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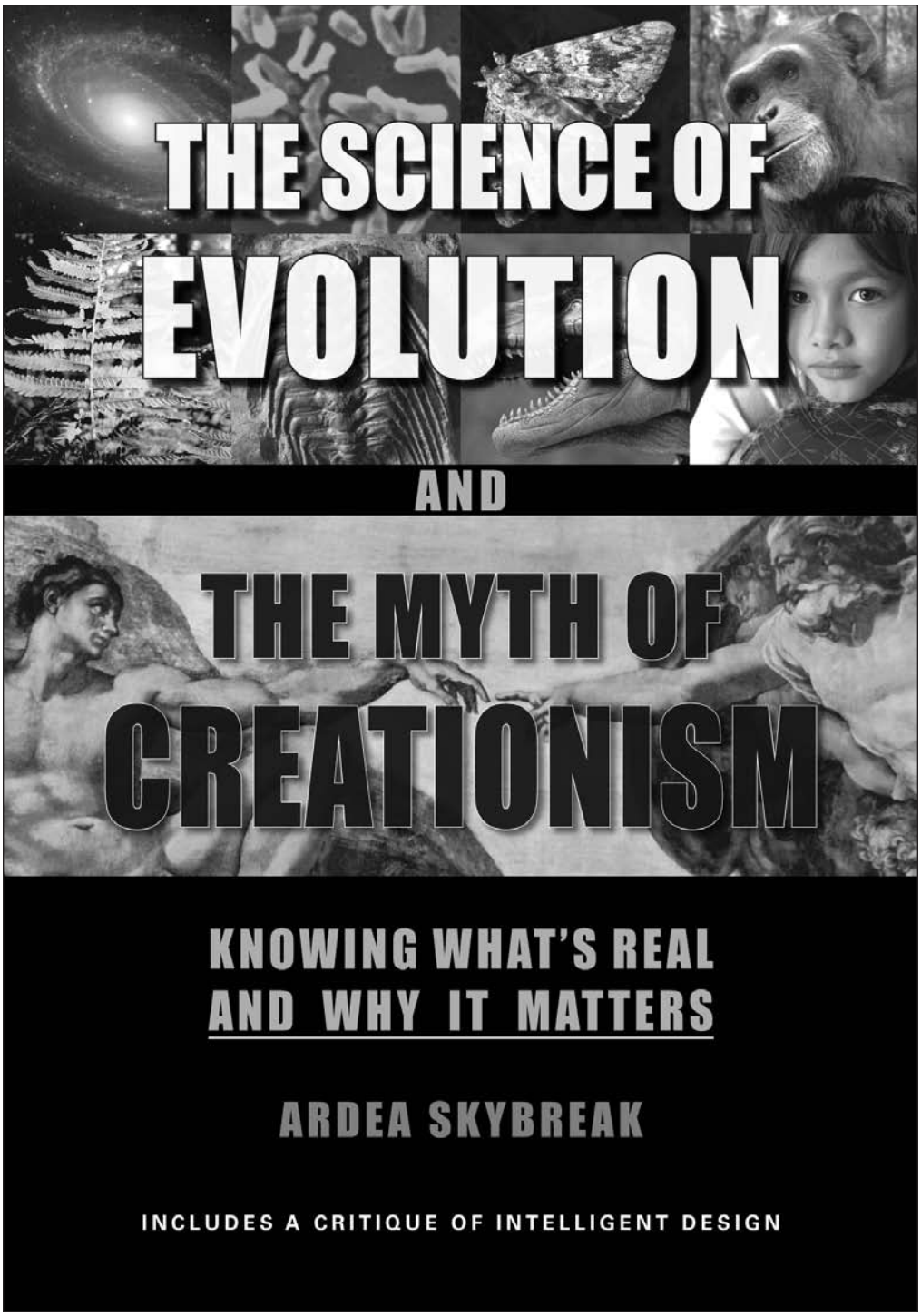

Chapter One

An Overview

Excerpts from *The Science of Evolution and The Myth of Creationism*

Chapter 1

An Overview

Our planet, like all things, has a history. It is *a history of change*—all sorts of dramatic changes, taking place over billions of years. Changes have never stopped happening, and are still going on.

So let me just start off by briefly going over a few things that all modern scientists and most people who have had the opportunity to learn basic scientific facts know to be true—as definitely and undeniably true as the fact that the earth is not flat or that it goes around the sun.

Our planet was birthed in some cosmic explosions about 4.5 billion years ago, hurtling through space as a fiery ball of hot rocks and gases, and settling into orbit around one of the many stars in the cosmos—the one we call "our" sun. For the first billion years or so the planet went through many physical changes—starting to cool down for one thing—but there was no life.

Fast forward about a billion years. By then a lot of things have changed in the physical composition of the planet: surface temperatures have cooled considerably, and some land masses and water bodies have begun to take shape. But temperatures are still fairly extreme, and the waters and atmosphere are full of acids and poisonous gases.

In fact, if you could somehow go back in time about 3.5 billion years, you would have a hard time even recognizing our planet! You would find no animals walking the land, no insects or birds in the skies, no fish in the seas. You would find no grasses, no trees, no flowering plants. You would find no familiar landmarks: none of the familiar continents, mountain ranges, plains, or oceans of today. And you would find no fresh water to drink, absolutely nothing you could eat, and you wouldn't even breathe the air which didn't yet have any oxygen.

But if you'd known where to look 3.5 billion years ago (and could have somehow protected yourself from the extreme temperatures and poisonous atmosphere!) you might have found the very first forms of life on this planet. You would have had to look closely, because life wouldn't have looked like much back then—imagine something like microscopic clumps of organic molecules coming together and forming very stripped-down versions of living cells, simpler in structure even than modern-day seaweeds or

bacteria. A kind of chemical "soup," alive only in the sense that these new little tidbits of matter could do two things that non-living things cannot do on their own: actively draw in energy from the outside environment (allowing them a means to grow and develop, as well as a basic means to cause transformations of that outside environment) *and replicate*, or make new copies of themselves. *(See "The Earliest Emergence of Life" below.)*

If you dig down into the earth today, you can find fossilized (hardened and preserved) remnants of ancient creatures, many of which no longer exist today. The oldest fossils which have been found are the remnants of ancient bacteria which lived about 3.5 billion years ago.

We don't really know whether primitive life may have emerged and then perhaps "petered out" (and later re-emerged) a number of different times in the very early history of the earth. But, at any rate, there is plenty

The Earliest Emergence of Life

So many things have changed on this planet in the past 3.5 billion years or so that it is very difficult to re-create in a laboratory *exactly* the same conditions as existed back then—just the right "mix" of temperature and energy and just the right proportions of chemical compounds (such as methane, ammonia, carbon monoxide, water vapor, etc.) that existed in earth's early atmosphere. But even though no one has yet been able to fully recreate the emergence of simple life-forms in a test tube, scientists are getting closer all the time to being able to do just that. Beginning with Stanley Miller's famous experiments in the 1950s, a number of lab experiments have demonstrated that some of the basic chemical building blocks of life (including sugars and the basic components of proteins and DNA) will actually begin to coalesce ("self-assemble") *spontaneously* (on their own) given the right physical and chemical environment!

To qualify as a "life-form"—rather than as an inanimate (non-living) object—a bit of matter has to have two main characteristics:

1) the ability to actively extract energy from the outside environment (such as when living plants derive energy from the sun, or when living animals derive energy from eating) and,

2) the ability to *replicate* itself: to qualify as "alive," matter has to be able to make copies of itself (though not necessarily perfectly identical copies) and in replicating itself it has to be able to "pass on" at least *some* of its characteristics to its descendants.

On this planet at least, all life-forms also form some kind of *membrane* or compartment—such as a cell membrane—which serves to contain the replication and energy-tapping mechanisms and keep them relatively separate and distinct from the rest of the outside world. Most scientists today think that the earliest living organisms on earth were *little more than self-replicating protein molecules enclosed in a simple membrane*, and that all subsequent life-forms evolved over millions and billions of years *from these simple beginnings*.

For a number of decades now, scientists have been conducting experiments aimed at trying to recreate the initial steps in the emergence of life on this planet. Back in the 1950s, Stanley Miller's famous laboratory experiments were the first to prove that very simple chemical reactions could in fact produce some of the simplest "building blocks" of life: he showed for instance that simply sending jolts of electrical energy (similar in effect to lightning bolts striking the early earth) into a mixture of methane, ammonia and water (chemicals which are known to have been present in the environment of early earth) ends up producing

of evidence that all the life-forms which are around on earth today—all the bacteria, all the species of plants, all the species of animals, including humans—are descended from *a single* common ancestor. One of the most important indicators of this "common descent" is that all living things on this planet make use of *the same basic underlying genetic code* and share many particular mechanisms of protein synthesis. The particular DNA/RNA-based method of replication and inheritance, which is a characteristic of all living things on this planet, is *not* necessarily the only way that "life" could reproduce itself: we may well some day discover life-forms in other corners of the universe which use a completely different system and different chemical building blocks for their own replication and transmission of inheritable characteristics. But what's important to understand here is that all living organisms on *this* planet use basically the very same system and underlying

some new chemical compounds, including *amino acids and sugars*. This was a very exciting discovery, because amino acids and sugars are *fundamental building blocks of the more complex molecules found in all living organisms*! Given that lightning, methane, ammonia and water would have been abundant in the early stages of our planet's history, and (importantly!) given that there would have been no creatures around yet which could *eat* any amino acids or sugars being produced through such simple chemical reactions, the early oceans could well have become rich and concentrated "soups" of these "building blocks" of the more complex organic molecules found in all living things. And other experiments have also shown that such substances can assemble themselves spontaneously into more extensive "films" or "mats" of interacting compounds. It is easy to imagine such mats clinging to the ancient rocks or drifting in the ancient seas, serving as early templates for the assembling of more complex molecules.

