations. Two powerful ideas emerged from this insight:

1) Rock units formed during a particular geologic time can be recognized by their unique assemblage of fossils. In other words, Certain kinds of rocks (sedimentary rocks) are laid down one atop the other in different points in time. Each layer of rock represents a different episode in the geologic history. As each layer of sediment is formed, it tends to preserve the remains of plants and animals alive at the time. This discovery led to the development of relative dating techniques and the growth of a

geologic time scale. Using fossils, geologists could demonstrate that a given rock formation was either older or younger than other distant formations in a sequence of formations.

2) Seeing evidence that fossils changed over time, the idea that life evolved was hard to ignore. According to this idea, the unique kinds of living things in the fossils represent an accumulation of evolutionary change of life from one form to another. All new forms are descendents from their parental stock. And each new form in turn may give rise to still newer forms.

William Smith's principle of faunal succession supported the idea that large-scale evolutionary change did in fact occur. More importantly, it was now possible to place fossils along a time line. According to this simple idea, the fossil record in the rocks indicates that during its tenure on Earth, life underwent many changes. Exactly how life accomplished this feat remained a mystery that was soon addressed by several great scientists.

Let us pause for a moment and consider where we are. The overall topic of evolution is about two big ideas. The first idea wonders whether or not life actually went through changes to produce new varieties. Steno's work on fossils, Hutton's ancient Earth, and William Smith's principle of faunal succession provided powerful support that life on Earth experienced large-scale evolutionary changes. The second big idea wonders how these evolutionary results came about. What were the natural mechanisms that produced evolutionary change?

9.8 As naturalists discovered ecological principles, theories of evolution began to take shape

The middle 1800s was an appropriate time to set upon a quest for an explanation of this extraordinary process. During this period, humankind's knowledge of the natural world in many new disciplines began to achieve a sort of critical mass. Keep in mind that the 19th century advocates of various evolution theories were not the first to do so. It is just that they were the beneficiaries of an accumulating knowledge base of greater breadth than anyone had ever seen before. The time was nearly right. All that was needed was a few trips around the world.

In travelling the Earth, naturalists noticed that there was a mysterious relationship between living things and their physical environment. In the early 1800s, German botanist, Carl Ludwig Willdenow (1765-1812) saw that similar climates supported similar kinds of vegetation. For example, completely unrelated plants in dry climates on different continents looked very much alike, presumably as a consequence of their similar environments. Could this be evidence of evolution? Willdenow's provocative observations helped focus the exuberant energies of a young botanist named Friedrich Heinrich Alexander von Humboldt (1769-1859).

In 1799, Humboldt and French botanist, Aimé Bonpland, embarked on a 5-year botanical odyssey to the New World. Occasionally referred to as the second discoverer of America, Humboldt explored the botanical riches in the regions of Colombia, Ecuador, Mexico, Peru, Venezuela, and Cuba. He was one of the first naturalists to recognize the great diversity of tropical life. Humboldt was stunned by the huge number of plants and animals he found there. As he traveled and collected over 60,000 specimens, it occurred to him that there must be many more species in the world than anyone had previously imagined. On another front, Humboldt confirmed Willdenow's previous observations concerning the puzzling association between plant types and their environment. He noted that a given type of physical environment usually was populated with a particular group of plants. The plants had physical characteristics that seemed suitable for their environment (adaptations) Wherever he encountered this kind of environment, so did he see this group of plants. Humboldt observed that plants appeared to be adapted to their environment.

In 1804, Humboldt returned to Paris where he spent the next 25 years preparing a 23-volume work describing his findings. Despite Humboldt's deep interest in nature, he did not deal directly with ideas about evolution. Nevertheless, his findings regarding tropical diversity and plant adaptations contributed greatly to evolutionary understanding.

9.9 Lamarck's theory of evolution argued that individuals reprogrammed themselves to best adapt to their environment: Evolution-by-necessity

NOTE: The expression, 'living things adapt to their environment' is consistent with Lamarck's evolution theory but it is NOT consistent with Darwinian evolution theory.

In 1809, the first cohesive theory of evolution appeared. It was introduced by French Biologist, Jean Baptiste Pierre Antoine de Monet, Chevalier de Lamarck (1744-1829). In his *Zoological Philosophy*, Lamarck described evolution as an inevitable process in which, given enough time, species changed in response to a changing environment. Here, Lamarck addressed the origin of adaptations by clearly linking anatomy to the environment. That is, the features we see in animals (and plants) are consistent with their surrounding physical environment. . But from where did new features arise? Unfortunately, his speculative answer to this question greatly overshadowed Lamarck's otherwise valuable contributions to evolutionary theory

Lamarck explained in *A Natural History of Invertebrate Animals* (1815) that innovative features arose within the lifetime of an individual in response to some change in the environment. That is, individuals assessed their environment and made small but incomplete internal adjustments to best exploit it. This resulted in slight changes to the individual. These adjusted features were then transmitted to offspring. Offspring, having inherited a head start, made additional internal adjustments and changed still more. This process continued for many generations until the species reached a point of perfection.

