James Hutton

Geological Studies

Hutton did not have a degree in geology, but his experiences on the farm gave him the focus to form theories about the formation of the Earth that were novel at the time. Hutton hypothesized that the interior of the Earth was very hot and that the processes that changed the Earth long ago were still at work millenniums later. He published his ideas in his book, "The Theory of the Earth," in 1795.

Hutton asserted in the book that life also followed this long-term pattern. The concepts in the book about life changing gradually by these same mechanisms since the beginning of time were in line with the principles of evolution well before Charles Darwin came up with his theory of natural selection.

Hutton's ideas drew much criticism from most geologists of his time, who followed a more religious line in their findings. The prevailing theory at the time of how rock formations had occurred on Earth was that they were a product of a series of "catastrophes," such as the Great Flood, that accounted for the form and nature of an Earth that was thought to be only 6,000 years old. Hutton disagreed and was mocked for his anti-Biblical account of the Earth's formation. He was working on a follow-up to the book when he died.

Legacy

In 1830, geologist Charles Lyell rephrased and republished many of Hutton's ideas in his book "Principles of Geology" and called them Uniformitarianism, which became a cornerstone of modern geology. Lyell was an acquaintance of Robert FitzRoy, captain of the HMS *Beagle* on Darwin's voyages. FitzRoy gave Darwin a copy of "Principles of Geology," which Darwin studied as he traveled and collected data for his work.

It was Lyell's book, but Hutton's ideas, that inspired Darwin to incorporate the concept of an "ancient" mechanism that had been at work since the beginning of the Earth in his own world-changing book, "The Origin of the Species." Thus, Hutton's concepts indirectly sparked the idea of natural selection for Darwin.

Jean Baptiste Lamarck

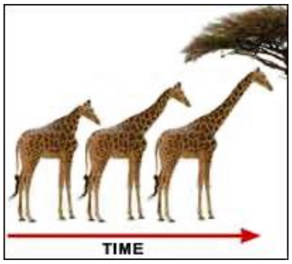
Early Concepts of Evolution: Jean Baptiste Lamarck

Darwin was not the first naturalist to propose that species changed over time into new species—that life, as we would say now, evolves. In the eighteenth century, Buffon and other naturalists began to introduce the idea that life might not have been fixed since creation. By the end of the 1700s, paleontologists had swelled the fossil collections of Europe, offering a picture of the past at odds with an unchanging natural world. And in 1801, a French naturalist named Jean Baptiste Pierre Antoine de Monet, Chevalier de Lamarck took a great conceptual step and proposed a full-blown theory of evolution.

Lamarck started his scientific career as a botanist, but in 1793 he became one of the founding professors of the Musee National d'Histoire Naturelle as an expert on invertebrates. His work on classifying worms, spiders, molluscs, and other boneless creatures was far ahead of his time.

Change through use and disuse

Lamarck was struck by the similarities of many of the animals he studied and was impressed too by the burgeoning fossil record. It led him to argue that life was not fixed. When environments changed, organisms had to change their behavior to survive. If they began to use an organ more than they had in the past, it would increase in its lifetime. If a giraffe stretched its neck for leaves, for example, a "nervous fluid" would flow into its neck and make it longer. Its offspring would inherit the longer neck and continued stretching would make it longer still over several generations. Meanwhile organs that organisms stopped using would shrink.



Lamarck believed that the long necks of giraffes evolved as generations of giraffes reached for ever higher leaves.

Organisms driven to greater complexity

This sort of evolution, for which Lamarck is most famous today, was only one of two mechanisms he proposed. As organisms adapted to their surroundings, nature also drove them inexorably upward from simple forms to increasingly complex ones. Like Buffon, Lamarck believed that life had begun through spontaneous generation.

But he claimed that new primitive life forms sprang up throughout the history of life; today's microbes were simply "the new kids on the block."

Lamarck also proposed that organisms were driven from simple to increasingly more complex forms.