Some more recent laboratory experiments have even demonstrated that certain simple sequences of nucleotides (short bits of RNA for instance) will sometimes *self-replicate*, or make copies of themselves, *even in the absence of any protein enzymes* (which until recently were thought to be absolutely required for this process to occur), and these new bits of RNA have even been observed beginning to *evolve* on their own! Given the right mix (or chemical "soup"), fatty acids—which are key components of living cell membranes—have *also* been shown to assemble spontaneously, suggesting that some kind of similar process may well have been involved in the formation of the very first living *cells*. Again, the first living cells are likely to have been little more than tidbits of self-replicating DNA or RNA molecules surrounded by a simple membrane. Experiments investigating and demonstrating how earliest forms of life might have emerged on this planet have been going on for only a few decades, so there is obviously still much to discover about these processes. But what has already been learned through these experiments clearly demonstrates how some of the first steps involved in the development of primitive life could have taken place spontaneously (without the hand of any divine "Creator" or "Intelligent Designer") in the primeval chemical "soup" of this planet.

Beyond that, it is very important to understand that, while every detail of the process of the *earliest emergence* of life hasn't yet been fully worked out, scientists do know that life *evolved* after it emerged. And as we will see, there is actually a great deal of concrete evidence and proof of *how* this process has actually taken place over the past 3.5 billion years.

foundation to replicate themselves. And this observable fact—the fact that no life-forms on earth employ any *other* system of genetic replication—is considered by most biologists to be very strong evidence that all living creatures on this planet (including people) are *descended from one single common ancestral life-form*, which then, over hundreds of millions and even billions of years, evolved and diversified (branched out) into all the many life-forms we are now familiar with.

OK, but if the first forms of life on this planet were just simple things like bacteria, *how the hell did **we** get here*? Or how about the elephants, or the pine trees, or the grasses, or the parrots, or the mosquitoes? Even with billions of years to work with, how could things "get" from bacteria to any of those complex creatures? If life started out so simply (and in fact fossils indicate that a wide variety of bacteria remained the only game in town, so to speak, for about 1 billion years!), *why didn't life just "stay" simple?* Why are there now *so many* different kinds of plants and animals, and why are many of them so complex? And why aren't *all* the life-forms that ever existed on this planet still around? Why, for instance, did some creatures—like the dinosaurs or giant armadillos or saber-toothed tigers, and many other animal and plant species—go *extinct*? Why are more than 90 percent of all the species that ever lived gone? Why is it that, as ancient fossils reveal, some creatures that lived millions of years ago hardly ever changed over time (such as some species of cockroaches, crocodiles, ginkgo trees or horseshoe crabs, which seem nearly identical to their fossilized ancestors from millions of years ago) whereas most lineages (broad "groupings" of related plants or animals) changed dramatically and repeatedly over those same millions of years? How does the growing collection of hominid (human-like) fossils (as well as molecular DNA evidence), prove that the lineage which eventually led to modern human beings diverged (split) from an ancestor species which was also the ancestor of modern-day chimpanzees and gorillas, and what can this evidence also tell us about the defining features of that divergence?

As I hope to show in the course of this book, we need the science of evolution to answer all these kinds of questions. In fact, the *only* way we can answer these types of questions is if we understand evolution. *(See "Not Everyone Wants You to Learn About Evolution," right.)*

So What Is Evolution Anyway?

Many people have some misconceptions about what evolution is and what it is not. In a most basic sense, evolution is "change." But not just the kind of *quantitative* change that occurs when something grows or expands or decays, but a more rich and complex kind of *qualitative* change, the kind of change that produces novelty and innovation—*new things* that have never before existed. And evolution isn't so much about how *individual*

things change, but about how whole *systems* change, over *time* and over *generations*.

In one sense, even non-living systems can "evolve" as long as they meet certain criteria. Non-living systems which can be seen to evolve over time include human *cultural systems*, such as languages, traditions, musical styles, philosophies, car designs, computer programs, and so on. Of course—and this an important distinction—in non-living *cultural* systems the *mechanism* of evolutionary change (of replication, transmission, and modification of "information" over a series of successive "generations") is very different because it is not based (as it is in living things) on DNA molecules and the mechanisms of random *genetic* variation and inheritance (and if you don't know about any of this yet don't worry—it should all become clearer a bit later on). But such non-living systems do nevertheless "evolve" in ways that can be very analogous to the processes of biological evolution. In fact, studying basic principles of Darwinian biological evolution has actually helped people better understand such things as the evolution of human languages, engineering designs, and even the more basic and fundamental philosophical principles underlying human creativity and innovation more generally. In turn, stopping a moment to review what *all* systems that are capable of evolving have in common can sometimes help people better understand the more particular ways in which living (biological) systems have evolved, and continue to evolve to this day.

What All Evolving Systems Have in Common

To be able to "evolve," a system (any system) first has to be made up of some kind of distinct *populations* (groups) made up of *"varied individuals"* (in other words, individual components which are not all alike but which instead have *different* features or characteristics).

This is very important: without individual *variation* there can be no evolution.

Not Everyone Wants You To Learn About Evolution

Here's something we should all recognize: in today's world, not knowing at least the basic facts and evidence of evolution leaves you vulnerable to being preyed upon by those people who stand to benefit from promoting mass ignorance and superstition.

At the dawn of the 21st century it is shocking that a great many people still don't know even the most basic facts about how all life (including people) evolved on this planet. Of course many people have been kept in the dark *through no fault of their own*. Nevertheless, such a state of ignorance often leads people to assume that some imaginary supernatural force must be what created life, and that such a supernatural force must still be "pulling the strings" and have the power to change human life for better or worse according to some divine "plan."

Then there has to be some kind of mechanism whereby "individuals" can *pass on* at least some of their features to the next generation. In other words, it has to be possible for descendants to somehow *inherit* some of that variation that exists between individuals.

This is also very important: without some way to transmit variation (*heritability*) there can be no evolution.

Evolution is "*descent with modification*." Evolutionary change takes place not all at once but over many "generations." Evolution is said to have occurred (for reasons we will get into later) whenever there are changes, from generation to generation, in the *proportional representation* of the variant types of individuals in a population (that is, whenever a change has occurred in the "relative numbers" of "variants"—individuals having different characteristics—which make up the population).[1]

So far all we have been discussing could apply to both living and non-living systems. But how do we know for sure that such processes actually take place in *living* (biological) systems? What do we know about the particular ways in which living systems evolved over billions of years and about how life *continues* to evolve? And how do we now know for sure that every single life-form on this planet, including human beings, can be fully accounted for by the workings of evolution, without requiring any outside force or divine plan?

It's important to realize that, for most of human history, human beings did not even know that life *had* evolved—and people certainly had no idea that our most distant ancestors looked like some kind of bacteria! In the ancient world and right up to the 19th century, most people saw the world as a very *static* (unchanging) place. They imagined that the different kinds of plants and animals they saw around them looked pretty much exactly the way they'd *always* looked. They had no way of knowing, as we do today, that the distant ancestors of all frogs, for instance, were a kind of fish that had evolved a primitive lung and stumpy leg-like fins that allowed them to spend some time out of the water. Most people never imagined that the different kinds of living creatures could in any way be *related* to each other, even though some people had noticed that different creatures seemed to have pretty similar skeletons or "body plans."

Of course, people had always wondered why there were so many different types of plants and animals, where they had come from, where people had come from, and so on. But, for most of human history, people just didn't have the scientific tools and methods to answer these questions! So, in the meantime, people rather creatively made up stories, in an attempt to explain what could not yet be understood.

Such imaginative stories—often called "origin myths" or "creation myths"—can be found at the very core of the different religions in the world. The different myths have some basic features in common, though

they also tend to incorporate some distinct local features having to do with the particular region and time in which a given tribe or people lived. But everywhere throughout human history people would tell each other these stories and pass them on from generation to generation to try explain how the world and "the people" (by which they usually meant "themselves") came to be. *(See "Creation Myths" on page 14.)*

How can we really tell whether the stories contained in various religious scriptures are true or not? And, on the other hand, how can we tell if evolution is true or not?

The best way to determine the basic truth or falsehood of an idea is to go out in the world and *test it*. This is how human beings learn—we experiment, we manipulate and transform the outside world, and in the course of doing this we uncover a lot of information about the way things *actually* work, and about the underlying processes and dynamics of things.

But the creation myths contained in various religious scriptures the world over are stories that people are asked *not* to test for truth or falsehood but to accept and believe in simply as a matter of unquestioned *faith*. Even the leaders of various religions admit that ideas such as "in the beginning God created the world and everything in it" cannot, by definition, be subjected to scientific testing or any means of concrete human verification.

