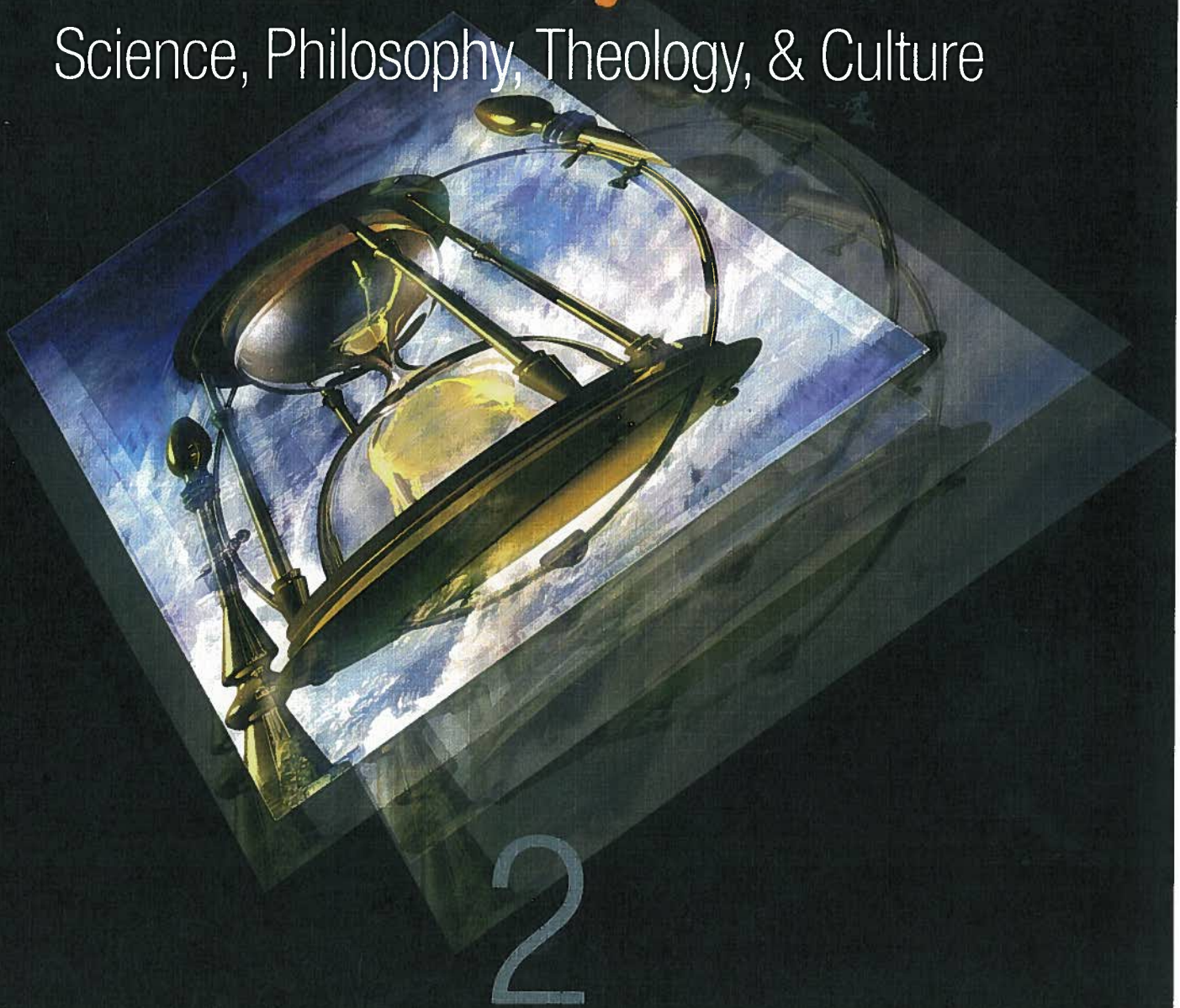


H. James Birx *Editor*

ENCYCLOPEDIA OF TIME

Science, Philosophy, Theology, & Culture



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College, Cambridge, in 1758, from which he graduated and where he later became a fellow and tutor. (Nearly 70 years later, Charles Darwin also enrolled in Christ's College, lived in rooms formerly occupied by Paley, and studied—and admired—the latter's writings.) Ordained in 1767 and married in 1776, William Paley advanced through clerical ranks and held various appointments. In 1782, he became archdeacon in Carlisle. There he began the process of expanding his Cambridge lectures on apologetics and ethics for publication.