Evolution by natural processes

Lamarck was proposing that life took on its current form through natural processes, not through miraculous interventions. For British naturalists in particular, steeped as they were in natural theology, this was appalling. They believed that nature was a reflection of God's benevolent design. To them, it seemed Lamarck was claiming that it was the result of blind primal forces. Rejected by some on religious grounds and shunned by scientists like Cuvier for lack of deductive rigor in his arguments, Lamarck died in 1829 in poverty and obscurity.

But the notion of evolution did not die with him. The French naturalist Geoffroy St. Hilaire would champion another version of evolutionary change in the 1820s, and the British writer Robert Chambers would author a best-selling argument for evolution in 1844: *Vestiges of a Natural Creation*. And in 1859, Charles Darwin would publish the *Origin of Species*. Lamarck, St. Hilaire, Chambers, and Darwin all had radically different ideas about how evolution operates, but only Darwin's still have scientific currency today.

Lamarck	Darwin
Use and disuse	Variation
Transmission of acquired characteristics	Inheritance
Increasing complexity	Differential survival
No extinction	Extinction

Different from Darwin

Darwin relied on much the same evidence for evolution that Lamarck did (such as vestigial structures and artificial selection through breeding), but made completely different arguments from Lamarck. Darwin did not accept an arrow of complexity driving through the history of life. He argued that complexity evolved simply as a result of life adapting to its local conditions from one generation to the next, much as modern biologists see this process. But of course, Darwin's ideas weren't entirely modern either. For example, he tried on and eventually rejected several different ideas about heredity (including the inheritance of acquired characteristics, as championed by Lamarck) and never came to any satisfying conclusion about how traits were passed from parent to offspring.

Lamarckian inheritance is an idea that today is known mainly from textbooks, where it is used to as a historical contrast for our modern understanding of genetic inheritance, which began with the rediscovery of Mendel's work in the late 1800s. Despite all he got wrong, Lamarck can be credited with envisioning evolutionary change for the first time.

Thomas Malthus

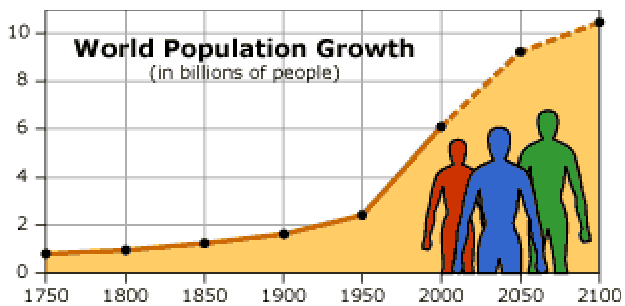
The Ecology of Human Populations: Thomas Malthus

Thomas Malthus (1766-1834) has a hallowed place in the history of biology, despite the fact that he and his contemporaries thought of him not as a biologist but as a political economist. Malthus grew up during a time of revolutions and new philosophies about human nature. He chose a conservative path, taking holy orders in 1797, and began to write essays attacking the notion that humans and society could be improved without limits.

Population growth vs. the food supply

Malthus' most famous work, which he published in 1798, was *An Essay on the Principle of Population as it affects the Future Improvement of Society*. In it, Malthus raised doubts about whether a nation could ever reach a point where laws would no longer be required, and in which everyone lived prosperously and harmoniously. There was, he argued, a built-in agony to human existence, in that the growth of a population will always outrun its ability to feed itself. If every couple raised four children, the population could easily double in twenty-five years, and from then on, it would keep doubling. It would rise not arithmetically—by factors of three, four, five, and so on—but geometrically—by factors of four, eight, and sixteen.

If a country's population did explode this way, Malthus warned that there was no hope that the world's food supply could keep up. Clearing new land for farming or improving the yields of crops might produce a bigger harvest, but it could only increase arithmetically, not geometrically. Unchecked population growth inevitably brought famine and misery. The only reason that humanity wasn't already in perpetual famine was because its growth was continually checked by forces such as plagues, infanticide, and simply putting off marriage until middle age. Malthus argued that population growth doomed any efforts to improve the lot of the poor. Extra money would allow the poor to have more children, only hastening the nation's appointment with famine.