But there *is* plenty of concrete evidence to suggest that these supernatural forces have actually never existed anywhere *except* as *ideas* in the *minds* of people, in the *stories* that people tell, in the *songs* people sing, in the *books* that people write, etc. So, while science can only test and investigate actual material reality, it is important to realize that the content and history of all the different religions of the world—their own origins and how they have changed over time, as well as the ways in which they have attempted to explain the natural world and human society—*is all part of that material reality that* ***can*** *be scientifically explored and investigated.*

Take the Bible, for instance. The Bible is after all a book. It was written thousands of years ago, by a series of different human authors. The fact that human beings wrote the Bible explains a lot why the Bible contains things which are simply factually not true. For instance, according to the Bible the Earth is only a little more than 6,000 years old, but in reality (as shown by modern scientific dating techniques) it is actually closer to 4.5 *billion* years old!

Millions and Billions of Years

Science is not a religion. It does not accept things on blind faith. It requires much concrete proof and evidence before scientists can even reach any kind of consensus and agree among themselves that something is true. We know the age of things because we now have a great variety of scientific techniques which allow us to *date* just about anything: we can now calculate

Creation Myths

One thing that all religions have in common is that they all tell stories. The Christian Bible, the Jewish Tanach, the Muslim Koran, the Buddhist Vedas, and so on, are all books of stories. Stories that people are supposed to pass on through the generations. Stories that are supposed to teach us how to live, and how not to live, our lives. Stories which were told and retold to serve certain social and political agendas, to set down rules of acceptable conduct.

One of the most common types of religious stories all around the world is called a "creation myth": it is the story people tell of how the world, and all the people and animals and plants, supposedly came to be. Every human culture has tried to put together such an explanation, and in the absence of scientific methods and knowledge every human culture has invoked some supernatural forces to try to explain how we all got here and where we came from. Here are just a few interesting samples (drawn in large part from *Encarta Encyclopedia*):

Ancient Babylonian Creation Myth

According to this Near Eastern myth (the Enuma Elish), which dates back to around the 12th Century BCE, in the beginning there was only a watery void and there was a male god of fresh water (Apsu) and a female god of salt water (Tiamat). In time a younger god of lightning and thunder (Marduk) killed Tiamat and split her body in two to form the heavens and earth.

Hopi Creation Myth

First there was Tawa the sun god and Spider Woman the earth goddess. Spider Woman made all the people and other creatures out of clay deep inside the earth and then guided them to the surface where Tawa the sun god breathed life into them and dried the land.

Iroquois Creation Myth

The world was formed on the back of a giant turtle. First Woman fell from the sky and lived with the help of the animals. She had one good grandson and one bad grandson from which stemmed the conflict of good and evil among humans.

Maya Creation Myth

According to this complex creation myth there are many gods and goddesses; the earth is the flat back of a giant caiman (crocodile) floating in a pool; heaven has 13 levels and the underworld 9 levels. A giant ceiba tree anchors the heavens through to the underworld; human rulers are embodiments of this tree, living links between the supernatural and natural worlds. The whole world is destroyed and recreated every 500 years (the next destruction cycle is due in 2012, according to traditional Maya mythology).

Aztec Myth

Also complex with many levels of heaven and underworld and many cycles of repeated creation and destruction. But humans are living in the very last cycle, after which there will be only oblivion.

Inca Creation Myth

Also lots of gods and goddesses, and repeated cycles of creation. Ancestors are links to the supernatural world (bodies are preserved through mummification); distinctive features in the physical world (mountain peaks, rocky outcroppings, plants and pebbles, etc.) are inhabited by special spirits (huacas) which humans can visit.

Ancient Egyptian Creation Myth

In the beginning, there was only water. Then Ra the sun god emerged out of the water. Two of his children became the atmosphere and stood on the shoulders of a third child, who became the earth; and then they all propped up the 4th child who became the sky. Ra was the #1 god of Ancient Egypt, but there were also many other gods and goddesses, including many which were borrowed and incorporated from religions which were being practiced in other lands during that period, and also some animal spirits which had been adopted from even older African belief systems.

Indigenous Australian Creation Myths

According to this myth the earth was formed during the Dreamtime and the spirits emerged from the earth and roamed the land visiting water holes and scattering about the spirits of unborn children. They

taught the humans how to live and then some went back down into the earth while others married humans. People can conduct rituals to try to enter the Dreamtime and become spirits themselves, retracing the past creation journey.

Inuit Creation Myth

A young woman married a seabird; her father tried to bring her home; the bird dangerously stirred up the sea; the father tried to throw his daughter out of his boat and when she tried to hold on he cut off her fingers—her severed joints then became all the important foods for the people (seals, walruses, whales, etc.).

Navajo Creation Myth

The Holy Ones carefully hung the stars in the sky and placed the plants on the earth. But Coyote the Trickster god (representing chaos and defiance of moral order) came out and scattered everything about, making a mess of the world. Then he caused a great flood which brought humans up to the surface world.

Scandinavian Creation Myth

According to the Scandinavian Eddas (from the 1200s BCE), in the beginning there was a chaotic world which included gods, giants, and humans. A great tree reached through time and space; it was attacked by a wicked serpent, but under its roots was the fountain of wisdom. The God Thor helped protect the humans from the giants.

Mali Creation Myth

A Creator made the universe and then withdrew. Spirit forces inhabited the animals and plants. The first being was a toolmaker who was able to use the earth and fire to make tools. Then he fell from heaven to earth and broke into pieces. His elbow joint represents the ability to work. His clavicle, shaped like a hoe, is a message that humans should plant crops.

Ancient Greek Creation Myth

In the beginning there was Chaos, a dark void; out of it came the earth and stars and clouds. There were innumerable gods. Prometheus, one of the Titans, created people, designed to be superior to the mere animals his brother had created. He made the people walk upright and he stole fire from the god Zeus and gave it only to the people to use.

Hebrew and Christian Creation Myth

In the beginning there was a void. A few thousand years ago god made the heavens and earth and then the people and all the animals. God made all the living creatures separately, and in just six days; on the seventh day god rested. God made first man, Adam, and first woman, Eve. They lived in a state of bliss in a lush garden (the Garden of Eden) with dominion over all the animals. There was a special tree (the tree of knowledge of good and evil), and also a wicked serpent. The woman conversed with the serpent, broke the rules, ate the forbidden fruit of that tree, and gave the fruit to the man to eat. Because of this rule-breaking, both the woman and the man were punished and were thrown out of the garden. First Man and First Woman had one good son (Abel) and one bad son (Cain) and then Cain killed Abel. Tired of the sinfulness of man, god created a giant flood to destroy the whole world, allowing only Noah and the few humans and animals that could fit into his boat to survive. All the living people and animals are descendants of the only survivors of this flood.

Islamic Creation Myth

Islam is the youngest of the three major one-god believing (monotheistic) religions in the world (Judaism, Christianity and Islam), which all originated in the Middle East. All three share the same basic creation myth. In Islam, as in the other two, a single all-powerful God created nature out of nothingness and made all of nature subservient to humanity. Adam was the first prophet, forgiven by a merciful god for his lapses. Each element of creation (all the people, the plants, the animals) reflects a specific set of divine rules and patterns. The created universe as a whole is well ordered, with no gaps or discontinuities, and everything is in its proper place. This very orderliness is itself proof of god.

the age of the known universe or the age of the earth as a whole; we can tell when individual mountain ranges were formed, when whole continents drifted apart or collided, or when the earth's whole climate underwent dramatic changes. We can date individual rock layers, all sorts of fossilized plants and animals embedded in rocks, and even tiny bits of organic material. Today we can even use the techniques of modern molecular biology to track changes in DNA and RNA molecules over time and to determine how far back certain significant genetic mutations and major "splits" in evolutionary lines occurred! We can date how far back whole new lines of plants or animals first appeared, or when long vanished species went extinct!

It is important to realize that it is only in the past century or so that scientists have been able to figure out accurate and direct dating techniques (and some of the newest "molecular" dating techniques are only a few decades old!). So obviously, the authors of the Bible and other ancient scriptures written a few thousand years ago would have had no way of accurately dating the age of the earth or of figuring out the sequential unfolding of plant and animal life on this planet. But today scientists can get at least good ball-park figures for the age of just about anything, and sometimes the results can be surprisingly precise and are often *corroborated* (that is, cross-checked and verified) by using a variety of different dating techniques *in combination. (See "Dating Techniques," right.)*

There is at this point a general scientific consensus on such things as that: the earth itself is about 4.5 *billion* years old (that's 4500 million!); the first and simplest forms of life (including the first bacteria) emerged on this planet about 3.5 billion years ago; a huge diversification of all sorts of marine animals happened about 540 million years ago (in a period referred to as the "Cambrian explosion"); the first jawed fish, amphibians and insects, as well as ferns and other land plants, all first appeared within the next 100 million years or so, i.e., in the period between about 540 and 440 million years ago. The land plants, insects and amphibians then diversified a lot, and the first reptiles appeared around 350 million years ago. Then around 250 million years ago the reptiles in turn diversified a lot (including giving rise to the first dinosaurs) and the very first mammals appeared. Around 200 million years ago the vegetation of the global landscape was still dominated by palms, ferns, pine tree-like conifers and ginkgoes, but now the first flowering plants appeared, and this was also when the first birds appeared. We also know that the last dinosaurs went extinct about 65 million years ago but that all sorts of mammals, birds, flowering plants and pollinating insects continued to diversify and spread around the globe. The most recent major wave of extinctions before modern times (the fifth since the beginning of life on earth) occurred when many of the largest mammals and birds went extinct at the end of the Pleistocene Ice Age about 10-12,000 years ago—a time of dramatic climate changes with temperatures rising

Dating Techniques

There are many reliable dating techniques, such as various radiometric dating techniques based on measures of radioactive decay, which were not yet available to scientists in Darwin's time. Radioactivity was only discovered at the end of the 19th century, and it was in the 1950s that scientists figured out that various radioactive substances, which occur naturally in various materials, will actually "decay" at constant and predictable rates, turning into non-radioactive stable forms (isotopes) of the same elements.