Though he published several other books, Paley's fame rests on four works, all of which exerted considerable influence in his lifetime—and beyond. His first study, *The Principles of Moral and Political Philosophy* (1785) became a standard textbook at Cambridge. He taught a form of ethical utilitarianism and opposed the slave trade. In 1790, Paley published his second book, *Horae Paulinae, or the Truth of the Scripture History of St. Paul*, a defense of the Bible's historical nature. The third book, *A View of the Evidences of Christianity* (1794), another study on Christian apologetics, sorted and updated important material from earlier authors and achieved wide acclaim. In contrast to Hume, he supported the historicity of biblical miracles.

He published a fourth volume in 1802 under the title *Natural Theology, or Evidences of the Existence and Attributes of the Deity Collected from the Appearances of Nature*. Paley regarded this last book as the most important, a logical predecessor to the rest. Through an orderly arrangement and readable style, Paley—like his predecessors who advanced the cause of natural theology (e.g., John Ray, William Derham)—compiled a series of case studies to support the teleological argument for the existence of God, also known as the argument from design. In his *Natural Theology*, still in print after more than two centuries, Paley pointed primarily to complex parts and systems of human anatomy as arguments in favor of “intelligent design.” As a watch's functioning components imply the existence of a watchmaker, he suggested, the biological realm reflects the work of a purposeful designer.

Critics point to various flaws in this famous analogy (e.g., it begs the question by assuming that the watchmaker must be the God of the Bible) and claim

that Darwin's conclusions have obviated the need for an external, divine artificer. Others still find Paley's simple premise compelling. As the church reacted to intellectual challenges of that era (e.g., deism; Enlightenment writers such as Hume and Kant), Paley offered hope to readers who believed in a Creator with a personal interest in the universe.

Gerald L. Mattingly

See also Bible and Time; Creationism; Darwin, Charles; God and Time; Gosse, Philip Henry; Scopes “Monkey Trial” of 1925; Teleology; Watchmaker, God as

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PANBIOGEOGRAPHY

In 1964 the biogeographer and evolutionist Leon Croizat published a book titled *Space, Time, Form: The Evolutionary Synthesis*. The title of the book presented a renewed emphasis on the role and significance of space and time in the evolutionary process and in understanding evolutionary history. Many representations of the theory of evolution from the time of Darwin's *On the Origin of Species* (1859) assumed that space and

time together constituted a separate environmental container through which organisms moved and evolved. Croizat pointed out that this perspective resulted in an erroneous understanding of the evolutionary process.

For most people, time is perhaps the most compelling element of evolution that directly links the present with the past, principally through the geological fossil record. Fossilized organisms are identifiably related to those of the living world, either at a general level of organization or at more specialized levels such as those of genera and species. These fossils have contributed to the idea that living species have a history of ancestral species, some of which are preserved in the fossil record. However, this record alone was not necessarily enough to convince everyone of evolution by descent with modification—including Darwin himself. But it was during his world voyage on H.M.S. *Beagle* that Darwin found that some fossils in Argentina were more closely related to organisms currently living in that region than to those of other areas. This geographic juxtaposition of temporal records and biological relationships provided Darwin with a critical insight that helped lead him from a creationist to an evolutionary perspective. So it is no surprise that the very first sentence in Darwin's 1859 book began with the observation that the distribution of organisms and the geological relationships of the present to the past inhabitants of South America "seemed to throw some light on the origin of species."