Between 1800 and 2000 the human population increased about six-fold. Has the food supply kept pace? Will there be enough food to support the projected population of 9.2 billion in 2050?

A new view of humans

Malthus made his groundbreaking economic arguments by treating human beings in a groundbreaking way. Rather than focusing on the individual, he looked at humans as groups of individuals, all of whom were subject to the same basic laws of behavior. He used the same principles that an ecologist would use studying a population of animals or plants. And indeed, Malthus pointed out that the same forces of fertility and starvation that shaped the human race were also at work on animals and plants. If flies went unchecked in their maggot-making, the world would soon be knee-deep in them. Most flies (and most members of any species you choose) must die without having any offspring. And thus when Darwin adapted Malthus' ideas to his theory of evolution, it was clear to him that humans must evolve like any other animal.

Georges Cuvier

Extinctions

By the 1700s, fossils had been inducted into the living world. Instead of being produced by rocks themselves, fossils were recognized as the remains of animals or plants. They looked too much like particular living species to be anything else. As the eighteenth century wore on, some fossils emerged that could not be tied so neatly to the known living species. Elephants, for example, had left fossils in Italy, where they could no longer be found. Yet elephants still lived in Africa, and naturalists assumed that other fossils had living counterparts of their own in some remote part of the world. But, at the end of the century, a French naturalist popularized an astonishing revelation: some species had actually vanished from the face of the Earth.

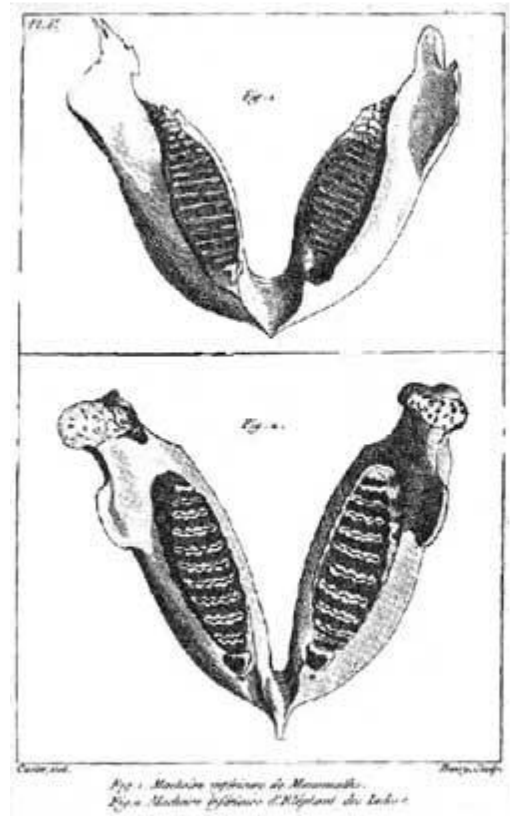
Georges Cuvier (1769-1832) joined the fledgling National Museum in Paris in 1795, and quickly became the world's leading expert on the anatomy of animals. He then used that knowledge to interpret fossils with unprecedented insight. Legend has it that sometimes even a few fragments of bones were enough for him to reconstruct the complete anatomy of a previously unknown species with uncanny accuracy.

This print shows the recovery of the first mosasaur fossils in 1780. Cuvier used the fossils to support his radical ideas on extinction.

A few earlier naturalists, such as Buffon, had argued that species might become extinct. But for some people in Cuvier's day, the idea of extinction was religiously troubling. If God had created all of nature according to a divine plan at the beginning of the world, it would seem irrational for Him to let some parts of that creation die off. If life consisted of a Great Chain of Being, extending from ocean slime to humans to angels, extinctions would remove some of its links.

Cuvier carefully studied elephant fossils found near Paris. He discovered that their bones were indisputably distinct from those of living elephants in Africa and India. They were distinct even from fossil elephants in Siberia. Cuvier scoffed at the idea that living members of these fossil species were lurking somewhere on Earth, unrecognized—they were simply too big. Instead, Cuvier declared that they were separate species that had vanished. He later studied many other big mammal fossils and demonstrated that they too did not belong to any species alive today. The fossil evidence led him to propose that periodically the Earth went through sudden changes, each of which could wipe out a number of species.