By concretely measuring the *relative* amounts of radioactive isotopes vs. stable forms of the same elements present in a sample, scientists can figure out just how long the radioactive decay process has been going on, and in this way determine how old the object is. And since different kinds of radioactive isotopes (of carbon, potassium, rubidium, and so on) decay into their particular non-radioactive forms at different rates, scientists can often double-check the age of a sample by using more than one dating technique. This kind of method has been used to very precisely figure out the age of different kinds of rock layers (and even moon rocks!): the rate of decay of certain isotopes found in rocks is so constant and predictable that scientists sometimes refer to them as "clocks in the rocks." Measures of the decay of such things as potassium isotopes to argon, rubidium-87 to strontium-87, thorium-232 to lead-208, uranium-238 to lead-206 are all commonly used and mutually corroborating techniques for dating many different kinds of rocks.

When plants and animals are alive, they take in carbon from the environment. Their bodies contain this carbon in two forms, carbon-12 and carbon-14, always in fixed proportion one relative to the other. When a plant or animal dies, it stops taking in carbon from the environment. And while the carbon-12 left in its body stays the same, the carbon-14 begins a gradual process of *radioactive decay*, through which the carbon-14 turns into nitrogen. This decay of carbon-14 happens at a known, constant, and predictable rate. So by measuring the carbon-14 level still left in the remains of a dead plant or animal, comparing it to the amount of carbon-12 present in these remains, and factoring in the known steady rate of decay of the carbon-14, it is possible to calculate quite accurately how long ago a plant or animal died, going back up to about 50,000 years ago.

Different methods of radiometric dating measuring the decay of other kinds of isotopes can be used to date materials older than 50,000 years. And even though such radiometric dating techniques cannot be used to directly date fossils which are found in sedimentary rocks, these fossils can also generally be consistently and reliably dated indirectly, simply by directly measuring the age of igneous (volcanic) rock layers found right above and below those fossils.

In recent decades, advances in molecular biology have added yet another important kind of dating technique to the scientific repertoire—that of "molecular clocks," which involve measuring the amount of "neutral" mutations which have accumulated over time in different lineages of related species. These are types of mutations which are considered to occur at relatively constant rates, so that calculating the amount of certain kinds of molecular differentiation between related species can provide a pretty good estimate of the amount of time which has passed since their lines diverged (split) from a common ancestor. Additional methods, such as DNA hybridization techniques, can also assess the degree of similarity or difference in the DNA of different species, and this has been very helpful in providing more specific calculations of how closely different species are related, and how far back in time they must have shared a common ancestor.

and glaciers retreating and also a time when human activity and impact on various environments likely increased.

We also know that the hominid line diverged (split) from its ape ancestors only a few million years ago (4 to 10 million by most estimates, and probably closer to 4 than 10) and ended up producing a series of different human-like bipedal (upright-walking) species. All but one of these hominid lines eventually became extinct. The only species of hominid still around today (our own species *Homo sapiens*, to which all human beings belong) dates back only about 100,000 (one hundred *thousand*) years. While that might seem like a lot of years relative to an average person's lifespan, when you think about what the mere 100,000 years that we modern humans have been around looks like relative to the whole *3.5 billion* year history of diversifying life on this planet (complete with those repeated "waves" of species *diversification* and at least five periods of *"mass extinctions"* of a huge proportion of all the living creatures on the planet) the timespan occupied so far by our own species really seems like little more than a drop in the bucket!

The fact that our own species has so far occupied such a tiny sliver of history is brought home even more forcefully when we reflect on the fact that human beings didn't even develop agriculture (which ended up serving as a foundation for large and complex "civilizations") until only about 10,000 years ago!

The science of evolution and the development of scientific dating techniques has allowed us to confirm once and for all that the story of the origins of life told in the Genesis chapter of the Bible is not in fact accurate. The Bible says that god created the earth and the ancestors of all the plants and animals and people *in just six days*, but we now know that it has really taken about *3.5 billion years* for life to get to where it is today from its simplest origins. The Bible also says that all the different types of plants and animals (and our own ancestors) appeared on Earth just a few thousand years ago and *all at one time*, but we now know that many different kinds of plants and animals appeared (and also disappeared) at many different junctures in the much longer history of life on this planet. The Bible says that all the different types of living plants and animals *remained completely unchanged* since the time of Creation, but (as we shall see through the course of this book) we now know beyond all reasonable doubt that, time and time again, *brand new species of plants and animals emerged which had never before existed* and *always as modifications of the species which existed before them*.

There is lots of evidence for all of this, as we will see.

What the Fossils Tell Us

Fossils are like "snapshots" into the past. Fossils are basically the preserved traces and remains of plants and animals which died long ago but

whose bodies got quickly covered up by soils and sediments which later hardened into solid rock, thus sealing them in and preserving them. For centuries now, scientists and others have been digging up millions of fossils of all sorts, out of all sorts of rocks, from all over the world. These fossils have provided concrete evidence of what many ancient plants and animals looked like, and often also something about the environments in which they lived. For instance, if you happen to be walking somewhere in a forest, along a road-cut, or on a mountaintop that is hundreds of miles from any ocean, and you start noticing that the ground under your feet is full of little rock-like fossils which are easily recognizable as clams and other seashells, you won't need a degree in geology or paleontology to realize that it's a pretty good bet that right where you are standing was once—long ago—the bottom of an ancient sea! If you are lucky, you might even find a trilobite or two—the fossilized remnant of a small marine invertebrate which looked a bit like an aquatic cockroach. Something like 10,000 different species of trilobites lived in the Paleozoic period between roughly 300 million and 400 million years ago, but they've now all gone extinct, so we learn about them by studying their fossils. In fact, collecting and studying fossil plants and animals provided people some of the *first clues* that both environments and living creatures had *not* always been as they are today, so that life must in fact have evolved over time.

Long before people came up with sophisticated modern dating techniques such as radiocarbon dating, quite a few people had started to figure out that all the different types of plants and animals must not have appeared on earth all at one time. Even by the early 19th century, it was pretty clear that some "types" of ancient plants and animals had completely vanished from the earth, that some had first appeared very long ago, and some much more recently, and that some types seemed to have existed in the past for long stretches of time while other types seemed to have vanished more quickly.

Much of this kind of basic understanding that life had probably evolved through different stages over time came about in the 18th and 19th centuries when early geologists and naturalists started trying to scientifically study the ways soils and rock layers had accumulated over time, and the physical forces which they realized must have caused landscapes to change dramatically—but over almost inconceivably *long* periods of time—as when mountain chains had been pushed up or eroded back down, or when valleys had been carved out by slowly advancing or retreating sheets of ice. Realizing that *the physical surface of the earth itself had changed tremendously over time*—and beginning to realize just how *long* it would necessarily have taken for many of these changes to take place—caused some of the 18th- and 19th-century geologists and naturalists to begin to suspect that there was simply no way the earth could be as young as was said in the Bible.

This dawning realization made many of them very uncomfortable, because most of them had grown up believing in the literal truth of everything that is said in the Bible. But the growing amount of concrete evidence they were helping to collect could not be easily denied.

These early geologists also increasingly realized that the surface of the earth in any one spot is sort of like a layer cake: when soil and debris accumulates over time it eventually forms a rocky layer. As time passes, more accumulation takes place, and so new (more recent) layers accumulate on top of older (more ancient) layers. The distinctive layers which accumulated in different periods of the earth's past history actually look different enough that you can still tell them apart, so digging through them is like digging back through time. The same basic pattern of *"geologic stratification,"* as it is called, can be found all around the world, and this is what made it possible for the early geologists to figure out the basic sequence of geological eras in earth's history.

So this is what some of those early geologists and other naturalists realized: the surface or top layer of the earth is the most recent (or youngest) layer, and it sits on top of an older layer, which sits on top of an even older layer, and so on through the ages until you get to the very deepest ("oldest") layers.

And then they realized something else which was very important: different groups of plant and animal fossils always seemed to reliably turn up in different rock layers in a predictably ordered *sequence*. They saw that certain kinds of fossils were *always* found in rock layers of a certain age (as determined by the rock layer's position in the overall geological sequence of layers), but that those same fossils were *never* found in rock layers of a different age. And there even seemed to be a pretty predictable sequence of *whole groups of fossils* in some more recent layers having entirely "replaced" groups of fossils found only in older layers. The early naturalists and geologists were furthermore astonished to discover that this kind of *orderly sequencing* (and correlation of certain types of fossils with only certain kinds of rock layers) tended to hold up, again and again, wherever they tried to dig! In fact, this sequencing was by and large so consistent that quite a few of the early naturalists could impress their friends by correctly guessing, upon being shown a fossil, in exactly which geologic rock layer that particular fossil must have been found. They'd seen it before, because *the same pattern of succession held up, over and over, wherever anyone looked.*

What could account for such a reliably predictable sequencing of the fossils? Since the early naturalists understood that the different soil and rock layers had accumulated one on top of the other over long periods of time (and were therefore themselves of different ages), the fact that different types of fossils were associated with different layers certainly suggested that living creatures must have been different at different times and had

somehow probably *changed* (evolved) over time. Once again, this dawning realization made many of them *very* uncomfortable, because it ran counter to the story of Creation as told in the Bible which they'd grown up with. Even as they kept collecting more and more evidence which more and more strongly suggested evolution *had* somehow occurred, many of them still tried hard to figure out reasonable alternative explanations which would allow them to continue to accept the Biblical notion that all living creatures appeared at the same time and had remained essentially unchanged since the time of divine Creation.

