# Paleontology

(essay)

Paleontology is the study of ancient life forms — plant, animal, bacterial, and others - by means of the fossil record they have left behind. Paleontologists search for, unearth, and examine fossils to determine every aspect of these ancient life forms, including their body structure, geographic distribution, adaptation to environment, interaction with other species and other members of their own species, taxonomic relationship with ancient and modern life forms, and behavioral traits. The term paleontology is a combination of three ancient Greek words, “paleo,” “ontos,” and “logos,” which mean ancient, being, and knowledge respectively.

Paleontology is closely related to geology, the study of the structure of the Earth. Indeed, the work of paleontologists often informs that of historical geologists, as fossils provide critical information for the understanding of the structure and age of the Earth’s crust. More specifically, paleontological finds have been critical to the geology sub-discipline of stratigraphy, or the study of how stratification or layering occurs in the Earth’s crust. Aside from geology, paleontology has also provided key evidence for the theory of evolution. While largely an academic discipline, paleontology has its practical side too, as the distribution of various types of fossils have proven, in some cases, to be useful guides to the discovery of hydrocarbon reserves such as oil and natural gas, which are, essentially, the compressed remains of the ancient life forms studied by paleontologists.

Paleontology is subdivided into various disciplines depending on the life forms being studied. These include paleo-zoology (the study of ancient animals, itself divided into vertebrate paleozoology and invertebrate paleo-zoology), paleo-botany (plants), micropaleontology (bacteria and other microscopic life forms), palynology (pollen and spores), and paleo-anthropology (humans), among others. (While this article will touch on this last discipline, readers can find fuller coverage in the article: “Humanity, Origins of”.) Other sub-disciplines of paleontology, including paleo-ecology, paleo-geography, and paleo-climatology, focus on the environment in which ancient life forms lived and how ancient life forms affected that environment. A new and burgeoning sub-discipline is paleo-biology, which applies the findings of modern biology, particularly those concerning the genetic makeup of life, to the study of ancient life forms.

The discipline of paleontology is one of the oldest within the natural sciences, dating back in Europe to the seventeenth century, and among the most controversial, as its basic suppositions about the great age of life on Earth and the changes in life forms over time appear to contradict biblical and other religious accounts of creation.

Historians often refer to the general period in European history in which paleontology was born as the “age of reason,” a time when thinkers began to explore the world around them and move beyond theological explanations of natural phenomena. Among the first things that caught the attention of these early naturalists were fossils, many of which bore very little resemblance to existing life forms. By the turn of the nineteenth century, scientists—most notably the French naturalist, Georges Cuvier--were hypothesizing that the fossils were, in fact, evidence of extinct forms of life and, as such, pointed to a much more complex and lengthy history of the Earth than that offered in the biblical account of creation. The work of English naturalists Charles Darwin and Alfred Wallace in the middle years of the nineteenth century provided, with the idea of natural selection, the theoretical framework for the understanding of how species adaptation and extinction occurred.

Key discoveries of the twentieth century that have informed the work of paleontologists have included the asteroid theory of mass extinction, and plate tectonics, or the theory of continental drift. Key twentieth century technologies aiding paleontologists include radiometric dating, which allows precise dating of fossils based on the radioactive decay of the elements of which they are composed, and DNA analysis, which allows scientists to trace the evolution of fossilized life forms at the molecular level.

# Science and Methodology

Paleontologists largely work with several types of evidence. The first are the imprints life forms have left in rock, usually by means of the sedimentation process though, occasionally, through volcanic activity as well. Such imprints are not fossils in the technical sense, though they constitute such in the popular mind. The second form of evidence used by paleontologists are true fossils, that is, the remains of life forms or, more typically, the hard parts of life forms, such as teeth and bones, in which the organic molecules have been replaced by minerals. A different process of fossilization occurs with soft tissue when mineral-rich water fills in the spaces normally occupied by liquids or gases. This mineralization process can occur even at the cellular level, leaving behind incredibly detailed fossils. Both the mineralization and imprint processes can take thousands and even millions of years to occur.

Another form of evidence utilized by paleontologists is preserved organic tissue, usually from small invertebrates such as insects, trapped in fossilized plant resin, or amber, though the organic remains of some more recently extinct species, such as mammoths, have been found in glaciers and bogs. Finally, some paleontologists work with existing life forms. Popularly referred to as “living fossils,” such species — among the best known is the ancient fish species, coelacanth--have existed for up to hundreds of millions of years and are believed to resemble long extinct life forms. (For simplicity sake, all but the latter form of paleontological evidence will be referred to as fossils in this discussion.)