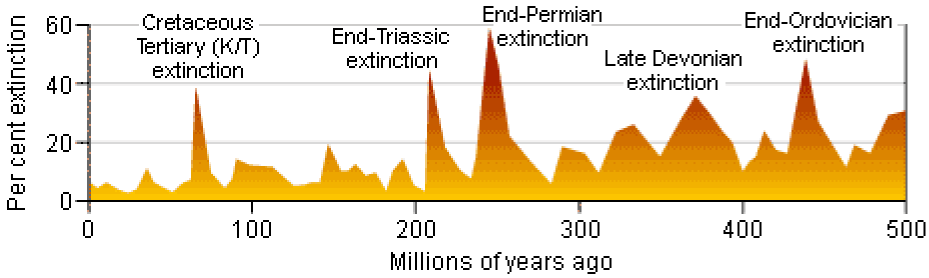
Cuvier established extinctions as a fact that any future scientific theory of life had to explain. In Darwin's theory, species that did not adapt to changing environments or withstand the competition of other species faced annihilation. Darwin did not, however, accept all of Cuvier's ideas on extinctions. Like Charles Lyell before him, he doubted that species went extinct in great "catastrophes." Just as the planet's geology changed gradually, so did its species become extinct gradually as new species were formed.



A 1798 paper by Cuvier contained this drawing showing the differences between the lower jaws of a mammoth (top) and an Indian elephant. These differences supported the idea that mammoths were indeed extinct.

Background extinction *and* catastrophe

On this score, Cuvier has been somewhat vindicated. Perhaps 99% of all species that ever existed on Earth are now extinct. Most of those extinct species disappeared in a Darwinian trickle—what paleontologists call "background extinctions." But several times over the past 600 million years, life has experienced "mass extinctions", in which half or more of all species alive at the time disappeared in fewer than two million years—a blink of a geological eye. The causes may include asteroids, volcanoes, or relatively fast changes in sea level. These extinctions mark some of the great transitions in life, when new groups of species got the opportunity to take over the niches of old ones. Mammals, for example, only dominated the land after giant dinosaurs vanished 65 million years ago in the Cretaceous-Tertiary extinction. We humans, in other words, are the children of extinctions.

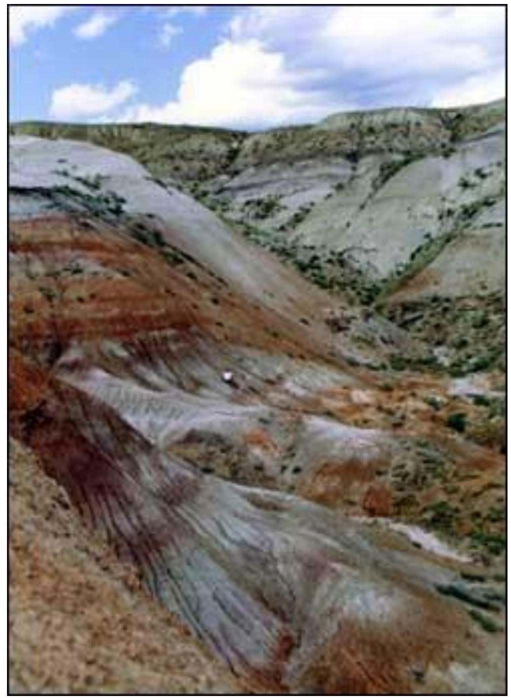


Life's history has been marked by both catastrophic extinction events (red spikes) and constant background extinction (yellow).

