ESSAY V: EVOLUTION FOR CHRISTIANS

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"Nothing in biology makes sense except in the light of evolution."
Theodosius Dobzhansky

INTRODUCTION

I've chosen this title for the essay on biological evolution because it has become clear to me that most Christians know little about the **scientific details of evolution**, either about the enormous amount of evidence already gathered to support evolution or the dominant theory that explains how it happens, **natural selection**. This is true both of Christians who accept evolution and support teaching it in the public schools of the United States and those who reject it and oppose its teaching. Part of the problem for this widespread ignorance lies with the politics of local education, as became clear the first year I taught "Science and Faith" at Berea College. After we had looked at evolution, I asked the twenty students in the seminar if they had learned about evolution in any of their high school science classes. Only four had, one in a Catholic high school. One by one, most of the students who attended public high schools stated, "The teacher skipped that chapter." After the fifth time, I said, "I know why the teacher skipped that chapter. She didn't want to get late-night phone calls with complaints from irate parents, or a pointed request from the principal to avoid 'controversial' subjects."

Clearly, most of my students had not learned a thing in high school about evolution, nor would any of their high-school classmates who have gotten no further exposure to science education. My students would have been exposed to evolution in the junior-level Natural Science core course and perhaps other science courses. Also clearly, they did not want to talk about evolution, even as I emphasized that this concept is at the core of every life science from genetics to biochemistry to ecology, and that the term "evolution" is used to describe not only the emergence of new species on this planet but also the emergence of the cosmos from the Big Bang. We live in an evolving creation, I asserted, and we really cannot understand what science is reading and finding in the Book of Nature unless we understand evolution. Yet, the topic made some of them uncomfortable, and others may have hesitated to speak up in class out of a concern that their point of view might cause conflict with other students. Attempts to draw them into discussion following presentations that dealt with evolution by their fellow students or myself were more often than not met with silence.

Many Berea College students are exposed to a negative view of evolution in their churches. They are taught that evolution is contrary to the Bible, that they cannot believe in both God and evolution, that evolution is an atheistic philosophy, and, sometimes, that evolution is an invention of the devil. Any information they receive about evolution in sermons or Sunday school usually comes from young earth creationists and not from evolutionary scientists, and, sad to say, what they learn is a not a true picture but a caricature. This anti-evolution viewpoint can stir powerful feelings in many students when the topic comes up in classes and reading assignments in college. One student told one of my science colleagues that when he was exposed to evolution in a previous course, he became physically ill. I hope and trust that such a reaction is rare, but it does point up the difficulty I and others face in trying to help students armed and armored against

evolution by religious authority figures to let down their defenses and listen to another point of view--to understand evolution in a different and positive light.

All the more reason, then, for me to explain, as best I can, what evolution is or is not. Since this essay is aimed primarily at an audience of Christian students, I will include among my sources the writings of several scientists who are evangelical Christians.

> **A significant number of scientists from all Christian traditions are among those who advance the research that every year more firmly grounds evolution as a valid scientific way of understanding the history of life.**

Like me, they earnestly desire that all Christians understand what evolution actually is and why one can accept it without giving up belief in God, the doctrine of creation and the Bible, including the assurance of salvation Holy Scripture proclaims. I would ask the reader who approaches this assertion with skepticism to try to set aside, to "bracket" as it were, any negative views or feelings, and listen to the voices of scientists, including their fellow Christians, as they explain evolution.

Like Big Bang and the history of the universe, biological evolution is such a broad and complex topic that I can do little more than summarize its most important features. I urge the reader to go farther, however, and fill in the details, using any of the books, articles, and on-line resources given in "Further Reading" or in the "Resources" section of this site.

Evolution vs. "Evolutionism"

First I need to challenge a serious misunderstanding about evolution. "Evolution" is commonly presented as a materialistic philosophy by both its young earth and intelligent design opponents and those at the opposite end of the spectrum of opinion who claim that the material world is all there is. Whether you read the works of anti-evolutionists like young earth creationist Ken Ham and intelligent design advocate Phillip Johnson, or evolutionary materialists like scientist Richard Dawkins and philosopher Daniel Dennett, you will find these strange bedfellows of conservative Christians and atheists agreeing on one thing: if evolution explains everything in reality and if you accept it, then you can throw religion and belief in God out the window. Those of us who accept evolutionary science and believe that God's creation is an evolving one reject this tragically erroneous point of view. I shall address the arguments of these spokespersons in separate essays later, but I want to make the point here that both sides fail to distinguish between a scientific theory that empirically accounts for what nature has revealed, and a

materialistic belief system. The materialists argue that their philosophy necessarily follows from the science, and therefore evolution removes any need for God. The creationists, strangely, buy this faulty argument, and agreeing that one cannot separate the science from the philosophy reject both. So the young earth creationists offer their "creation science" and the intelligent design proponents their "theistic science." In later essays I will argue that both fail the test of good science.