But the evidence for evolution kept mounting, and no amount of rationalization could make it go away.[2] *(See "Change Was In the Air" on page 22.)*

When it became clear from the fossil record that different types of creatures had lived at different times in the earth's history, some naturalists and others tried to reconcile this disturbing realization with their Christian beliefs: they suggested that perhaps all living creatures had been created by God, but that there had been not just one but *repeated* acts of divine Creation. Others didn't think that was very plausible. The traditional view of the world, as a very static place full of things that never change, really had started to break down. If the *physical face* of the planet had itself changed over time (the physical forces involved in such things as mountain formation and the erosion of valleys were beginning to be understood), could it be that the different types of living plants and animals had also somehow been transformed over time?

These were the kinds of questions that some of the more advanced naturalists were excitedly discussing among themselves in the early years of the 19th century. And the more fossils were collected and examined, the more such questions were posed. Naturalists were beginning to see that there were *similarities, as well as differences,* among the different types of fossils. What could account for this? Could it be that the different fossil creatures were somehow related to each other? Could it be that at least some of the types of creatures whose fossils could be dug out of the lowest and oldest rock layers had actually not simply disappeared without a trace but had, somehow, "evolved" into some of those creatures whose "similar-but-different" fossils could be found in the upper (more recent) rock layers?

The great naturalist Charles Darwin caused a genuine revolution in human thought and understanding when he wrote a book published in 1859 called *The Origin of Species by Means of Natural Selection*.[3] This book presented a great deal of concrete *evidence* that living creatures *had* evolved over time. And Darwin went one giant step even beyond that, developing a comprehensive theory and proposing *a concrete mechanism* through which he thought evolutionary change could take place. Darwin called this basic mechanism of evolutionary change in living creatures *"natural selection"*; and, in the nearly 150 years since he published his breakthrough

theory, natural selection has actually been *proven* (again and again) to be one of the most crucial and fundamental mechanisms through which life does, in fact, evolve.

The publication of Darwin's *The Origin of Species by Means of Natural Selection* represents one of the most important milestones in the entire history of human thought. Once again, what was particularly significant about this event was that Darwin not only provided lots of evidence *that* life had evolved (over extremely long periods of time) but also proposed a mechanism (which could and would be *repeatedly tested and verified by many other scientists over the succeeding decades*) for *how* evolution could take place. He showed how evolution by natural selection could unfold based *only* on the already existing (and very variable) characteristics that could always be found among individual living creatures, and in this way he demonstrated

Change Was In The Air

The scientific theory of evolution was first put forward in systematic fashion by the great English naturalist Charles Darwin in 1859. It is interesting to reflect on just how much "change was in the air" in Europe and North America from the end of the 18th century and throughout much of the 19th, revolutionizing intellectual discourse in both the social sciences and the natural sciences. The end of the 1700s in Europe and America had been times of political revolution—when newly rising bourgeois classes and the masses of the dispossessed rose up to overthrow the feudal kings and noblemen. Large numbers of people began to flat-out reject the old feudal idea (which had been drilled into most people's heads literally for centuries!) that an individual's position in the social hierarchy (whether as prince or pauper, for instance) was permanently determined by birth and ordained by god (kings were said to rule "by divine right") and could therefore never be changed. People of all strata had been taught that they were supposed to "simply accept" their lot in life, whatever it might be, because this was just the "natural order" of things. But throughout the late 1700s and a good part of the 1800s, more and more people *challenged and rejected this way of thinking.*

Of course, realizing that things *can* change is not quite the same thing as knowing *how* things can change, that is, *on what basis* changes can occur. This became the subject of much reflection, discussion and struggle, in different spheres.

In the mid 1800s (during the same period that Darwin was starting to figure out not only that life *had* evolved but also *how* it had evolved), Karl Marx (who also lived in England during much of this period) was working out some of the underlying dynamics of how human social and political systems come to change: in 1848, together with Frederick Engels, he published "The Communist Manifesto," which spoke to how the material basis for dramatically new social change can be found *right within* the existing mode of production and class divisions of a society, and how social systems can be transformed through class struggle. Then, over the course of the following years, Marx worked out a comprehensive theory (the theory of surplus value) which explained the system of exploitation of workers under capitalism, and he further developed the thinking about why the people at the bottom of society (the proletarians) would in time come to replace the capitalists at the helm of society. Darwin's revolutionary scientific work *The Origin of Species by Means of Natural Selection* came out in 1859, and the first volume of Marx's socially revolutionary *Capital* was published in 1867. One could definitely say that "change was in the air" in the mid- to late 1800s!

how evolution could have taken place without the involvement of any external guiding hand or divine design.

This was truly revolutionary, and certainly very unsettling to anyone clinging to strictly Biblical views of divine Creation. And yet within only a few years the majority of scientists pretty much agreed that life *had* evolved. But whether life had evolved via the mechanism of natural selection or by some other means continued to be hotly debated for years. This was especially the case because in Darwin's time the principles involved in the inheritance of individual characteristics were not yet understood, and so it wasn't really clear yet exactly how living creatures "passed on" some of their variable characteristics from one generation to the next. As we will discuss further, later on in this book, it was not until almost the middle of the 20th century that Darwin's theory of evolution by natural selection was definitively proven to be correct, when advances in the understanding of the principles of inheritance and the discovery of genes and DNA (leading to the development of the whole new science of genetics) made possible a better understanding of how some of the variable characteristics of individuals are not only passed on, but also "reshuffled" in new ways, from one generation to the next. This new understanding made it possible to really concretely *test* how evolutionary changes take place in populations of plants and animals (both in laboratories and in the wild), and the thousands and thousands of experiments and observations made throughout the 20th century ended up thoroughly verifying and *confirming* the basics of Darwin's theory of natural selection once and for all.

So What Did Darwin Figure Out?

One thing about Charles Darwin is that he was very observant and studied nature very closely. Like any good naturalist of his day, he had seen fossils, and he was intrigued by both the similarities and differences among different types of fossils, and by the fact that they occupied predictable locations in different geologic layers. And he wondered about why some creatures had vanished from the earth, and about what could possibly explain the fact that he had himself been able to collect fossil seashells miles from any ocean, high up on some mountaintops in the South American Andes.

Besides fossils, Darwin also studied living creatures, and he spent a great deal of time closely examining all sorts of populations of snails, birds, flowering plants, ants, bees, farm animals, and so on, both in his native England, and in many other parts of the world. He had been given the chance of a lifetime when he got a job as an on-board ship naturalist on an explorer ship, the H.M.S. *Beagle*. As the *Beagle* explored coastlines and dropped anchor to survey and explore many exotic places, including in Latin America, the Pacific Islands and southern Africa, Darwin collected

tons of detailed information about the land formations and the many exotic plants and animals he encountered wherever he went. He was only 22 and still himself a believer in Biblical Creation when he started out on this trip. In fact, the captain of the ship actually expected (and hoped) that Darwin would bring back evidence that would *disprove* some of the new-fangled ideas about evolution that many other European naturalists were starting to think about. Instead, Darwin ended up bringing back evidence of evolution!

As Darwin explored, he was fascinated by the diversity of species he encountered and by how well "adapted" (or closely fitted or attuned) many species seemed to be in relation to the particularities of the environments they occupied. For instance, he found cactus plants whose water-preserving needle-like "leaves" seemed especially well adapted to dry desert conditions; and in the Galápagos Islands he found birds whose beaks seemed to be especially well adapted to the foods that they ate—the species which fed on hard seeds had short and stout seed-cracking bills (beaks), those that ate small seeds or insects had much thinner pointier bills, and some that sucked nectar from flowers had thin and curved, almost straw-like, bills.

Darwin collected a series of such birds on the different islands. When the bird expert John Gould later told Darwin that, despite their clear differences in beak size and shape, all these birds (known today as Darwin's finches) had many features in common and actually belonged to the very same group of birds, this reinforced Darwin's sense that species had not been created separately and had not remained unchanged over time. He speculated that the birds' **similarities** meant they were all descended from a single ancestor species (which had migrated from the mainland to the different islands at some point in the past), and that their **differences** in such things as beak size and shape meant that the original populations had, over the generations, become increasingly "modified" in relation to different features of local island environments. His hunch has since proven to be correct. Darwin encountered similar patterns of island variation among the mockingbirds, tortoises and plants of the Galápagos and all this later helped him develop his basic theory of evolution as "descent with modification" from common ancestors, involving a natural "sorting out" (selection) of inheritable features over many generations.

In the course of his travels Darwin also found lots of odd species which had features they weren't using, like birds with webbed feet that never went in the water, or penguins with wings that didn't fly. He suspected that these apparently "useless" characteristics might simply have been passed down to descendants from some very different ancestors (Darwin would later be proven to be correct about this too). These kinds of clues are some of what convinced him that living species must have changed over time—that they had indeed evolved.

By the time Darwin came home, he was convinced that evolution had occurred. But it would take him 22 more years to fully develop a plausible mechanism for how evolution could have occurred (by natural selection) and to have the guts to publish his findings, knowing full well it would cause an uproar in religious circles and in society more broadly.