Charles Lyell

Uniformitarianism: Charles Lyell

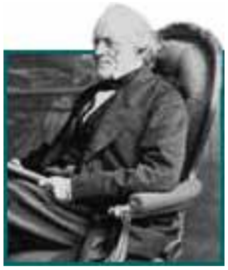
Thanks to the pioneering work of researchers such as William Smith, geologists in the early 1800s were able to swiftly organize rock formations into a single colossal record of Earth's history. Many geologists saw in this record a stormy epic, one in which our planet had been convulsed repeatedly by abrupt changes. Mountains were built in catastrophic instants, and in the process whole groups of animals became extinct and were replaced by new species. Giant tropical plants, for example, left their fossils in northern Europe during the Carboniferous Period, never to be seen there again. Earth's history might not fit a strict Biblical narrative any longer, but these revolutions seemed to be a sign that it did have a direction. From its formation, catastrophes altered the planet's surface step by step leading towards the present Earth. Life, likewise, had its own arrow through time.



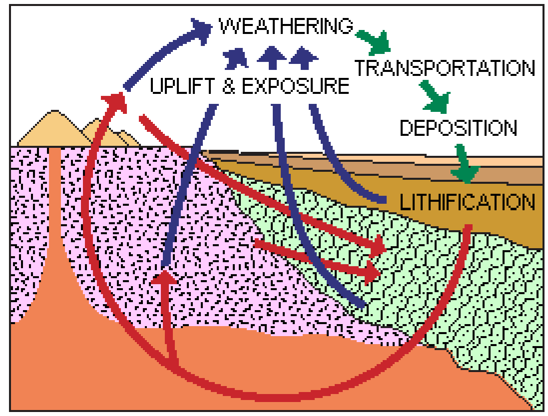
Discrete rock layers containing different fossils reinforced the idea that the Earth's history could be divided into ages marked by catastrophic change. However, gradual change, like that caused by erosion, has also played an important role in the Earth's history.

Catastrophism

Even before this geological evidence had emerged, some naturalists had already claimed that Earth's history had a direction. Buffon, and later the physicist Joseph Fourier, both claimed that the Earth had begun as a hot ball of molten rock and had been cooling through time. Fourier argued that the tropical plants of Europe must have lived during those warmer times. Some geologists suggested that the cooling of the planet occasionally triggered violent, sudden uplifts of mountains and volcanic eruptions.



"Catastrophism," as this school of thought came to be known, was attacked in 1830 by a British lawyer-turned-geologist named Charles Lyell (1797-1875). Lyell started his career studying under the catastrophist William Buckland at Oxford. But Lyell became disenchanted with Buckland when Buckland tried to link catastrophism to the Bible, looking for evidence that the most recent catastrophe had actually been Noah's flood. Lyell wanted to find a way to make geology a true science of its own, built on observation and not susceptible to wild speculations or dependent on the supernatural.



Gradual change

For inspiration, Lyell turned to the fifty-year-old ideas of a Scottish farmer named James Hutton. In the 1790s, Hutton had argued that the Earth was transformed not by unimaginable catastrophes but by imperceptibly slow changes, many of which we can see around us today. Rain erodes mountains, while molten rock pushes up to create new ones. The eroded sediments form into layers of rock, which can later be lifted above sea level, tilted by the force of the uprising rock, and eroded away again. These changes are tiny, but with enough time they could produce vast changes. Hutton therefore argued that the Earth was vastly old — a sort of perpetual-motion machine passing through regular cycles of destruction and rebuilding that made the planet suitable for mankind.

Lyell found evidence that valleys were formed through the slow process of erosion, not by catastrophic floods.

Lyell traveled through Europe to find more evidence that gradual changes, the same we can see happening today, had produced the features of the Earth's surface. He found evidence for many rises and falls of sea level, and of giant volcanoes built on top of far older rocks. Processes such as earthquakes and eruptions, which had been witnessed by humans, were enough to produce mountain ranges. Valleys were not the work of giant floods but the slow grinding force of wind and water.

Uniform Processes of Change

Lyell's version of geology came to be known as uniformitarianism, because of his fierce insistence that the processes that alter the Earth are uniform through time.

Like Hutton, Lyell viewed the history of Earth as being vast and directionless. And the history of life was no different.