Both sides tend to make their voices loudly heard in the public arena through speeches, debates, books, articles, on-line sites, and verbal jousts on cable news channels. But they are the extremes that exclude the middle, and the middle is this:

> evolution as science is not a materialistic philosophy; it makes no assertions about any realm of reality outside of nature; it makes no claims for or against the existence of God or the notion that we live in a created universe.

The philosophical system that totalizes reality is better referred to as "Evolutionism." As an "-ism" combined with Scientism, the view that only science offers the way to truth, it competes with young earth Creationism and its "Intelligent Design" variant. While materialists claim support for their belief system from the science of evolution, the belief system and the science are not identical. The scientific concept of evolution simply accounts for the world as nature presents it. It needs to be understood and evaluated as science, not as philosophy.

I want to make this point as strongly as I can, because what I present here is science. I will outline and highlight the major elements of the empirical study and research that has placed evolution at the center of the modern scientific world-picture.

PART I: MACROEVOLUTION

Today's generation of naturalists look out with astonishment at the extent and range of life in all of its incredible diversity. As evolutionary biologist Francisco Ayala has noted, "More than two million existing species of plants and animals have been named and described; many more remain to be discovered, at least ten million according to most estimates." The two million include "approximately 250 thousand species of living plants, 100 thousand species of fungi, and 1.5 million species of animals and microorganisms, each occupying its own peculiar ecological setting or niche..." (Ayala 21, 32). The fossil evidence from earth's long history indicates that many more, perhaps 90% of all species that have ever lived, are now extinct (Price, chapter 9). No less astonishing are the incredible variety of species and their habitats. Living species range in size from the giant Sequoias of California to bacteria less than one-thousandth of a millimeter in length. The range of life's habitats is equally staggering, for species are found in every nook and cranny on earth from the heights (if not the peaks) of the Himalayas to the deepest ocean vents, in the coldest ice masses in Antarctica and the hottest springs in Yellowstone park. Some 800 species of microbial life do good or ill in your intestines, and mites too small for the naked eye but fearsome-looking creatures when viewed through an electron microscope clean your eyelashes. There is hardly a niche on earth where life does not dwell.

How does one account for all of this incredible diversity? The answer that scientists have come to, and have since reinforced with each new discovery, is that all of this variety is the outcome of evolutionary processes. All living things are interrelated; all have descended over time from one or a few common ancestors. Charles Darwin (1808-1886) called this process **descent with modification**, and the phrase still accurately describes what scientists today technically call **macroevolution**.

Fact and theory

A great deal of confusion exists over the meaning of the word "Evolution." When a state school board such as Alabama's directs that every science textbook carry a "warning label" stating that "evolution is a theory, not a fact," more likely than not the board members have misunderstood both "fact" and "theory" and also are more than likely to have misunderstood "evolution." I want to straighten this matter out.

> "'Biological evolution'," Keith Miller, geologist and member of the American Scientific Affiliation (ASA), writes, "is an incredibly broad unifying scientific concept. It consists of a large array of proposed mechanisms and draws on a wide range of observational data from geology, paleontology, ecology, population biology, genetics, developmental biology, [and other related fields of science]" (ASA list, Oct. 19, 2003).

As a unifying scientific concept, it provides a core of solidly established fact and theory that is ringed by a number of related theories and hypotheses.

In this context of an overarching scientific concept Evolution is described as *fact*. It is important to understand what the word "fact" means in science. A scientist does not mean by "fact" an "absolute proven unquestionable truth." Rather, a scientific fact refers to a truth "generally accepted to a degree of precision as to have predictive value in subsequent experiments and the accumulation of data," or, as paleontologist Stephen Jay Gould put it, "confirmed to such a degree that it would be perverse to withhold provisional assent" (Gould, 1983, 255). Newtonian mechanics are factual in that no one expects an apple to move upward from the ground to a tree, contrary to gravity, or that the earth will suddenly fly out of its orbit and depart from its pathway round the sun. In the same way, evolutionary scientists assert that the cumulative evidence for descent with modification is so extensive and so strong that it is appropriate to say that evolution in this respect is a *scientific fact*.