Darwin had lots of "raw evidence" of evolution he had collected during his travels and observations. But to figure out the *mechanism* of evolution he would have to bring this evidence together with two important concepts: the concept of *individual variation within populations*, and the concept of *selection of inheritable characteristics.*

What Darwin Learned about Selection from Farmers

Darwin had spent a lot of time talking to farmers, and he knew about the kind of methods of selection that farmers have used for thousands of years to improve their stocks of animals or crop plants and to produce new varieties with more desirable characteristics. Farmers know that some (though not all) of the features of animals and plants can be passed on to their offspring (their young of the next generation) and that farmers can themselves "select for" some of these inheritable characteristics to improve their stocks. For instance, if they want a herd of dairy cows that produce more milk, they should select out and breed (allow to reproduce) *only* the individuals that produce the most milk. And, at the next generation, they should repeat the process, again selecting out and breeding only the best milk producers. Every farmer knows this. If they keep doing this over some number of generations, they *will* end up with a herd of cows made up mainly of better milk producers.

You can do the same thing with pigs to get bigger and meatier pigs, or with crop plants to get bigger or sweeter ears of corn, for instance. Just select those animals, or those seeds of crop plants, that have the *most* favorable characteristics (as long as those are characteristics that can actually be passed on to offspring—since not all characteristics can be passed on or inherited) and, generation after generation, breed *only* those individuals that have those most favorable characteristics. After a number of generations, your whole "population" (herd of animals or fields of crops) will be made up *mainly* of individuals with those desirable features you were "selecting for."

This kind of selection is called *artificial selection* (to distinguish it from the kind of natural selection that happens in the wild without human intervention), and in this way it is possible not only to gradually change ("improve") the features of particular livestock and crop plants, but even sometimes to produce whole new varieties, such as when a gardener manages to produce a whole new variety of rose or a juicier tomato. Or just look at all the many varieties of dogs which people have managed to produce through selective

breeding over many generations—an astonishing variety, considering that *all* dog varieties, from tiny Chihuahuas to German shepherds or Great Danes, are *all* descended from a *single* common wolf-like ancestor!

So Darwin knew about artificial selection by farmers and other animal and plant breeders. But could something like that happen on its own, in natural wild populations?

The big breakthrough about "natural" selection happening on its own, in the wild, came about when Darwin realized two things:

First of all, animals and plants in the wild seem to produce *many more offspring than can possibly survive*. This suggested to Darwin that something generally must be *limiting* what would otherwise be the endless expansion of organisms in the natural world. He suspected organisms must be engaged in some kind of "struggle for survival" through which only the most "fit" managed to survive and reproduce. (What Darwin was getting at is what modern biologists refer to as "differential reproductive fitness." This is simply a measure of how some organisms, in a given local environment, end up producing more offspring which are themselves able to survive and reproduce. Such "fitness" does not involve notions of any other kind of superiority.)

Second, Darwin made the very important observation that in any population of animals or plants, while all the individuals have some features in common (which is what allows us to recognize them as belonging to the same species in the first place), *no two individuals are ever exactly alike*. Darwin realized that this natural *variability* between individuals in a population could provide a kind of "raw material" for the entire population to change over successive generations through a process of blind and unconscious "natural selection" of some of those features over others, without people or gods having to be involved in any way.

To understand how natural selection works you have to remember that individual organisms (individual plants or animals) don't live in a vacuum. They live in the context of (and in interaction with) an outside environment (which consists of *both* the "physical" features of the outside world, like temperature and humidity, and the "biotic" environment made up of all the other living plants and animals that occupy that same environment). This outside environment—both physical and biotic—is *always changing*. It's essential to remember that.

So, let's walk through an example of natural selection in action. Let's say there's a population of plants or animals of a certain species (let's call it species X). No two individuals in that population will be exactly alike. Now imagine there's a lot of variability between individuals for a feature which can be passed on to the next generation (that is, for something that the offspring can inherit from their parents). So far so good. OK, now imagine that this feature is something that, in *that* particular environment at

that particular time, gives that individual a *"reproductive edge"* of some sort (relative to those individuals which *don't* have that feature). This feature might be something that allows individuals to simply live longer (so the reproductive "edge" comes simply from having more time to produce more descendants); or maybe it's a feature which allows individuals who inherit it to be better able to withstand a drought or other dramatic change in the environment; or maybe it's a feature that allows individuals having this feature to be better than some of the others in their population at finding more *food*, or *mates*, or *nesting sites*, or to be better at *avoiding predators*—all of which can be helpful in making it possible for an individual to end up producing more descendants (an animal can't very well produce lots of descendants if it gets eaten before it even gets a chance to reproduce!).

In real life, scientists have documented many such examples of features giving individuals a "reproductive edge" compared to individuals in the same populations that don't have such features. Whatever the feature might be (and it could be just about anything as long as it's something that can be passed on and *inherited* by offspring), if this feature confers on an individual some kind of overall reproductive advantage (meaning nothing more than that individuals who have that feature will produce more descendants than individuals in the same population who *don't* have that feature) then those descendants will in turn tend to produce more offspring that have that feature, and over a series of generations that feature will tend to spread, and generally will come to predominate in the population as a whole. In this way we can say that the population has "evolved."[4]

Let's take another example. Let's say you have a population of insects of one type and these insects get preyed upon (get eaten) by a species of bird. And let's say *most* of the individual insects in that population are drab-colored and tasty but, purely by chance, a few of the insects in that population happen to have bright and noticeable black and yellow colors along with a stinger full of venom which makes them toxic to the birds. The birds will quickly learn to avoid the brightly colored poisonous insects and to feed mainly on the drab venomless ones. Now, if that happens, the bright venomous ones will obviously have *a better chance on average of surviving and producing offspring than the ones which didn't have these features.* As a result, the next generation will be made up of *a greater proportion* of (you guessed it) brightly colored venomous insects.

Repeat the process generation after generation (at each generation the brightly colored venomous insects get to leave a greater number of descendants than the drab non-venomous ones). After a number of generations, the whole population will look different! Now the whole population will be entirely (or almost entirely) made up of brightly colored venomous insects, for no reason other than that is the kind of individual that got to leave more descendants at each successive generation. Through what is called

the "differential reproduction" of these "variable individuals" the whole population has changed—it has evolved!

Here's another example many people may be familiar with: the evolution of antibiotic resistance in bacteria. Take a population of bacteria that causes some disease. Expose them to antibiotics which kill bacteria. Many of them will die. Let's say *most* of the bacteria are killed by the antibiotic, but *a few*, purely by chance, happen to have some feature which allows them to survive the antibiotic and they go on to reproduce and pass on this "antibiotic-resistant" feature to their descendants. So maybe you give the patient more of the same antibiotic, but now those antibiotic-resistant bacteria survive the attack and go on to produce more generations of resistant bacteria. Now you have a big problem: after a number of generations (and bacteria produce new generations *very* quickly in a host body!) the only bacteria left will be the resistant kind, and they will reproduce unchecked. Unless you can come up with a *different* antibiotic, which these bacteria are not yet resistant to, a patient could end up with a life-threatening "galloping infection" as the bacteria that nothing can seem to kill start to overrun the patient's body.

So a big problem these days is that the excessive and careless use of some antibiotics has led to the emergence of a number of strains of bacteria (including new strains of tuberculosis) which so far are resistant to *all* known antibiotics. *This is a classic case of evolution in action, and there is no way for advances to be made in the science of treating contagious diseases unless we apply to medicine our understanding of evolutionary principles.*

What I have just described in basic terms is the mechanism of evolutionary change that Darwin discovered and named natural selection. There is absolutely zero doubt among modern scientists that this kind of evolutionary change (sometimes called *micro*evolution to distinguish it from larger scale *macro*evolutionary changes, which we will also discuss more, later in this book) occurs within *all* living populations and species—not "instantly," but over many generations—and that this kind of evolutionary change is extremely commonplace. It has been observed in real life time and time again, in populations of all sorts of different kinds of plants and animals, both in the wild and in the laboratory.

Has Darwin's Theory of Natural Selection Really Been Tested and Proven to Be True?

Yes, and many times over. Darwin himself never got to witness the final definitive proof of his theory, because during his lifetime scientists had not yet been able to discover *the source of the individual variation* which Darwin knew was so crucial to his theory. Darwin understood that organisms do *not* pass on to their descendants features which they have *acquired during the course of their lifespan* (for instance, if you work out at the gym and acquire

big muscles, you will not pass these on to your children; or if a giraffe stretches its neck to reach leaves in high tree branches day after day, it still will not give birth to baby giraffes with longer necks). But for Darwin's theory of evolution by natural selection to work, *something* had to be passed on to successive generations—there had to be some mechanism whereby descendants could inherit some of that "favorable variation" found in their parents. What could that be?

It took less than 100 years after Darwin's time for scientists to figure out the answer by working out the basic principles and mechanisms of *inheritance* and by discovering the basic structure of *genes* and *DNA*. This missing piece of the puzzle provided definitive proof of Darwin's basic mechanism of evolutionary change through natural selection (this was accomplished through, among other things, countless experiments involving fast-reproducing animals, such as fruit flies, in whose populations evolutionary changes and underlying genetic changes over multiple generations could readily be observed).