The first step in analyzing fossils is to find them unless, of course, the paleontologist chooses to examine fossils that have already been collected. Fossils of all types are relatively rare. That is because the conditions for fossilization depend on many factors coming together. For mineralization, there has to be just the right combination of minerals and groundwater, while, for the process that leaves imprinted fossils, just the right geological processes have to be at work soon after the organism dies. Thus, paleontologists look for telltale geological formations to guide them to fossil remains. Examination of such formations, known as topology, can also allow paleontologists to date the fossils. This method—now outdated--is known as “relative dating” because it was best for determining the order in which fossils were created and not their precise ages.

Once fossils have been found they can be analyzed using a variety of methods. The most obvious and earliest of these methods is simple visual observation of the remains. Such observation can help the paleontologist classify the life form. For more complex life forms, such as vertebrates, paleontologist use visual observation to assemble the various parts to recreate the whole organism.

Analytical tools developed over the past 60 years have moved paleontologists far beyond simple visual observation and comparison of fossils. Perhaps the most important has been radiometric dating, that is, the analysis of the radioactive decay that naturally occurs, to one degree or another, in all elements or, more specifically, within the radioactive isotopes present in elements. Because radioactive isotopes break down at a specific rate—their so-called half-lives—scientists can note the amount of a radioactive isotope in a given element and know when it was created. Since carbon forms the basis of all life, scientists in the mid-twentieth century first focused on the decay of the isotope carbon-14. But carbon-14 proved a useful indicator for relatively short periods of time only—roughly good for about 40,000 years—making it helpful in the study of human remains but largely useless for paleontologists who work in time frames of hundred of thousands to hundreds of millions of years. Scientists soon discovered that potassium-40, a radioactive isotope of potassium, a metal found in all life on Earth—breaks down into the inert gas argon over a period of roughly 1.3 billion years, making it an ideal radiometric marker for paleontologists.

With the discovery of the structure of DNA in the 1950s, paleontologists were offered a new avenue for the analysis of fossils, at the molecular level, though it took several decades for the tools to be developed to make sense of fossilized DNA, usually found in life forms persevered in amber. Changes in the structure of the DNA molecules found in fossils allow paleontologists to examine very specific evolutionary changes within extinct species as well as the physical and even behavioral traits of those species in a way simple visual and even chemical analysis is incapable of. DNA analysis also provides key insights to evolutionary biologists, that is, scientists who examine the biology of adaptation and extinction.

Paleontologists divide Earth history into eons, eras, periods, and epochs. Eons cover billions of years, eras cover hundreds of millions of years, periods are usually in the tens of millions of years, and epochs, the shortest of these periods, is measured in millions or hundreds of thousands of years. The time spans in these eons, eras, periods, and epochs vary greatly, as they do not signify specific time periods, such as years or millennia. Instead, they are marked by great changes in the fossil records.

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Earth is believed to be about 4.5 billion years old while life as we know it emerged about 3.7 billion years ago. During that period, carbon atoms were gradually transformed into complex carbon-based, or organic, compounds, and eventually, organelles, the basic components of living cells, such as mitochondria. The roughly 3.2 billion years that followed—known to paleontologists as the Archaeon and Proterozoic Eons—saw the emergence first of anaerobic and then oxygen-breathing life forms. But these early life forms were simple and largely microscopic, leaving virtually no fossil record behind.

It was not until the beginning of the Paleozoic era, around 540 million years ago, that more complex plant and animal forms began to appear and leave a fossil record. The earliest period of the Paleozoic era is known as the Cambrian; thus, most paleontologists refer to the time span before complex life forms began to emerge as pre-Cambrian time. For the most part, paleontologists are forced by a lack of a physical record to study life forms from the Cambrian period forward.

# History of the Discipline

Among the key issues paleontologists grapple with is how life has evolved on Earth. In that sense, they are examining two key questions that have exercised the human imagination for millennia: why is there such a diversity of life and where did it all come from? Virtually all cultures have myths and stories to answer these questions. To Western readers, the most familiar is that in the book of Genesis—six days in which God first created the physical universe, the Earth, and then populated the latter with animals, plants, and finally human beings. The Book of Genesis also spoke of a planet-wide flood ten generations after Adam and Eve—generations that lasted hundreds of years each--but it noted that all of Earth’s creatures were saved by Noah in his ark: “every animal, every creeping thing, and every bird, everything that moves on the earth, went out of the ark” after the flood.

This biblical explanation, of course, left no room for fossils. Among the earliest thinkers to wonder about this natural phenomenon was the Greek philosopher Xenophanes in the sixth century BCE. Examining the fossils of shellfish, Xenophanes assumed they were the remains of existing species though he was required to come up with an explanation for why they were found so far from the sea. Xenophanes hypothesized that land forms shift. The eleventh century CE Chinese scientist Shen Kuo explained the presence of bamboo fossils in dry climates incapable of supporting that particular species by a theory of climate change over time.