Likewise, the word "theory" needs to be clarified. In popular speech we often use "theory"

to mean "a guess." But scientists never use "theory" in this way. Rather, by "theory," scientists denote "an explanation supported by repeated observation and confirmed repeatedly by further experimentation and data." Under "theory" are classified the various explanations put forth to account for the descent of life, such as Darwin's theory of natural selection or its revised version known as the Modern Synthesis, or the more recent theory of punctuated equilibrium developed by Niles Eldridge and Stephen Jay Gould (see below).

Finally, evolutionary biologists have been engaged in the business of reconstructing the "family tree of life," i.e., the emergence over time of these innumerable species and their relationships with other forms of life. The image of a branching tree appropriately describes common descent, for evolution clearly does not proceed in a straight line. Rather, lineages diverge from common ancestors analogous to the way branches grow from the trunk of a tree. As those who work on the historical reconstruction of evolutionary pathways study the mounting evidence about various species derived from paleontology and molecular biology, they continually redraw this tree and its branches as they find more accurate evidence of how living species have diverged from common ancestors in the past. This branch of evolutionary biology is called **systematics**.

> So, the evolutionary sciences constitute a web or constellation of facts, theories, and speculative hypotheses that has been established by the ongoing scientific work of gathering data and making predictions on the basis of hypotheses and testing them.

In this respect their practitioners are like all scientists, confident that the basic concepts are unlikely to be altered, but incomplete in that there is more to be discovered about the evolution of life. Many hypotheses will be confirmed or abandoned as new facts of nature are brought to light. The narrative of life's history will continue to be revised, its portrait redrawn. Like the story of the cosmic universe (essay IV), life's story remains unfinished with respect to both evolution's story and its future.

In essay IV: "Big Bang and the History of the Universe," I addressed an objection often raised by young earth creationists against the ancient age of the universe--the claim that an event in nature must have been observed by human beings in order to count as scientifically legitimate. I dealt with this false notion at length in that essay, and suggest the reader click this link and read those paragraphs now. Let me just say here that the historical sciences of cosmology, paleontology, and evolution, are just as rigorous in their application of scientific method as are such sciences as physics and chemistry, and just as reliable in establishing knowledge about the history of the world.

Evolution or descent with modification

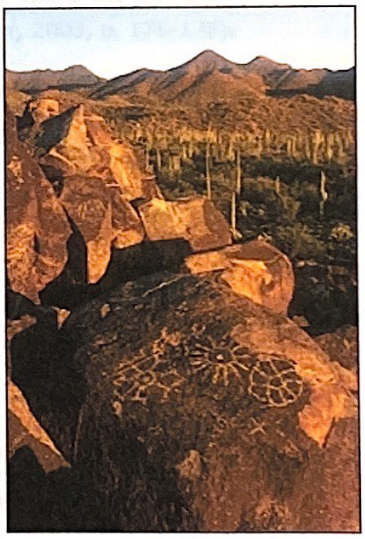
"Biological evolution is the process of change and diversification of living things over time, and it affects all aspects of their lives-morphology, physiology, behavior and ecology. Underlying these changes are changes in the hereditary materials. Hence, in genetic terms, evolution consists of changes in the organism's hereditary makeup" (Ayala 36). Now critics of evolution often say that they accept *microevolution*, that is, the changes in an organism's heredity makeup, the variants within species due to genetic modification and environmental pressures. (How could they deny such clear and compelling evidence?) The widely varying breeds of dogs exemplify *microevolution*. However, they claim that macroevolution, the process of change or diversification over time, or descent with modification, is a philosophical dogma without scientific evidence to support it. In public debates over evolution, this claim has been expressed so often that it has taken on the character of a mantra--but it simply is not true. The genetic mutations that lead to the varieties within species are the same kinds of changes in the hereditary material that eventually lead to macroevolution, or the emergence of new species. The distinction often made between micro- and macro- may serve some pedagogical and analytical functions

but it does not indicate that these are essentially different evolutionary processes. In reality, they are not.