Despite his theory's problems, Lamarck got a few things right. First, he correctly applied the idea of reproduction with inheritance. According to this system, adaptive traits are passed on to the next generation. Secondly, he correctly observed that refined adaptations arise following many generations of small changes. According to this system, each generation adds small changes. After many generations, these small changes add up to big changes. The end point is a polished and useful adaptive trait.

Lamarck was an astute zoologist and his theory of evolution was reasonable although incomplete. It failed on two counts: 1) He misunderstood how innovations appeared and created variety within a species; and 2) He was unaware of how ecological stresses arise to act on the variety within a species. Still, Lamarck's theory of evolution attracted so much heat from religious conservatives that it depleted their reserves and their will to resist. Lamarck had cleared the way to the ultimate theory. Two great naturalists, Charles Darwin (1809-1882) and Alfred Russel Wallace (1823-1913), later slipstreamed along Lamarck's path. Armed with additional ecological knowledge and worldly experience, they independently developed a durable theory of evolution by natural selection.

9.10 Darwin and Wallace saw how ecological stress naturally filters out some individual but not others

In the summer of 1992, I stood on the grave of Charles Darwin. There in the cloistered halls of Westminster Abbey, next to Sir Isaac Newton, lay the man who today is so reviled by religious fundamentalists. The thick irony was inescapable, that a man of such notorious history should be so valiantly honored in this historic cathedral — there, near the tombs of such historic figures as Queen Elizabeth I, Charles Dickens and Rudyard Kipling. Although his work was met with either excitement or hatred, Darwin was a man of complete humility who devoted his life to find out what was going on. Upon reflection, I suppose my visit to Darwin's grave was my personal way to share in his triumph — a victory not easily discovered.

Charles Robert Darwin was the sixth of eight children born to Susannah (Wedgewood) Darwin and Dr. Robert Waring Darwin. In his youth, Charles demonstrated some interest in the biological world but generally exerted very little effort in his formal studies. Nonetheless, he was sent by his father to study medicine at Edinburgh University. There, he indulged himself in non-medical pursuits such as collecting specimens in the nearby tide pools and other explorations of the natural world. Apparently, Darwin had no interest in medicine.

Frustrated with his son's poor progress, the elder Darwin proposed that Charles seek a new career as a clergyman. This idea appealed to Charles, as he was a practiced student of the Bible. So, Charles Darwin went to Cambridge University to prepare himself for the holy order. Once there, he could not restrain his primary interest in nature. Instead of minding his studies, Darwin became an insatiable collector of beetles. As a consequence of his biological interests, he tended to associate more with men of science than with men of the cloth. So, despite the wishes of his father, Charles Darwin was a poor student but irrepressible naturalist.

The historic turning point in Darwin's life came with his voyage around the world. Professor Henslow of Cambridge recommended Darwin for the position of ship's naturalist upon the survey ship, *H.M.S. Beagle* (although Darwin was not his top pick). Final placement of Darwin in this capacity was not a forgone conclusion. Darwin's father strongly objected and, were it not for arguments by Darwin's Uncle Josiah Wedgewood, there would have been no voyage. Next, Captain Robert Fitz Roy of the *H.M.S. Beagle* expressed doubts about Darwin's chances for success. This was in part due to the captain's adherence to the theory of phrenology, which argued that the shape of a person's head determined their mental capacity. Captain Roy thought the shape of Darwin's nose indicated a certain lack of vigor. Apparently, Darwin's father also was a follower of phrenology when he was heard to exclaim upon Darwin's return, "Why, the shape of his head is quite altered". In December 1831, Charles Darwin left his clerical studies at Cambridge to embark on one of humanity's most historic journeys.

The *Beagle* took five years to circle the Earth. Its mission was to make all manner of surveys of the Cape Verde Islands, South America, the Galapagos Islands, Tahiti, New Zealand, Australia, Mauritius, and South Africa. The trip lasted until October 1836, and except for periodic calls to port, Darwin was seasick nearly the entire time.