But not all scholars concurred with these findings. As late as the sixteenth century, most European thinkers questioned whether fossils were even evidence of life at all, assuming that fossils, though lifelike in appearance, were simply odd-looking stones. Indeed, the original Latin meaning of the word fossil was simply “something dug from the Earth,” with no implicit meaning that the things being dug up had once been life forms. Ancient and medieval Chinese came to a different conclusion about the dinosaur bones that they found, explaining them away as evidence of the mythical creatures, dragons, which, they believed, still existed in faraway places.

With the rise of the so-called Age of Reason and the Scientific Revolution of the seventeenth century, many European thinkers began to seek non-theological explanations for natural phenomena. In 1665, the English scientist Robert Hooke, utilizing the newly invented microscope, put forth the theory of a mineralization process to explain petrified wood. Such a process assumed a much greater time span for life than that offered in the Bible. Roughly a century later, French naturalist Georges Buffon explained the existence of fossilized elephant bones in Europe by saying that the Earth was undergoing a gradual cooling process over time, since tropical elephants no longer lived in a temperate Europe.

The greatest breakthrough of the pre-Darwinian era in paleontology, however, came with the findings of Cuvier. Utilizing the newly invented species classification system of Swedish scientist Carl Linneaus, Cuvier established that existing elephant species differed from the elephant-like creature, which he named the mastodon, whose fossilized bones had been discovered in North America’s Ohio Valley region. Cuvier then hypothesized that this species was extinct, thereby undermining both the idea that fossils were the bones of existing species and Buffon’s cooling Earth theory. Instead, Cuvier put forth the theory of catastrophism, that sudden geological changes explained extinction. This undermined another existing paradigm, known as uniformitarianism, which stated that geological change occurred gradually and uniformly through time. These various findings have led historians of science to consider the French naturalist the father of both comparative anatomy and paleontology.

The next great breakthrough in paleontology came not through the result of fossil analysis but by way of the studies of existing species. With their theory of natural selection, Darwin and Wallace, who developed it at roughly the same time in the mid-nineteenth century, offered an explanation for extinction that connected geological and climatic change with species transformation. Changes in the environment forced life forms to adapt; those that did so effectively survived, passing on their characteristics to new generations, while those that did not died out.

New theories from outside the discipline have also contributed to paleontology in the twentieth century. Of these the two most important are the geological theory of continental drift, which explains how the major landforms on Earth have shifted over time, offering a new understanding for the distribution of various species, existing and extinct. The asteroid theory of extinction, also from the late twentieth century, has offered a powerful causal factor for the various extinction events in Earth’s history, though some paleontologists still believe that mass volcanic activity, either independent of asteroid collisions or connected to them, are the major cause of such events. In either case, it is these catastrophic events that mark a number of key divisions between eras and periods.

From within the discipline, perhaps the most important theoretical development of the late twentieth century has been that of punctuated equilibrium. First propounded by American paleontologists Niles Eldredge and Stephen Jay Gould in the 1970s, this theory revisits—in biology rather than geology--the old uniformitarianism-catastrophism debate of the eighteenth century. What Eldredge and Gould argue is that evolution, even in the absence of non-catastrophic events, is marked by bursts of genetic change followed by long periods of stasis.

Twentieth century technology has also given paleontologists remarkable new tools. Radiometry has allowed for precise and accurate dating of fossils while DNA analysis has opened a window on changes at the molecular level, permitting paleontologists to study precisely how species have evolved or failed to evolve. DNA analysis has also given scientists the ability to map the relationships, based on subtle changes in fossilized DNA, between species with incredible precision.

While paleontology is largely seen as an interesting academic exercise by much of the public, as well as a source of fascinating facts for dinosaur-loving children, it may also offer lessons about humanity’s current relationship to its environment. The current period in paleontological history, known as the Quaternary, which began roughly 1.8 million years ago, has been marked by the rise to dominance of a species from the hominid family of the primate order of mammals, known as homo sapiens. With its great intelligence this species has come to control and change its environment to an unprecedented degree and, in paleontological terms, in a very short period of time. Like the cataclysmic events of the past, human-wrought change to the environment may be occurring too fast for other species to adapt. Scholars of the environment estimate that species extinctions in the past century have occurred at a rate anywhere between 100 to 1,000 times above the average, or “background,” rate of extinction--a result of hunting, pollution, habitat loss and, most recently, climate change. Thus, some paleontologists hypothesize that the planet may be undergoing a new extinction event, known as Holocene extinction event, after the current epoch, which began about 10,000 years ago, produced not by asteroids or great geological forces but by the very species that had unraveled the story of Earth’s long history.

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