> There is an enormous amount of empirical evidence that in its totality makes such a compelling case for macroevolution, that, with few exceptions, it is accepted by the world-wide community of biological scientists (Ayala 21).

This evidence is not uncritically accepted; indeed, the community of scientists is a most critical bunch. They, not their opponents, continually gather new information from nature and test and argue over their own hypotheses and theories about the mechanisms of evolution and the historical reconstruction of life's descent. They do not doubt the fact that evolution has occurred; rather, they are debating how it happened and what pathways it has taken (Gould, 1983, 256). If evolution were merely philosophical dogma this scientific activity would not be taking place.

Since the critics of evolution concede microevolution, I shall devote the rest of Part I to laying out the case for macroevolution. What sorts of evidence do scientists bring forward to support descent with modification? Here are four very important sources: (1) the fossil record, (2) comparative anatomy, (3) biogeography, and (4) comparative molecular biology.



(1) The fossil record: New fossils of extinct species, hundreds of thousands of them already, continue to be found in numerous geological strata (i.e., layers of sedimentary rock) throughout the world and studied extensively by paleontologists. Thanks to this work, many gaps in the fossil record Darwin noted have been filled by the discovery of thousands of previously unknown species including transitional forms. Strata which geologists have uncovered over the decades, and from which they have mapped out the history of the earth, shows a steady progression in the fossil record of new phyla, genera, and species. The chronology of the strata first worked out by geologists has been refined considerably using numerous well-established and reliable radioactive dating techniques (Weims) among others. As one goes up the geologic column of strata, beginning with the simplest microbial life (3.5 billion years ago [bya]), life has emerged into more complex bacteria (1.4 bya) to the first multicellular animals (670 million years ago [mya]), to shell-bearing animals (540 mya), to vertebrate fishes (490 mya), to amphibians (350 mya), to reptiles (310 mya), to mammals (200 mya) to modern humans (100,000 years ago). This order with no reversals is preserved in successive geological layers all over the planet, demonstrating that life has developed from the simpler to the more complex. Such a succession cannot be accidental: it reveals a fact about the development of life (NAS 13).

Anti-evolutionists continue to assert that the fossil record is incomplete and therefore poor evidence for common descent (e.g., Johnson, 1997). In truth, a very large number of intermediate forms have been found in the fossil record, so many that it is often difficult to determine when a transition occurs from one species or class of organisms to later descendents (NAS 14). Miller would go further and say, "In a very real sense, all fossil species within a line of descent are transitional forms in that they are anatomically intermediate in many features between earlier and later forms" (Miller, 2003, 173).

> Francis Collins, Director of the Human Genome Project, has noted that, "Elephants, turtles, whales, birds often have been cited as species where transitional species have not been identified. This is no longer true. We have gained more in the fossil record in the last ten years than in almost the entire previous history of science" (151; cf. Miller, 2003, p. 180).

Let me cite just a few examples out of thousands. Over 250 species of the extinct order of therapsids (mammal-like reptiles) discovered in recent years have provided evidence of a transition from reptiles to mammals (Lamoureux 36). Going back even further in geologic time, paleontologists now understand more accurately the evolution of creatures moving from water to land. Fossils of a group of rhipidistian fishes, the *panderichythids*, provide evidence for the evolution of amphibians from fish (Miller, 1994, 117). A growing number of fossils of extinct ungulates (hoofed mammals) illustrate the later evolution of legs to flippers in the earliest species of whales, supporting this transition from land to water creatures that took place some 35 mya (Miller, 2003, 173-176). The transitional pathways that led from dinosaurs to birds have also been greatly enhanced in recent years by new finds. Fossils of a group of small theropod dinosaurs called *maniraptorans* are now identified as the ancestors of birds. The famous *Archaeopteryx* shares numerous features with these maniraptorans, a genus that includes among its species the *velociraptors* of "Jurassic Park" fame. While *Archaeopteryx* differs from modern birds in several ways, the discovery in just the past several years of new fossil birds has provided a subclass, called *enantiornithes*, showing transitional features between *Archaeopteryx* and more modern birds. Thanks to these newly discovered transition fossils, "birds are now recognized as simply a specialized group of feathered dinosaurs!" (Miller, 2003, p. 176-178).