Darwin's discovery pointed to a key aspect of evolution, that time and space are causally interrelated. But this interrelationship was taken largely for granted in much of evolutionary theory until nearly a century later, when Leon Croizat developed his unique approach to evolution called panbiogeography. In this approach Croizat did what no one else had ever done before. He tested Darwin's theory of evolution through the comparative study of animal and plant distributions, whether living or fossil. Animal and plant distributions provide a direct representation of time and space in evolution. The spatial component is represented by their location, while the temporal component is represented by their differentiation or divergence as well as the spatial correlation of distributions with tectonic features associated with earth history.

In recognizing the integral relationship of time with geographic location and the evolution of biological form, Croizat proposed the representation of evolution as the summation of their individual and combined effects by the following equation: Evolution = space + time + form. This formulation showed that the study of evolution was effectively the study of how all three elements are interrelated and affect each other, rather than just the study of a purely physical (biological) process. Time now becomes part of the evolutionary process rather than just a temporal record of evolutionary events. Because of this integral relationship, Croizat regarded the process of biological evolution (which he referred to as "form-making") in space over time as fundamental for the whole of biology in both its theoretical and practical aspects.

Croizat's approach to time as an aspect of space has its historical background in new ways of thinking about time and space that were developing at the transition between the 19th and 20th centuries, particular in Italy where Croizat was born and spent his formative years concurrently with the emergence of the Italian futurist movement. Futurists challenged the conventional assumptions of space and time as absolute categories by developing space and time as relational concepts with physical form. This was further developed in challenging presence and absence as independent and localized concepts. Croizat's panbiogeography showed that the full meaning of an organism at any one place and time is always permeated by a phylogenetic, morphological, ecological, or biogeographic counterpart or complement that is located somewhere else in space and time. The trace of this vicariant counterpart is represented graphically as a line or track that shows the connection of organisms in space and time. In this context, organism and environments are not absolute entities, but biogeographic and ecological relationships where spacing and temporalization are the ways in which replication of the past in the present influences the future.

By comparing the geographic distributions of animal and plant species, Croizat concluded that evolutionary differentiation of biological form (e.g., speciation) results in related taxa (species, genera, families, etc.) occupying different geographic sectors without any of these taxa having individually moved to those locations. This process was made possible by their common ancestor

already having a distribution range that encompassed all the descendant locations. Each descendant came to occupy different areas through their biological divergence over different parts of the ancestral range. Croizat called this process *vicariant form-making*. These various taxa may be assigned any one of a number of different taxonomic ranks (species, genus, family, etc.), but Croizat was adamant that time in evolution is not tantamount to age as expressed in any particular taxonomic group. He argued, for example, that even though one might assume that a genus comes before a species because the genus is made up of species, in reality a genus could hardly exist independently from at least some of its species, so that the two ranks are effectively contemporary in origin. In this way Croizat attempted to distinguish between absolute time as an overall process inherent to the spatial evolution and differentiation of taxa, and relative time as the relationship between a specific taxonomic rank and its place in evolutionary rather than absolute time, so a species in one group may be as old as a genus or family in another group.

Key questions of time in evolution include the estimation of evolutionary rates of differentiation and the provision of a temporal scale for divergence between lineages. To address these questions, evolutionists often refer to the fossil record. The fossil record provides a general geological timescale for the first appearance of various lineages in the fossil record. Fossils can represent only the minimal age of fossilization for a recognized group of organisms. Fossils contain no information on whether or how long a group existed before the appearance of their earliest fossil. For example, the earliest known bird fossil, dated at about 150 million years old, may show that birds had evolved by this time, but the fossil contains no information as to how much earlier birds originated or the age of the common ancestor of birds and their nearest dinosaurian relatives. The fossil record is replete with examples of organisms for which the fossil record extends the organism's history tens of millions of years further than previously existing records did.