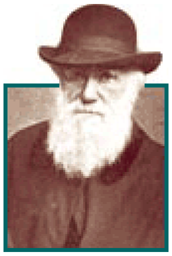
Lyell crafted a powerful lens for viewing the history of the Earth. On Darwin's voyage aboard the *Beagle*, for example, he was able to decipher the history of the Canary Islands (right) by applying Lyell's ideas to the volcanic rock he encountered there. Today satellite measurements reveal that mountains may rise an inch a year, while radioactive clocks help show how they've been rising that way for millions of years. But Lyell could never have grasped the mechanism — plate tectonics — that makes this kind of geological change happen.

Yet geologists today also know that some of the factors that changed the Earth in the past cannot be seen at work today. For example, the early Earth was pummeled by gigantic hunks of solar debris, some as big as Mars. For the first one or two billion years of Earth's history, plate tectonics didn't even exist as we know it today.

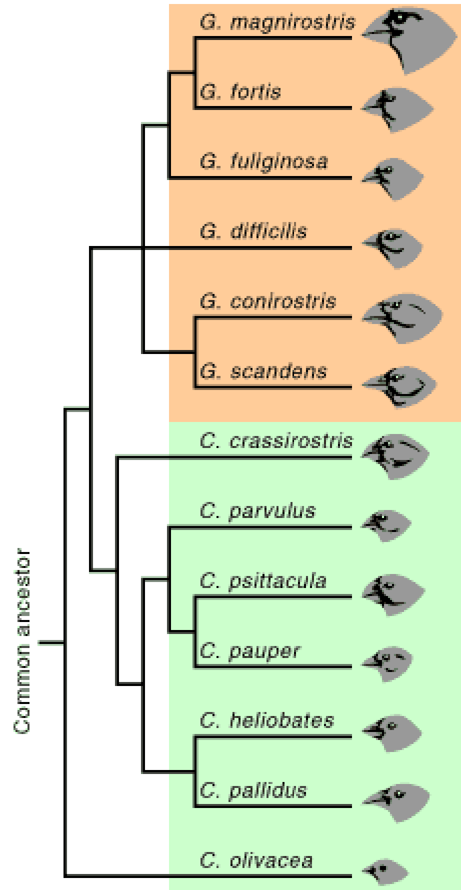
Lyell had an equally profound effect on our understanding of life's history. He influenced Darwin so deeply that Darwin envisioned evolution as a sort of biological uniformitarianism. Evolution took place from one generation to the next before our very eyes, he argued, but it worked too slowly for us to perceive.

Charles Darwin & Alfred Russel Wallace

Natural Selection



The genius of Darwin (left), the way in which he suddenly turned all of biology upside down in 1859 with the publication of the *Origin of Species*, can sometimes give the misleading impression that the theory of evolution sprang from his forehead fully formed without any precedent in scientific history. But as earlier chapters in this history have shown, the raw material for Darwin's theory had been known for decades. Geologists and paleontologists had made a compelling case that life had been on Earth for a long time, that it had changed over that time, and that many species had become extinct. At the same time, embryologists and other naturalists studying living animals in the early 1800s had discovered, sometimes unwittingly, much of the best evidence for Darwin's theory.



A visit to the Galapagos Islands in 1835 helped Darwin formulate his ideas on natural selection. He found several species of finch adapted to different environmental niches. The finches also differed in beak shape, food source, and how food was captured.

Pre-Darwinian ideas about evolution

It was Darwin's genius both to show how all this evidence favored the evolution of species from a common ancestor and to offer a plausible mechanism by which life might evolve. Lamarck and others had promoted evolutionary theories, but in order to explain just how life changed, they depended on speculation. Typically, they claimed that evolution was guided by some long-term trend. Lamarck, for example, thought that life strove over time to rise from simple single-celled forms to complex ones. Many German biologists conceived of life evolving according to predetermined rules, in the same way an embryo develops in the womb. But in the mid-1800s, Darwin and the British biologist Alfred Russel Wallace independently conceived of a natural, even observable, way for life to change: a process Darwin called natural selection.