Given that the discovery of new fossil species continues at a rapid and accelerating pace, paleontologists are confident that more and more transitional species will connect more clearly the pathways of macroevolution. The preservation of remains is haphazard, and the fossil record is likely never to be completed to the extent paleontologists desire and anti-evolutionists demand; yet it is far more complete than it was one hundred and fifty years ago (Ayala 29-30). Like a huge and growing chorus of voices, these numerous fossils cry out that the concept of common descent accurately describes the systematic development of new species over time.

(2) Comparative anatomy: There is ample evidence that different species share basic forms that have been modified in a variety of organisms. One need only look at the skeletal structures of humans, dogs, whales, and bats to see how strikingly similar these mammals are, although the animals belong to widely varied species. Ayala noted that "The correspondence, bone by bone, can be observed in every part of the body, including the limbs: yet a person writes, a dog runs, a whale swims, and a bat flies with structures built of the same bones" (31). These phenomena reinforce the evidence for evolution gathered from paleontology and molecular biology (see below).

(3) Biogeography: Environment has a major impact on the divergence of species and provides another important source of evidence for descent with modification. Variation followed by speciation takes place when members of the same species become geographically isolated: some species migrate to islands or to other places where they become separated by geographical features such as oceans, lakes or mountain ranges. The invading species modify in response to the new environments. Over time, and more quickly in a new ecological niche, their offspring reach a point of development where they can no longer

interbreed with their relatives on the mainland or in the next valley--the surest sign that a new species has evolved. One finds, for example, avian forms on the Galapagos Islands similar to those on the South American mainland but belonging to different species. The fly *Drosophila* migrated to the Hawaiian Islands, and among its different ecological niches speciated rapidly; about one-third of the 1500 species of this fly are found only on these islands (Ayala 46). Some species adapt to highly limited niches: the fungus *Laboulbenia*, which "grows exclusively on the rear portion of the covering wings of a single species of beetle (*Aphaenops cronei*) found only in some caves of southern France," is one example of many (*ibid* 32).

> The hypothesis that an evolutionary process of variation and environmental adaptation accounts for these phenomena has been repeatedly tested and confirmed. Geographical isolation and adaptation (see below) provides one of the strongest kinds of evidence for macroevolution.

(4) Comparative Molecular Biology: Some of the most convincing evidence for macroevolution comes from the astonishing discoveries made in the science of molecular biology over the past fifty years. This latecomer to the scene provides the data that spectacularly confirms the historical picture patiently constructed first from the fossil record and then from genetics (Gray 257-258).

A problem plagued Darwin as he attempted to explain evolution: he knew of no mechanism by which he could account for the variations he observed in natural species and that he took advantage of when breeding domesticated animals. The mechanism was discovered by Augustinian monk Gregor Mendel in the 1870s. Through patient experiments with generations of plants, Mendel discovered the patterns of variability in traits inherited from parent plants. His pioneering work, rediscovered in 1900, led eventually to the development of the science of genetics, and by the 1930s, geneticists could account for the variations on which natural selection worked. In the 1950s the structure of DNA was discovered by Francis Crick and James Watson, greatly advancing research in evolution on the molecular level. The process by which genes replicate and undergo mutations was discovered. Crick, Watson, and others received Nobel prizes for their important work.

Why does molecular biology and biochemistry providing such convincing evidence for descent? Because all living things share the same biochemistry--the same structure of the DNA molecule and the same four component nucleotides, or bases. Furthermore, nearly every living thing synthesizes proteins from different combinations and sequences of the same 20 amino acids. During the 1990s, scientists mapped the human genome, one of several that have been decoded, and which have yielded valuable information for the descent of life. Thanks to comparative studies, geneticists have discovered that the genetic code is the same in almost all organisms and that all share a high percentage of the same genes. For example, geneticists have compared the human with the genome of the mouse, the animal most used in testing new pharmaceuticals for human beings. Evidence from protein evolution (described below) indicates that humans and mice diverged some 80 million years ago. A close examination of their gene sequences shows that there is a great deal of similarity: in some places the sequences of the two is identical or nearly so over a stretch of 100 base pairs (Collins 147). Minute changes in organisms through genetic mutation take place in the same identical fashion in all species. These identities and similarities at the molecular level make no sense as the product of separate creations; they make most sense if they are understood as deriving from a common

why? economy in God?

origin (cf. Gray 260-262).

Let me illustrate this commonality further with a familiar example from the evolution of protein molecules, one of many that could be chosen. It is possible to quantify with some precision the degree of similarity or of change in the sequence of the protein molecule *cytochrome c*, so that comparisons may be made within families or classes of living things, both as to their present relationship and to their descent in the past.