Darwin's transformation from a believer special creationism to a proponent of evolution happened as a result of this fateful expedition. As he traveled down the coast of South America, he made the same observation that Humboldt made. There appeared to be a relationship between the physical features of species and their physical environments. And the huge numbers of closely related but distinct species caused Darwin to wonder why God should bother creating so many close lineages. The tropical rain forest, with its millions of species, greatly overshadowed the deforested and impoverished wilderness of Darwin's England. Darwin, like Humboldt, was forced to reevaluate his understanding of nature.

In addition to studying the plants and animals, Darwin also investigated interesting geological features. He was intrigued by the writings of geologist Charles Lyell, whose *Principles of Geology* text was a clearer exposé of James Hutton's theory of an ancient and constantly changing Earth. On his visits to land, Darwin studied the geology and collected fossils where he could. In the process, he noted that his observations were consistent with Hutton's geological theory. All the while, Darwin was exposed to a world of nature so rich and diverse that it was bound to impress him in unexpected ways. The most powerful blow to his withering creationist faith came to Darwin long after visiting the Galapagos Islands.

The Galapagos Islands presented Darwin with the most unusual and inexplicable assemblage of animals that he had yet encountered. There are about 20 islands that make up the Galapagos, situated on the equator about 500 miles west of South America. What surprised Darwin most was that 21 of the 26 species of birds on the Galapagos Islands were like no others in the world. More than that, he found that many of the individual islands themselves had unique species that were not present on any other island. Still, they resembled birds on mainland South America. The same general observations held true for the plants and other animals there. Overall, Darwin saw a trend in the degree of relatedness between similar species. He noted that the unique species on different islands were more closely related to each other (were more similar) but were more distantly related to mainland species (were less similar). What could have caused this?

Long after his voyage was over, Darwin sought to explain his observations of the Galapagos finches. According to Darwin, the Galapagos Islands were colonized by mainland species. But this happened only very rarely. Since they were isolated from a fresh infusion of mainland stock most of the time, the island species proceeded to diverge from their mainland ancestors. To Darwin, this seemed like a more reasonable explanation that one of special creation. Why would God endeavor to create species that gave the appearance of such natural divergence? Nevertheless, Darwin was unsure of the means by which such divergence would happen.

Darwin's journey soon ended. Now a naturalist of global experience, the puzzling discoveries of his 5-year voyage haunted Darwin for many years afterward. What could they mean? Upon returning to London in October 1836, Darwin spent the next six years organizing and recording his observations. In 1842, he moved to Down, England where he indulged in the classification of barnacles for eight years. While in England, other things were going on that caught Darwin's attention.

He became deeply interested in the activity of domestication of animals and plants. For example, Darwin investigated how farmers bred specific and diverse varieties of cattle, sheep and crop plants. His studies on domestication led him to the notion of *selection* as a method of creating new varieties. That is, agricultural breeders consciously selected specific individuals for breeding based upon the possession of traits the breeder wanted. After many generations, this form of artificial selection gradually enhanced desirable traits. This meant bigger beef cattle, more productive dairy cows, more robust grains of wheat. Darwin saw in domestication the fruitful consequences of selection as an amplifier of characteristics. Once he understood artificial selection, Darwin wondered if selection could act in the wild. A book by the English economist, Thomas Malthus (1766-1834), provided Darwin with the last piece of the puzzle.

Thomas Malthus is best known for the 1798 publication of the book entitled, *An Essay on the Principle of Population, as it Affects the Future Improvement of Society*. Malthus's central prediction was that the human population would increase until such point that we would outpace our ability to grow enough food for everyone. Should this happen, many but not all humans would die from starvation. When Darwin read this book in 1838, it helped him see the importance of ecological stress as a filtering mechanism. It occurred to him that natural populations are limited in size because of chronic shortages of resources, like food and territory. This being so, many individuals from each generation must die before reaching sexual maturity while others, because of their particular mix of attributes, will survive. Hence, it is self-evident that the survivors must have traits that favor survival under such stressful conditions. And, those traits will tend to be passed on to future generations at greater frequencies than will non-beneficial traits. Over many generations, this could result in the refinement of traits best suited for the environment — adaptations. Given enough time, these phenomena could lead to whole new varieties. At last Darwin had discovered a compelling natural mechanism for selection in nature. He called it *natural selection*. If true, it meant that evolutionary change could be produced purely by natural forces. With some reluctance, Charles Darwin was about to bring modern human culture to an exciting but anxious crossroads.

Darwin pondered the significance of his new insight and roughly laid out his ideas in unpublished essays in 1842 and 1844. He communicated his thoughts privately with Charles Lyell who encouraged Darwin to publish his findings before someone else reached the same conclusion. Despite Lyell's warning, Darwin waited until 1854 before he began to organize and write his findings on evolution.