Method

Panbiogeography provides a spatial method for estimating temporal divergence and understanding

evolutionary rates by correlating animal and plant distributions with tectonic features involved with geological history. Tectonic formations such as spreading ridges, plate boundaries, transform faults, and zones of uplift or subsidence are all indicators of geological process that underlie the geological topography now occupied by plant and animal distributions. These features can be geologically dated through radioactive decay rates to provide a geological timescale for their formation. A temporal correlation is often made for fossils that are imbedded in dated geological strata, but this approach may also be used for living taxa. This geological correlation technique may have significant implications for dating the origin of taxa where the fossil record is sparse or lacking altogether, and it may even lead to controversial challenges to accepted ages of origin based on the fossil record.

The possible temporal implications for evolutionary rates and age of origin may be illustrated by the spatial correlation between the 200-million-year-old Triassic fossil mollusk *Monotis* and the modern flowering plant genus *Coriaria*. The fossil distribution of *Monotis* overlaps with extensive circum-Pacific geological terranes (geological strata that have a different origin than other strata immediately adjacent) as well as a series of terranes extending through central Asia to Europe. This fossil range is spatially comparable with the modern distribution of *Coriaria* with the exception of western North America, where the plant is absent and no fossil representatives are known. The overall spatial correlation with circum-Pacific terranes may suggest that the modern distribution of *Coriaria* is as old as the Triassic, or it may have a more recent origin that was still affected by the subsequent geological history of those terrains that previously influenced the Triassic distribution of *Monotis*. The controversial aspect of this spatial correlation between geology and biology is that it suggests the genus *Coriaria* may be older than the earliest known fossil flowering plants recorded from the early Cretaceous (125–130 million years ago). Although some interpretations of the fossil record allow for an earlier origin for the evolution of flowering plants, the idea that some modern genera may also be this old would be widely viewed as problematic if not impossible.

Croizat's Mesozoic Theory

Spatial correlations between modern distributions and the earth's tectonic features (including spreading ridges, faults, and ocean basins) led Croizat to conclude in the 1950s that the origin of most groups of plants and animals distributed between continents originated in the Mesozoic. He proposed that their ancestors were already widely distributed before the Mesozoic, and so they are now isolated between continents, because these land areas have since become isolated. Croizat argued that some modern plant groups may have originated within the Jurassic, while others originated later in the Cretaceous. Even within continents he suggested that many groups originated in the Tertiary and survived the Pleistocene glaciations, an evolutionary model that was later to gain greater support from researchers but at the time was rarely considered.

The Mesozoic theory was strongly opposed by the influential theorists of Croizat's time, such as George Gaylord Simpson and Ernst Mayr, who looked to a much more recent origin of modern life and therefore had to appeal to theoretical migrations, whereby a vast range of animals and plants had to embark on a globetrotting series of migrations in different directions all over the globe to establish themselves on the different continents. Over the last 3 decades, Croizat's model has become widely accepted, although it remains controversial for many groups where other biogeographers believe that the plants or animals in question are of recent origin. A Mesozoic origin for modern life also has critical implications for understanding the mass extinction of dinosaurs and other groups at the end of the Cretaceous that has been attributed to a comet impact. The correlation of modern plant and animal distributions with Mesozoic tectonic structures may suggest that the ancestors of these groups survived the extinction event.

The expanded biogeographic timescale for plant and animal evolution was even proposed for the origin of animals and plants on oceanic islands such as Hawai'i and the Galapagos. Even though these islands were only a few million years old, Croizat argued that they inherited life that occupied earlier islands or island groups that no longer existed in the immediate vicinity. This model was later corroborated by the discovery that the

Galapagos and Hawai'i, for example, are the latest formations in a series of volcanoes generated at a stable hotspot, and that both hot spots have a history of volcanic eruption extending back at least 90 to 100 million years. If these hot spots came into contact with mobile island arcs or microcontinents, some of their inhabitants may have colonized the volcanoes and continued to persist at the hot spots by sequentially migrating onto new volcanoes as they appeared, while the older islands were moved away by plate transport and as they eroded finally submerged beneath the sea. Because life is able to colonize new landscapes, it is possible for a young geological surface to support a very ancient biota, whether in reference to recent volcanic islands, volcanoes within a continent, or newly emergent land covered by recent oceanic sediments (e.g., mudstone, limestone).