> "Comparisons of sequences of *cytochrome c* from different organisms produced an evolutionary tree that was nearly identical to what had been ascertained from comparative biology and the fossil record" (Gray 265).

For example, humans and chimpanzees share the same 104 amino acids of this molecule in the same order, but differ by one amino acid with the rhesus monkey, by 11 with the horse, by an additional 21 with the tuna (Collins 147). As biochemist and ASA member Terry Gray notes, common ancestry, hypothesized on the basis of paleontological and other evidence gathered in an earlier period of evolutionary research, has proved to be a testable hypothesis. The dramatic, independent test has been provided by the evolutionary sequences of *cytochrome c* and other protein molecules (ibid 276-268). I would go further, and say that the abundant evidence for common descent gathered from biochemistry and molecular biology establish its factual basis in science.

PART II: HOW DOES EVOLUTION OCCUR?

While paleontology, comparative anatomy, biogeography, and molecular biology provide powerful evidence for descent with modification and constitute evolution as scientific fact, I move now to theory: how do biologists *explain* descent? **Natural selection** remains the major theory that accounts for change, though there are related processes that create the genetic circumstances for selection.

Darwin described the process of the natural selection of variants in species in three simple steps:

1. More individuals are born than are able to survive;
2. In the struggle for food and shelter, those who bear some variations may have a selective advantage over those without such a variation;
3. The survivors will breed more offspring, and eventually a new variety and then a new species may emerge.

Darwin contended that this process has taken place slowly and gradually over immense periods of time, and by itself accounts for descent with modification. His model of speciation is often characterized by the term "gradualism." I make this point because when some of its more popular opponents criticize evolution, they label it as "Darwinism" or "gradualism." But evolutionary theorists, while honoring Darwin's fundamental contribution, have moved far beyond this early, simple model.

> How evolution occurs is explained now by a *web* of theories. While natural selection remains the central explanatory theory, other factors also account for variation and speciation.

Most important, and the basis of natural selection, is changes in **gene frequency**. Gene frequency measures the frequency in a population of a particular gene relative to other genes in its locus, i.e., its position on the chromosome. In fact, this is a measure of the

frequency of **alleles** or alternate forms of the same gene. Four processes affect gene frequency change: "mutation, migration, drift, and natural selection" (Ayala 37). Related to changes in gene frequency are the phenomena of *gene flow* and *genetic drift*. We briefly look at these phenomena as well as *reproductive isolation* and *adaptive radiation*. In conjunction with natural selection they constitute what is called the **Modern Synthesis** of evolutionary theory.

Natural selection: Ayala has defined natural selection as "the differential reproduction of alternative hereditary variants" or alleles that enhance the survival of the organisms that carry them and enable them to "reproduce more successfully than organisms carrying alterative variants." The term "differential reproduction" includes differences in survival, fertility, mating success, and rate of development (Ayala 36). The amount of genetic variation is astonishingly high in all organisms, especially those that reproduce sexually, and thus the opportunities for evolutionary change in response to environmental conditions are virtually unlimited. While most genetic mutations are adaptively neutral, and many prove to be harmful, the comparatively smaller number of beneficial mutations is more than enough to account for innumerable variations that have made possible the emergence of new varieties and new species. As the number of favorably variable genes increases, and the number of forms of these genes likewise increases, the frequency of change in these forms is likely to grow at the expense of other variations. The frequency in a large natural population may be very small in a generation but increases in effect over several generations. It has been demonstrated mathematically that "there is a direct correlation between the amount of genetic variation and the rate of evolutionary change by natural selection" (Ayala 36, 37).

Gene flow and genetic drift: One factor that enhances selection is known as gene flow. The "flow" takes place when some individuals migrate from one population of the same species to another and interbreed, thus changing the genetic makeup of the other population. Another factor is called genetic drift, i.e., changes in gene frequency that occur when small groups of individuals are separated from or leave a larger population. *Genetic drift* may account for changes in a smaller population that becomes isolated from other populations of the same species, such as a small group of migrants that colonize an island or lake, that eventually result in new species.