Meanwhile, another world-exploring naturalist named Alfred Russel Wallace (1823-1913) also had read Malthus's essay and had been similarly inspired. Wallace was working in Malay and had independently arrived at the notion of evolution by natural selection. While formulating his ideas in 1858, Wallace sent Charles Darwin an Essay entitled, 'On the Tendency of Varieties to Depart Indefinitely from the Original Type.' Wallace had solicited Darwin's comments before submitting the essay for publication. To Darwin's astonishment, Lyell's warning had come true. Wallace also had discovered the ecological phenomenon of natural selection. Deflated and having no stomach for a priority dispute, Darwin was inclined to let Wallace publish first. But Darwin's associates, Joseph Hooker and Charles Lyell, intervened and arranged that Darwin and Wallace should present a joint paper to the Linnean Society in London in1858 — which they did.

Shortly thereafter, Darwin finished his manuscript arguing that natural selection was the main mechanism driving evolution. On November 24, 1859, 23 years after the conclusion of his voyage, *The Origin of Species* appeared. By the end of the day, the entire first edition (1250 copies) was sold out.

9.11 The combining of Darwin's theory of natural selection with the Mendelian theory of heredity completed the modern theory of evolution

Darwin and Wallace presented only a partial picture of how evolution might work. The issue of inheritance was a major difficulty for the theory of natural selection. Although the theory of evolution by natural selection heavily relied on the inheritance of traits, there was no solid theory to explain inheritance. In the time of Darwin and Wallace, science did not fully understand how variations arose or how traits got passed to offspring. What was needed was a theory of inheritance. Mendelian genetics addressed these shortcomings.

The pioneering work in genetics by Gregor Mendel was rediscovered in the early 1900s. Eventually, his explanation became the accepted model of inheritance by the 1920s. But the relationship between Mendelian genetics and evolution still was unclear. This situation soon changed. In the 1930s, R. A. Fisher and J. B. S. Haldane each published books that vividly explained the connections between the theory of natural selection and the Mendelian theory of heredity. These works emphasized the genetic basis for the origin and inheritance of innovative traits. In effect, natural selection selects which genes get copied into the next generation. The basic structure of the modern theory of evolution was then complete – a synthesis of genetics theory and ecological theory. Its new form commonly is referred to as *Neo-Darwinism*, or *the modern synthesis*. In the next chapter we will explore how ecological circumstances act on genetically controlled traits to produce evolutionary results.

9.12 It was a long, hard journey

Let us retrace the steps that led to the development of the theory of evolution by natural selection.

<u>1. Evolution was considered early and often.</u>
The idea that living things evolved into different forms throughout the Earth's history originated, at least in the literature, with the ancient Greeks. Since then, many philosophers suggested their own versions of how this might have happened. But all previous theories were incomplete mainly because of ignorance in geology and ecology.

<u>2. The acceptance that fossils are the remains of once-living things meant that evolutionary change actually happened.</u>
By the 1700s, it finally became acceptable to consider fossils as the remains of plants and animals that lived long ago. Fossils provided evidence that evolutionary changes happened, although there was still no way to reliably place fossils on a time line.

3. Hutton's theory meant that long periods of time were available for evolutionary changes to accumulate.

James Hutton established a coherent theory of the Earth in 1795. His theory of established an important cornerstone for the theory of evolution — immense amounts of time. Since large-scale evolution probably takes many generations, it is more reasonable to consider evolution on an Earth millions of years old rather than an Earth only 8000 years old.

4. William Smith's work made it possible to place fossils on a time line.

William Smith reinforced the idea that the organisms represented by the fossils lived in a definite sequence in time. This strengthened the idea that certain living things appeared, lived for a time, then were replaced by newer forms. The progress of evolution could be tracked through time, catalogued and understood.

5. Naturalists observed that there is a relationship between the features of living things and their environment.

Naturalists, like Willdenow, Humboldt, Darwin and Wallace could not help but notice that the observable features of plants and animals were consistent with their particular physical environments. This idea cemented the concept that living things share some special relationship with their environment. The notion of adaptations appeared.

6. Many naturalists considered that the close similarities of distinct species could imply evolutionary kinship.

They also noted the existence of possibly millions of species, many of which were just slightly different from each other. For such species, it was reasonable to consider them in terms of their possible evolutionary kinship.

7. Lamarck saw that evolution requires the introduction of innovations, and there must be reproduction with inheritance.

Lamarck argued that the logical route to a complete evolutionary theory had to involve the introduction of innovation and the passing on innovative traits to offspring.