In later chapters, we will review some more examples of the concrete evidence which has provided definitive proof of how evolutionary change by natural selection happens over time within species, and also how evolutionary change can take place through both cumulative effects of natural selection and some additional associated processes to give rise to whole new types (species) of plants or animals—a process referred to as *speciation*. Darwin himself was very interested in factors leading to the emergence of whole new species, and his work provided a very good initial foundation for understanding how new species can in fact emerge as modifications of previously existing species. In the century and a half since Darwin, scientists have been able to both confirm and reaffirm the basic principles of evolution by natural selection and to further extend and develop evolutionary theory in many important directions on the basis of this Darwinian foundation.

There have been many advances made since Darwin's time which allow us to better understand how life can diversify and whole new species emerge when, for instance, separate populations of a given animal or plant species undergo evolutionary change to differing degrees and/or at different rates in different localities. There are a number of reasons why such differences might exist between different populations of a given plant or animal species: certain features conferring a reproductive advantage (and thus "selected for") in one environment might confer a reproductive "disadvantage" in a related population which happens to occupy a different environment; the type and amount of genetic variation present in one given population might also be different than in another related population simply because of phenomena like "genetic drift" and "founder effects," especially in small and isolated populations. *(See "Genetic Drift and Founder Effects" on page 30.)*

Sometimes geographically and reproductively separate populations will evolve along different lines because different local environments "favor different features," and sometimes just because the amount of genetic variation available for selection at the start, within the separate populations, just happened to be only a small fraction of what was available in the species as a whole.

Over time, as local populations go through local changes, they can sometimes end up becoming sufficiently different from their ancestor population, and from what characterizes the species as a whole, that they actually become a new species.

A population will actually come to be defined as a new species if it has become so different that its individuals would no longer be able to mate with individuals of the ancestor species and produce viable offspring who will themselves be capable of reproducing.

New species can and do emerge in this way, and this kind of evolutionary change has taken place throughout the history of life and continues to do so. The evolution of life on this planet should be thought of not as a straight-line process but as a branching bush, with some relatively short twigs (evolutionary dead ends) and relatively longer twigs and branches giving rise to lots more lines of "descent with modification from a common ancestor," as Darwin so aptly characterized the process.

Today Darwinian theory continues to be extended and further developed. The "new frontiers" in the development of the science of evolution *are not calling into question the basics of Darwinian natural selection*; they are *adding* to classical Darwinism by exploring some additional and related concepts to more fully understand larger scale (macroevolutionary) changes—including the emergence of new species and orders of plants and animals over millions of years, as well as the differential extinction or survival of whole large groupings of plants and animals at different junctures in earth's history.

Genetic Drift and Founder Effects

Genetic drift and founder effects are related phenomena which refer to random changes in the gene frequencies and overall genetic diversity of populations, due purely to chance occurrences and which are not the result of natural selection. For example, founder effects can occur when new individuals come into an area by migration, introducing some new genetic material into a population. Overall gene frequencies in a population can also change through random genetic drift, simply because of such things as accidental deaths of individuals, or because some of the total genetic material available within a population gets severely *reduced* when part of a population gets wiped out or just gets "cut off" and reproductively isolated from the larger source population. Not surprisingly, the effects of such non-selective factors as random genetic drift and founder effects on overall evolutionary change can be amplified and particularly pronounced in especially *small* populations.

For instance, there is quite a bit of interest these days in understanding better what factors may have led to periods of especially intense diversification of evolutionary lineages in relatively short timespans (by geological standards), such as the famous "Cambrian explosion" of a little more than 500 million years ago. And there is great interest in better understanding the kinds of factors which can lead to major overhauls of life on the planet through mass extinctions: the five major waves of mass extinctions in the history of life on this planet (up to this point) occurred at the end of the Ordovician period (roughly 450 million years ago); at the end of the Devonian (around 350 million years ago); at the end of the Permian (around 250 million years ago); at the end of the Triassic (around 200 million years ago); and at the end of the Cretaceous (around 65 million years ago). The fossil record reveals that each of these five different periods in the history of life on earth were marked by rates of extinction which were way beyond normal "background" rates of species extinction: it has been estimated for instance that more than 75% of all the species then in existence disappeared through the course of the Ordovician and Devonian mass extinctions; that perhaps as many as 95% of all species then living became extinct through the course of the Permian mass extinction. The well-known period of mass extinctions which occured in the late Cretaceous around 65 million years ago was not altogether quite as devastating to life on this planet as the earlier Permian mass extinction, but it still resulted in the final extinction of a tremendous proportion of all living plants and of a vast array of especially large marine and terrestrial vertebrates (including the last of the dinosaurs).

The history of the earth has also been marked by a number of smaller waves of mass extinctions, including the Pleistocene mass extinction which occurred around 10,000 years ago (towards the end of the last great Ice Age), during which many species of large mammals and birds became extinct on all the continents. This most recent wave of mass extinctions was probably caused by a combination of factors, including some global climate changes plus some additional effects caused by increasingly efficient hunting by human beings.

In fact most waves of mass extinctions are likely to have been caused by a combination of factors. There is no one single formula leading to mass extinction: global climate and other environmental changes spread out over fairly long periods of time (though still occuring relatively rapidly on a geological time-scale) can "stress" whole big assemblages of previously successful plant and animal species, greatly intensifying the normal rates of species extinction; in addition, some truly sudden events (such as the impact of a huge asteroid or meteorite smashing into the earth and likely blocking sunlight for weeks on end as happened at the end of the Cretaceous) can also precipitate, or at least greatly intensify, periods of global mass

extinctions; and since the last period of mass extinctions some 10,000 years ago, human beings themselves have directly contributed in some new ways to the extinction of many species, at first through widespread hunting, and more recently through our rapidly accelerating abilities to transform many aspects of the physical and biotic environment on a global scale, which has led not only to the loss of many individual species but also to the destruction of entire natural habitats at an ever increasing pace. Today some scientists (such as renowned paleontologist and conservationist Richard Leakey) argue that we may already be seeing the beginning of the *6th* wave of mass extinctions — one directly attributable to the extremely rapid and domino-like effects of the environmental destruction and depredation caused by human beings just in the last couple of centuries or so. *(See "The Continued Existence of Life on this Planet Is Not a Given," below.)*

Some of the more exciting questions which are being explored by Darwinian scientists today include issues of rhythm and pacing of large-scale evolutionary changes. All evolutionists agree that the accumulation

The Continued Existence of Life on this Planet Is Not a Given

While the extinction of species is in a sense a "fact of life" over vast periods of geological time, it would be wrong to assume that life on earth will necessarily always "bounce back" (even if in altered combinations) after each and every extinction event. The total extinction of all life on this planet at some point is certainly not theoretically inconceivable, whether as a result of cumulative environmental destruction or even nuclear war. And it is definitely conceivable that the physical and biological conditions necessary for *human* life to continue on this planet could be destroyed by how human beings interact with the environment (even without something like nuclear war). The necessary conditions for human life include not just such things as the appropriate quality of air and water, but also the right quantity and quality of sufficiently diverse habitats and sufficiently diverse species interpenetrating in an overall "mix" within which humans can continue to live.

The continued existence of a physical and biotic "mix" within which we happen to be able to live is not a given or certainty. In the absence of a more rational approach to the interactions of humans with the environment, it is really not all that difficult to imagine that we could create the conditions for our own extinction as a species in the not so distant future. Human beings now have the capacity to drive vast quantities of species beyond the point of no return, and to dislocate and destroy entire habitats—many of which can *never* be fully restored or repaired. And we can do all this within a span of just a few centuries, or even decades, if we act with little knowledge or forethought about the consequences of our actions and before we have even had the chance to fully understand just what kind and what degree of diversity and complexity of species and habitats may be essential to preserve some kind of at least minimal equilibrium of life on this planet, as well as our own particular survival and quality of life within that.

All this should make us reflect on the crucial importance of broadly grasping and further deepening (rather than seeking to undermine) the basic principles of evolutionary biology which are and will continue to be *at the very core* of how to address these questions rationally and scientifically—before it is literally too late.

of small-scale evolutionary changes within species is a continual, ongoing, process. And, as we will discuss elsewhere in this book, there is also plenty of evidence of the gradual accumulation of evolutionary change through natural selection giving rise to major transformations at the species level (and, contrary to what the Creationists might think, there is actually quite a bit of fossil and other preserved evidence of "intermediate" stages marking different steps in such development). But, *in addition* to the well-known evidence of gradual evolutionary change in animal and plant lineages, a number of scientists have been recording evidence strongly suggesting that major evolutionary "leaps"—including the relatively sudden emergence of new species or relatively sudden bursts of diversification of whole groups of plants and animals—can, under certain conditions, take place relatively quickly, at least in terms of the geological time-scale. I emphasize "relatively" and "in terms of the geological time-scale" because it is important to understand that no one is suggesting that major evolutionary "innovations," and the appearance of whole new species and/or lineages, somehow happens "overnight." No, everyone is still talking about major changes taking place over many, many generations! But what many evolutionists are debating among themselves these days is whether major evolutionary developments on a macro-scale (including the occasional "bursts" of intense species diversification which have punctuated the history of life on earth) could at least sometimes have happened *relatively* suddenly, in a geologically very concentrated period—as opposed to over millions and millions of years—though of course still over many successive generations.

As we will discuss later in this book, the pacing of evolutionary change even within living species is far from constant and can at times become greatly accelerated, especially in populations of plants or animals encountering rather sudden and dramatic environmental disturbances and/or finding themselves cut off and isolated from the larger intermingling gene pool of their species. Under such conditions, even relatively small evolutionary innovations can sometimes have greatly magnified effects, and it appears that new species often originate in just such a fashion.