Changes in gene frequency, gene flow, and genetic drift by themselves do not ensure evolutionary change, for these processes are random with respect to adaptation. Natural selection, which selects for beneficial over harmful mutations, provides the directionality for such genetic changes. Not only does it make possible the survival and improvement of the organization of living beings, it also makes possible their diversity (Ayala 40). This sustained directional selection leads to major changes in the forms of living things and their ways of life, with some changes occurring with greater rapidity than others, over long periods of geologic time, that is, time calculated in millions of years. These processes illustrate a convention often expressed by biologists: "natural selection works by converting variation within populations to differences among populations" (Gould, 2002, 748).

The origin of species

Given these genetic phenomena and the action of natural selection upon them, how do they account for the origin of new species? In other words, how does microevolution lead to macroevolution? First, let us define what a species is. While evolutionary biologists differ in their views about the concept of species, and in practice it is not always easy to determine whether various individuals belong to the same species, this definition is a widely accepted one:

> **Species are groups of interbreeding natural populations that have become reproductively isolated from other such groups and thus lose the ability to**

interbreed (Ayala 43).

Reproductive isolation: there exist a number of biological conditions that may keep populations of the same species from interbreeding. These conditions are called *reproductive isolating mechanisms* (RIMs). Genetic divergences appear between different populations of the same species. Cross breeding between such populations may occur naturally when they are in close proximity or as the result of breeding experimentations. However, when reproductive isolation is sufficient to keep their increasingly divergent genetic constitutions separated and preclude mating, over time different species result. Those RIMs that take effect prior to fertilization (prezygotic) and thus prevent the possibility of mating include ecological barriers (e.g., differences between rocky coasts and sand barrens), temporal barriers (e.g., differences in nocturnal vs. diurnal habits), ethological or behavior barriers (e.g., differences in mating rituals), and physiological barriers (e.g., differences in the morphology of sex organs). Other kinds of RIMs take effect after fertilization between species (postzygotic), whether the latter is attempted through artificial insemination or, less commonly, happens in nature. Hybrid inviability ensures that the hybrid embryo resulting from fertilization dies before birth if an animal or does not germinate or dies shortly after germination if a plant seed. Hybrid sterility occurs when two species (e.g., a horse and a donkey) mate and produce a sterile offspring (a mule). Thus, isolation combined with natural selection acting on accumulated genetic changes eventually makes interbreeding impossible (Ayala 44-46; ThinkQuest).

Adaptive radiation: Migrations of species to new environments and their resulting reproductive isolation have led to spurts of evolutionary development at different periods of life's history. The species that migrated from the oceans to land evolved from amphibians to reptiles some 340 mya. From them radiated the great number of reptilians forms, from the ancient "-saurs" (T-Rex & Co.) to modern crocodiles, lizards, snakes, geckos, and others. When the early mammals that arose in the Triassic period (248 to 206 mya) no longer needed to compete with the giant reptiles for habitat and survival, a rapid (in geological terms) radiation of various lineages emerged over time. The species of bats, rodents, whales, elephants, horses, rabbits, moles, and great apes living today are the present ends of lineages that radiated out over the lands, and some from there to the seas, from the earliest mammals of the Cretaceous Period (over 65 mya) (Price 137-143).

The Hawaiian Islands have proved to be an excellent natural laboratory for the study of adaptive radiation. A huge number of species existing there and nowhere else can be accounted for by the migration of ancestor plants and animals to these volcanic islands. There, thriving and free from natural predators, the newcomers quickly moved into new niches and populated the islands with a large number of new species found nowhere else. About two-dozen species of honeycreepers radiated from a single immigrant pair. More than 90% of the native species of flowering plants, insects, and 71 species of birds evolved in these islands and appear in no other place on earth (Ayala 46).

Punctuated Equilibrium

There is, however, an observation of nature that has called into question gradualist

explanations for evolutionary change. It is evident throughout the fossil record that most species in the past have experienced extended periods, in the millions of years, in which little variation appears in their forms. This phenomenon, called stasis, was the object of considerable study by Darwin's contemporary Hugh Falconer (1808-1865), one of the most admired paleontologists of his day. Subsequent studies of the fossil record have established that many of the changes leading to new species occur with relative rapidity during shorter periods of geological time after such long periods of stasis. The evidence led Stephen Jay Gould (1941-2002) and Niles Eldridge in 1972 to propose the theory of **punctuated equilibrium**. In Gould's own words, "punctuated equilibrium holds that the great majority of species, as evidenced by their anatomical and geographical histories in the fossil record, originate in geological moments (punctuations) and then persist in **stasis** throughout their long duration" (Gould, 2002, 766).