8. Darwin saw that the changes in domestic animals are the results of evolution by artificial selection.

In the area of agricultural domestication, Darwin saw a means of artificial selection. Farmers caused the enhancement of certain traits by consciously selecting which individual would breed and which would not. After many generations, artificial selection resulted in big changes in the species.

9. Thomas Malthus predicted that because of limited resources, more individuals are born to a generation than will survive to reproduce.

Thomas Malthus argued that populations would grow faster than their food supply. The consequence would be the death of many but not all individuals by starvation. The shortage of resources acts as a filter through which only the most capable will pass.

10. Darwin and Wallace demonstrated that evolutionary results occur following the ecological phenomenon of natural selection.

Darwin and Wallace saw that innovative variety exists in all natural populations as individuals are born with their own unique suite of characteristics. Both of them independently applied the principles of Malthusian overpopulation to natural populations. In a world of chronically limited resources, certain individuals, by way of their unique suite of characteristics, will be better able to survive than other individuals. The result is that traits which aid in success are more likely to be passed on to the next generation. Nature has a built in way to select favorable traits — natural selection.

11. Gregor Mendel worked out the genetic basis of inheritance.

In the late 1800s, Austrian monk, Gregor Mendel published his findings on the statistics of inheritance. According to his work, traits are controlled by discrete biological objects called genes. These genes are sorted in various ways during the production of sex cells like eggs and sperm. Offspring inherit unique combinations of genes from their parents. Depending upon the combination of inherited genes, offspring display traits inherited from their parents.

12. R. A. Fisher and J. B. S. Haldane combined the theory of natural selection with the theory of Mendelian genetics which resulted in the modern synthesis, or neo-Darwinism.

Neo-Darwinism came about with the combination of ecological theory(which includes the phenomenon of natural selection) with the theory of Mendelian genetics. Fisher and Haldane addressed what Darwin and Wallace couldn't — the area of inheritance. Fisher and Haldane addressed this shortcoming by integrating Mendelian genetics into evolutionary theory.

9.13 So, what did Darwin and Wallace accomplish?

The theory of evolution provides us with a better understanding of how adaptive traits arise and how new species can develop. It helps explain why we see so many different kinds of living things today all over the world. It helps us to understand the overall idea of evolution during Earth's history — why older rocks contain very unusual fossils and why younger rocks contain fossils of more familiar species.

Although the sciences of ecology and genetics did not yet exist in the time of Darwin and Wallace, evolution theory is dependent on and a synthesis of the basic principles of these sciences. For example, Darwin emphasized that competition (struggle for existence) between members of a species was vital to his theory. The concept of competition is a fundamental ecological concern. Darwin recognized its importance in shaping new species.

In another example, Darwin recognized that there is great variety amongst members of a species. But unlike Lamarck, Darwin correctly predicted (as did Aristotle) that new features arise spontaneously and with no predestined purpose. Darwin also saw that traits of the parents are inherited, with some variability, by their offspring. In their arguments about variability and inheritance, Darwin and Wallace had addressed the fundamentals upon which the science of genetics would later develop.

The theory of evolution is a classic example of an embedded scientific theory. It provides the central organizing principle upon which other fields of science have emerged and grown. If the theory were not useful, then new scientific understandings should demonstrate this fact. And there have been ample opportunities. Since Darwin's time, our understanding in many fields of science has grown exponentially. It turns out that our new knowledge in so many fields is consistent with the theory of evolution. As a result, scientists have come to accept that the theory of evolution is the best way to explain how life has become so complex, so diverse, and so widespread.

Sources used to prepare this chapter

Berry, William B. N., (1968). *Growth of a Prehistoric Time Scale, Based on Organic Evolution*. W.H. Freeman and Company, San Francisco.

Bowler, P. J. (1983). *Evolution: The History of an Idea*. University of California Press, Berkeley.

Dalrymple, G. Brent, (1991). *The Age of the Earth*. Stanford University Press, Stanford.

Darwin, Charles, (1859). *The Origin of Species by Means of Natural Selection*. Republished by many publishers.

Dillon, Lawrence S., (1978) *Evolution, Concepts and Consequences*. Mosby, Saint Louis, 2nd Edition.

Lemon, Roy R., (1993). *Vanishing Worlds, An Introduction to Historical Geology*. Wm. C. Brown Publishers, Dubuque.

Magner, Lois N., (1994) *A History of the Life Sciences*. Marcel Dekker, Inc., New York, 2nd Edition.

Smith, Robert Leo., (1990). *Ecology and Field Biology*. Harper and Ro, New York.