So there is a lot of interest these days in deepening the scientific understanding of the kind of factors which might affect the *rate and tempo* of evolutionary change, including rates of speciation and conditions under which one evolutionary line ultimately might end up branching out (diversifying) into many different descendant lineages, or perhaps only a few. There is also a lot of constructive interest in debating the *relative importance* of natural selection and non-selective factors such as random genetic drift, founder effects, or the random effects of catastrophic environmental events (such the impact of an asteroid striking the earth) on the emergence of evolutionary "novelty."[5]

The point is not to attempt to dig into all this here but just to point out that these are the *types* of questions that the dynamic field of evolutionary biology is delving into these days. Many exciting breakthroughs are being made, *both in theory and experimentally*, which continue to extend and further develop Darwin's legacy. *But* saying that the field of evolution is continuing to develop is definitely *not* the same thing as saying that "evolutionists can't agree among themselves and therefore evolution remains just an unproven theory, and the creationist theory is a just-as-valid alternative theory," as the Creationists often like to argue. Nothing could be further from the truth.

Once again, the basic principles of Darwinian evolution by natural selection are considered to be as solidly proven today as the fact that the earth goes around the sun and not the other way around. Scientific knowledge is, of course, always expanding and developing. But new advances in science (or in any other field of knowledge) will be realized only if we *base ourselves* firmly on the accumulated knowledge which has already been clearly demonstrated to be true and which has stood the test of time. There is absolutely nothing that is more solidly proven and demonstrated in all of science (and that includes in any field of science) than the basic principles of evolution.

Later in this book, after we've had a chance to get some further grounding in what evolution is, what it is not, and what evidence there is that evolution actually has taken place and that life is continually evolving, I hope we will all be more confident in being able to see what is wrong with the arguments of the so-called "scientific Creationists" who try to argue that they have "scientific" reasons for not believing in evolution. As we will see, so-called "scientific creationism" is not science at all! It is simply religion: a set of beliefs Biblical literalists would like us to accept, not on the basis of any concrete and verifiable scientific evidence (they have none!) but *simply on the basis of faith*.

It is important to study and reflect on the favorite *methods* employed by Creationists when they "challenge" evolution, because their very methods reveal what shaky ground they are on.

Creationists ask us to believe the Biblical story of Creation as literal truth (in opposition to the worked out and repeatedly tested theory of evolution) but, unlike evolutionists, Creationists not only cannot provide any evidence—they cannot provide any ideas that could possibly be tested in the real world to determine the truth or falsehood of their divine Creation proposal. That in itself should tell you something! By contrast, the theory of evolution has been repeatedly *tested* in the real world (through observation and experimentation) and many of the advances in all the modern sciences are very strongly rooted in an understanding of its principles.

In addition, like any good scientific theory, the theory of evolution is open to challenge and to being falsified or proven wrong. What does

this mean? It means that when scientists have a theory about something, they make predictions about how, if the theory is TRUE, then it should be possible to find such and such evidence. But they also indicate what kinds of evidence would be incompatible with the theory and would prove the theory to be FALSE. *The amazing thing about the theory of evolution is that in the more than 140 years since Darwin published his major breakthrough theory, thousands of scientists from all over the world have been able to collect literally tons of evidence of different sorts which is compatible with and demonstrates the truth of evolution theory, but no one—not a single person anywhere—has been able to come up with a single shred of concrete scientific evidence (of the kind that serious scientists can go out and verify for themselves) that would show the theory of evolution to be false.* And that, my friends, should also tell you something. Especially since (as many other people have pointed out) anyone who could somehow manage to prove the theory of evolution to be false would become an overnight celebrity for having been able to overturn one of the most solidly held facts in all of science!

It is important to understand that the theory of evolution is not about one or two simple points: it is a coherent theory made up of *many* different key components which all fit together into a comprehensive whole. If someone could somehow show any of the key fundamental components of the theory to be wrong (for instance, by finding fossil evidence the humans lived at the same time as dinosaurs, to use just one of millions of possible examples of something which, if found, would be completely incompatible with our understanding of how evolution has actually taken place) then the whole theory would go tumbling into oblivion! And yet, in all the time since Darwin, despite the fact that fanatical Creationists would probably do just about anything to find any actual shred of scientific proof that evolution is wrong, nobody has been able to do this.

In the absence of *any* concrete evidence with which to disprove the theory of evolution or validate the idea of Biblical Creation, by any means other than blind faith, and without being able to propose any serious and *testable* alternate scientific theory of their own, Creationists have been reduced to just trying to "punch holes" in areas of evolutionary theory they think of as "weak"—often because they don't understand it in the first place! More often than not, it seems that their attacks on evolutionary theory do not stem from principled disagreements but are instead just attempts to create confusion among people who have not received much scientific education, to give them a false impression that maybe the theory of evolution is not on such solid ground after all.

To create this false impression Creationists rely on smoke and outright lies. No matter how often the evolutionists answer their lies and distortions, Creationists just keep coming up with more lies and distortions. The famous paleontologist and evolutionist Stephen Jay Gould used to say that it can

be very difficult to beat the Creationists in a debate, precisely because of their unscientific and slippery methods, although in another setting, such as a courtroom, where they can be pinned down more and forced to put forward their *own* explanation of things, they can be demolished. After all, Creationists have no scientific standards of truth to stick to, so there's nothing to keep them from saying just about anything their twisted imaginations can come up with in the hopes of "wearing down" the scientists (who are often frustrated at having to waste time answering these mad idiots) as well as the general public, among whom the double burden of religious tradition and lack of real scientific education often makes it difficult for people to sort out truth from fiction.

To really see through the smoke and mirrors put up by the Creationists, it is necessary to get some grounding in the basic scientific method, as well as basic facts about evolution. This may be a struggle, but it is definitely worth it. It will take some effort (because learning about the science of evolution is a little like learning about the science of everything!) but hopefully this book will be able to help with this process. Through grappling with what we will be getting into and "walking through" in the course of this book, it should be possible, even if you started out unfamiliar with evolution, to acquire a basic understanding of the scientific facts and then to build on that—increasingly developing the ability to see through the smoke and mirrors used by any anti-evolution proponents of blind faith. And then maybe you'll have some fun and challenge *them*!

Chapter 1 Endnotes

1. As we will see later on, entire systems can further "diversify" over time when one "ancestor population" branches out and gives rise to a number of separate populations, and then certain factors impact the patterns of random variation in these different populations. The "sorting out" of the relative proportions of variant individuals from generation to generation may take place very differently in separate lines and, in time, descendant populations can end up being radically different from each other, as well as from the ancestral population. In such a way, genuine evolutionary "novelties" can arise out of the purely random variation which just happened to be present in preceding generations.

2. The Creationists of today have the same problem: some of them try to argue that the "reason" different fossils can be found in different layers is because, at the time of the supposed 40 Day Flood, spoken of in the Bible, the simpler "less intelligent" creatures sank to the bottom right away, while the more complex and advanced ones were able to better save themselves at least for a while, and would have kept swimming and died a bit later on, so that's how they got buried in the upper layers of mud. And of course the flying birds would have perched in the treetops and so would have been among the last to die when the Flood waters rose, according to some of these Creationists; so, they argue, *that* must be why bird fossils appear only in the upper-most geologic layers! Yeah, right.

Traditional Creationists make up many such laughable "explanations" as they try to cling to their outdated beliefs, but today very few people, even among devout Christians, can bring themselves to take such fanciful ideas seriously. Among other things, geologists studying landscapes and the formation of rock layers and continents have long understood that *there has never been a single global Flood as described in the Bible.* And even before Darwin, geologists understood that the layers of the earth had been deposited one on top of another *over hundreds of millions of years* and that the fossilized plants and animals trapped within these different layers had died in these very different geological eras, spread out over these millions of years, and could obviously not have died all at once or even over a short (40 day!) period of time.

3. Darwin's contemporary Alfred Russell Wallace came up with the same basic breakthrough idea at about the same time.

4. This does not mean, however, that the evolutionary change that has taken place will necessarily become permanently generalized within the population or continue in a single "direction." For instance, evolutionary change could accumulate in a certain seeming "direction" for a period of time but then a change in environmental conditions could lead to trends being reversed if the feature in question no longer brought individuals any reproductive advantage or even became disadvantageous. If so, over generations, the feature could actually get selected "out" (eliminated from the population altogether). Variable features in a population which may have somewhat less dramatic positive or negative effects on the relative reproductive fitness of individuals may simply persist in the overall variable mix of the population without being either completely eliminated or completely generalized to all individuals, but with their relative proportions or frequencies changing from generation to generation and in relation to changes in the external environment.

5. Questions are also being investigated having to do with the contributions to evolutionary change made by so-called "neutral" mutations; and attempts are being made to evaluate how much large-scale evolutionary change is the result of

the cumulative effects of the specific adaptations of populations of organisms to their environments vs. how much may actually not be all that much related to adaptation.

Other interesting questions in the field include such things as: Does evolutionary change necessarily lead to an increase in complexity? Do the same basic principles of natural selection apply at a number of different *levels* of organization (such as genes, cells, individual organisms, populations, species, clades); if so, are some levels more significant than others in terms of being principal sources and vehicles of major evolutionary change? Can the theory of evolution be further developed and integrated to encompass change operating *simultaneously* on a number of different levels?