The Mesozoic model and extended timescale for evolution has recently come into conflict with the popular application of molecular clocks. Molecular clock methods rely on the establishment of a temporal rate of molecular difference between related organisms as a function of time. In order to link a divergence rate to a particular temporal difference, it is necessary for the molecular divergence to be calibrated against a known geological age. This is most often accomplished by using a fossil representative and then extrapolating the relative age for those species for which there is no fossil representative. This method has resulted in the divergence of many groups being calculated as later than a particular geological event (such as the separation of continents occupied by the group), with the conclusion that the origin of the divergence postdated the earlier geological connection, so the current disjunction (such as between different continents) must be the result of recent dispersal or migration. This line of reasoning has been shown to be erroneous, because the molecular divergence date is calibrated by a fossil that can only provide a minimal divergence date. Any molecular dates applied by extrapolation to other taxa must, therefore, also represent minimal, not maximal, divergence estimates. Molecular divergence estimates that postdate a geological event do not, therefore, falsify the possibility that the geological event was actually involved with a divergence that was underestimated by the molecular clock. Molecular clock divergence dates may,

however, provide potential falsification of a later geological event. The widespread reference to molecular clock divergence estimates as a falsification of Croizat's biogeographic model is, therefore, unfounded.

Panbiogeography and Theories of Divergence

As a final example of the panbiogeographic perspective on time and molecular approaches to evolution, one may contrast the chimpanzee and orangutan theories of divergence between humans and their nearest living great ape relatives. According to molecular similarity, chimpanzees are our nearest living relatives. Based on the molecular clock theory calibrated by the fossil orangutan relative *Sivapithecus* at about 13 million years, or by other primate fossils, the divergence between humans and chimpanzees has been estimated from as little as 4 million years to as much as 10, with 6 to 8 million years being often favored. In the absence of a fossil record for chimpanzees or gorillas, there is no other corroboration of this divergence estimate. The orangutan theory of relationship would establish an entirely different timescale, with divergence between orangutans and humans occurring at least 13 million years ago. This temporal alternative is also supported spatially with fossil orangutan relatives being distributed around parts of the Mediterranean, central Asia, and eastern Asia. These distributions, along with that of the fossil hominids of East Africa, are largely vicariant, and this would suggest that the temporal differentiation of hominids, the fossil apes, and the orangutans all occurred in their respective areas from a common ancestor that was already widely distributed over all localities. Subsequent extinction of many of these lineages by about 9 million years ago (some apparently the result of climate change and loss of forested environments) resulted in the apparent discrepancy between the origin of hominids in Africa and the origin of modern orangutans in southeastern Asia. It is only through the triple consideration of biological affinity (the evolutionary relationships), the temporal history (in the fossil record), and the spatial distribution of living and fossil taxa that the modern geographic disconnection can be understood as a spatial

artifact resulting from the extinction of geographically intermediate forms.

John Grehan

See also Darwin, Charles; Evolution, Organic; Extinction and Evolution; Fossil Record; Fossils, Interpretations of; Phylogeny

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PANGEA

Pangea (Greek for "all earth") was a supercontinent that gradually formed during the early Paleozoic era (beginning approximately 450 million years ago) and broke apart beginning in the Middle Jurassic era (approximately 180 million years ago). At its most complete state in the Early Jurassic, Pangea consisted of nearly all of the world's continental crust sutured together into a single giant landmass. This landmass was C-shaped, centered on the equator, and surrounded by a single giant ocean, termed Panthalassa. Pangea enclosed an eastward-facing body of water called the Tethys Sea, of which the modern Mediterranean is a much-reduced remnant, and was home to vast subtropical deserts. The existence of a single giant continent had profound effects on life, and many important evolutionary events occurred on Pangea, including the radiation of the dinosaurs and the early evolution of birds and mammals.

During the early history of geology it was thought that Earth was a static, stable planet whose surface remained largely unchanged through time. However, beginning in the early 1900s,