Let me be clear: these rapid changes that lead to new species do not take place in anything like human terms of time. They are measured in tens of thousands to hundreds of thousands of years, not in weeks. Geologic time is a kind of "deep" time that cannot be calibrated in human terms. Punctuated equilibrium also folds microevolution into its parameters; it notes the minor variations that may occur during stasis, but it claims, strongly, that these changes tend not to accumulate over stasis; the fossil species at extinction hardly differs from the initial form that appears in the fossil record (ibid 767).

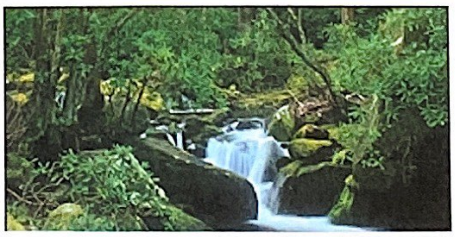
Since its introduction thirty years ago, punctuated equilibrium (nicknamed "punk eek") has generated considerable discussion and debate among evolutionary theorists. It has not replaced the Modern Synthesis as the dominant explanation for macroevolutionary change, since the current imperfections in the fossil record mean that different explanations continue to have their exponents. Still, punctuated equilibrium has remained a player in the ongoing discussions about how evolution takes place.

PART III: THE RECONSTRUCTION OF EVOLUTIONARY HISTORY

When I took college biology courses back in the Dark Ages, the great panoply of life was divided largely into the plant and animal kingdoms (now usually referred to as "domains"), though by that time biologists already had recognized that fungi, protists, and bacteria didn't fit into these categories. Much has changed in the decades since. When I audited an evolutionary biology course in the fall of 2001, forty-three years later, I learned that the 2,000,000 known and named species of living things past and present are now classified into five kingdoms: Monera, Protista, Fungi, Animals and Plants. Moreover, the relationships between these domains have been established in the past few decades through molecular biology, thanks to the DNA and protein sequences that have been identified, and reinforced by comparative studies of both fossils and living organisms.

Taxonomists, those who seek to classify living forms and determine their evolutionary relationships, look at two processes. One, **anagenesis**, has to do with the changes that occur within a lineage, such as the increases in the size of the human brain or the reduction in the number of toes in the lineage of the horse. The other, **cladogenesis**, looks at the splits in a lineage that lead to the development of new lineages and speciation. Cladogenic evolution traces the development over time of the amazing variety of phyla, classes, families, genera, and species of living things, and is best conveyed by the image of a branching tree (Ayala 47).

Within the field of evolutionary biology called **systematics**, the cladists are busy reconstructing pathways from the most ancient forms of life to those living in the present. The clades, or lineages of different phyla, classes, etc., have not been definitively worked out, but considerable progress has been made. A phylogenetic tree based on the similarities



evident from a particular ribosomal RNA sequence offers one hypothetical reconstruction. The earliest and most numerous life forms, the prokaryotes, microbial organisms that lack a nucleus, constitute the domain Monera. Out of the Monera came the Archebacteria (recently renamed Archea); the Eubacteria or "true" Bacteria; and the Eukaryota (the first life forms composed of a living cell). From the eukaryotes arose all of the other kingdoms. A large number of separate lineages constituting the Protista (e.g., slime molds and algae) branched off from the eukaryote lineage, and then from some of the latter, separately branching, came Plants, Animals and Fungi. The last three produced their own numerous lineages of phyla in which are classified all species in their domains from morel mushrooms to orchids to the now-extinct saber-tooth tigers. This model and others of the branching tree illustrate in detail the interconnectedness over time and space of all of life (Price 128, 154).

CONCLUDING THOUGHTS

I hope it has become apparent to the reader from even this brief exposition that evolution is as well-established an explanation for the origin of species and the descent of living forms through space and time as any other web of facts and theories in the natural sciences. I invite the Christian reader to see this fact not as a threat to Christian faith but as an invitation to think differently about the relationship between God, creation and evolution. There is nothing in the biblical proclamations of creation (essay I) when properly understood that conflicts with the theological notion that God has chosen to create through evolutionary processes. As I shall show in a subsequent essay, numerous thinkers from both evangelical and non-evangelical traditions are developing theologies of an evolving creation that argue just that.

Further Reading

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