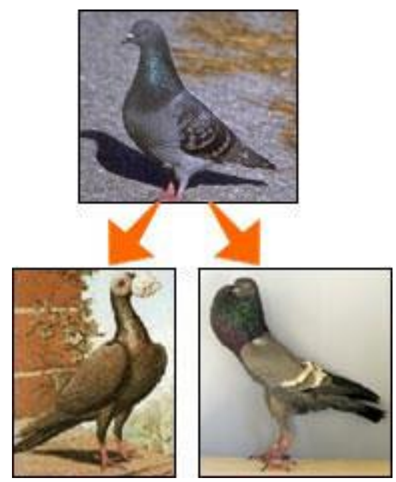
The pressure of population growth

Interestingly, Darwin and Wallace found their inspiration in economics. An English parson named Thomas Malthus published a book in 1797 called *Essay on the Principle of Population* in which he warned his fellow Englishmen that most policies designed to help the poor were doomed because of the relentless pressure of population growth. A nation could easily double its population in a few decades, leading to famine and misery for all.

When Darwin and Wallace read Malthus, it occurred to both of them that animals and plants should also be experiencing the same population pressure. It should take very little time for the world to be knee-deep in beetles or earthworms. But the world is not overrun with them, or any other species, because they cannot reproduce to their full potential. Many die before they become adults. They are vulnerable to droughts and cold winters and other environmental assaults. And their food supply, like that of a nation, is not infinite. Individuals must compete, albeit unconsciously, for what little food there is.

Selection of traits

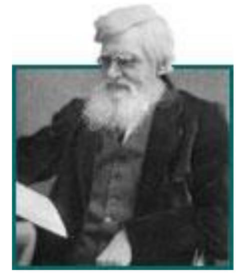
In this struggle for existence, survival and reproduction do not come down to pure chance. Darwin and Wallace both realized that if an animal has some trait that helps it to withstand the elements or to breed more successfully, it may leave more offspring behind than others. On average, the trait will become more common in the following generation, and the generation after that.



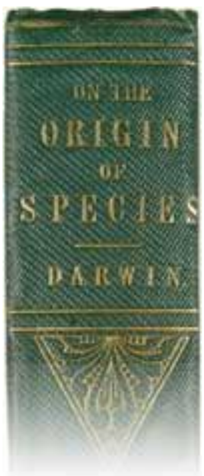
The carrier pigeon (bottom left) and the Brunner pouter (bottom right) were derived from the wild rock pigeon (top).

As Darwin wrestled with natural selection he spent a great deal of time with pigeon breeders, learning their methods. He found their work to be an analogy for evolution. A pigeon breeder selected individual birds to reproduce in order to produce a neck ruffle. Similarly, nature unconsciously "selects" individuals better suited to surviving their local conditions. Given enough time, Darwin and Wallace argued, natural selection might produce new types of body parts, from wings to eyes.

Darwin and Wallace develop similar theory



Darwin began formulating his theory of natural selection in the late 1830s but he went on working quietly on it for twenty years. He wanted to amass a wealth of evidence before publicly presenting his idea. During those years he corresponded briefly with Wallace (right), who was exploring the wildlife of South America and Asia. Wallace supplied Darwin with birds for his studies and decided to seek Darwin's help in publishing his own ideas on evolution. He sent Darwin his theory in 1858, which, to Darwin's shock, nearly replicated Darwin's own.



Charles Lyell and Joseph Dalton Hooker arranged for both Darwin's and Wallace's theories to be presented to a meeting of the Linnaean Society in 1858. Darwin had been working on a major book on evolution and used that to develop *On the Origins of Species*, which was published in 1859. Wallace, on the other hand, continued his travels and focused his study on the importance of biogeography.

The book was not only a best seller but also one of the most influential scientific books of all time. Yet it took time for its full argument to take hold. Within a few decades, most scientists accepted that evolution and the descent of species from common ancestors were real. But natural selection had a harder time finding acceptance. In the late 1800s many scientists who called themselves Darwinists actually preferred a Lamarckian explanation for the way life changed over time. It would take the discovery of genes and mutations in the twentieth century to make natural selection not just attractive as an explanation, but unavoidable.