TERTIARY HISTORY

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Contents

Summary

The Tertiary Period lasted from 65 million years ago, when the dinosaurs died out, to about 2 million years ago, when the current ice ages began. Long known as “The Age of Mammals,” it was the time when shrew-like mammals emerged from 130 million years of hiding from the dinosaurs to take over the planet, and by 50 million years ago, they had diversified into groups ranging from bats to whales. Birds, too, underwent a huge

diversification into essentially all the modern groups, as did a number of groups of insects. On land, the flowering plants, which originated in the Cretaceous Period, covered the entire planet, with temperate vegetation above the Arctic Circle about 50 million years ago. The sea floor was populated by essentially modern groups of marine organisms (such as the clams, snails, modern corals, and sea urchins), although many early Tertiary marine groups are members of extinct lineages that did not survive into the late Tertiary.

The Tertiary Period is the earliest timescale term still used in geology. Coined by Giovanni Arduino in 1759, it referred to the horizontally stratified, loosely consolidated sediments and sedimentary rocks that were thought to be deposited during and after Noah's Flood, and lay across tilted "Secondary" sedimentary rocks (now considered late Paleozoic and Mesozoic,) and the "Primary" granitic, and metamorphic basement rocks. Together with the Quaternary Period (2 million years ago to present) the Tertiary makes up the earlier part of the Cenozoic Era (65 million years ago to present). The Tertiary is divided into 5 epochs: the Paleocene (65–55 million years ago); the Eocene (55–34 million years ago); the Oligocene (34–23 million years ago); the Miocene (23–5 million years ago); and the Pliocene (5–2 million years ago). Some geologists prefer to divide the Cenozoic into two more equal parts: the Palaeogene (Paleocene, Eocene, Oligocene) and the Neogene (Miocene, Pliocene, Pleistocene, Recent). Recently, a number of geological organizations have recommended abandoning the archaic term "Tertiary" in favor of Palaeogene and Neogene.

In climatic terms, however, the most natural subdivision of the Cenozoic occurs between the middle and late Eocene (about 37 million years ago), when the Earth went from "greenhouse" climatic conditions left over from the Mesozoic to the "icehouse" conditions that prevail today. In the early Eocene (55–50 million years ago), tropical jungles grew as far north as Montana, and temperate plants and crocodiles lived above the Arctic Circle, surviving six months of warm conditions but total darkness. In the late Eocene and Oligocene, a series of plate movements caused changes in oceanic circulation, which in turn caused climatic deterioration of the "greenhouse" world.

By the early Oligocene (33 million years ago), there were glaciers on Antarctica, and by the middle Miocene (15 million years ago), those glaciers were permanent. In addition, the rise of the Himalayas (caused by the collision of the Indian Sub-continent with Asia in the early Eocene) may have contributed to the general cooling and drying of the planet by absorbing atmospheric carbon dioxide through increased weathering. Throughout the Miocene, this cooling and drying trend continued, so that by 7 million years ago, widespread grasslands and savannas were found in all temperate and tropical latitudes. About 3.5 million years ago, the Isthmus of Panama closed, uniting South and North America. This had a two-fold effect. Not only did it allow mammals from the North to migrate south and replace the endemic native mammals that had evolved when South America was an island continent, but it also cut off the flow of tropical water between the Caribbean and Pacific. This in turn changed oceanic circulation so that warm currents (the Gulf Stream) moved into the North Atlantic, providing moisture over the long cold but dry Arctic Ocean, and triggering the development of the Arctic ice cap. From this point onward, the Earth was locked into a bipolar glacial state, with alternating glacial and interglacial cycles every 100 000 years triggered by changes in the Earth's orbit and distance from the sun. Those glacial-interglacial cycles reached their peak during the Pleistocene ice ages. We are still in the ice ages, but at the end of an interglacial episode (the Holocene or "Recent" Epoch,), which began 10 000 years ago (see *Mesozoic History*, and *Quaternary History*).

1. General Characteristics

The Tertiary Period (and the Cenozoic Era) is not as long as the Paleozoic or Mesozoic eras, but it was a very eventful time, when most of the characteristics of the modern world were established. In addition, we know so much more about the Tertiary and Cenozoic than we do over earlier times, and know it in much more detail, because such young deposits are more likely to be preserved and exposed, and less likely to be eroded or metamorphosed than the much older, more deformed rocks of the Mesozoic and especially Paleozoic. In some cases, we can get extremely high-resolution deep sea cores, which can distinguish events from millions of years ago on 1000-year time scales or less—much better than the dating or resolution available for the Paleozoic or Mesozoic.

1.1 Evolution of Life in the Tertiary

At the end of the Mesozoic, the non-avian dinosaurs, which had dominated the land, and the ammonites and giant marine reptiles, which dominated the oceans, had both become extinct. However, most other denizens of the Late Cretaceous world survived. On land, most plants were unaffected, as were the reptiles and amphibians (especially crocodilians, turtles, and salamanders), which show that the Cretaceous extinctions were not as dramatic or catastrophic as some scientists have claimed. The mammals, which had been shrew-, or rat-sized creatures for the first 130 million years of their history, suddenly inherited a planet empty of large land vertebrates (except for huge predatory flightless birds, the sole survivors of the dinosaurian lineage). During the Paleocene, mammals underwent a huge evolutionary radiation to fill these vacant ecological niches, and by the middle Eocene, some had reached elephantine size; others were occupying niches as diverse as the seas (whales) and the air (bats). Birds, too, underwent a huge evolutionary radiation in the early Tertiary, diversifying from a few archaic Mesozoic groups to almost all of their modern orders by the middle Eocene. The evolution of insects is not as well known. Although most of the modern orders were around in the Cretaceous, it appears that their diversification, and establishment of most modern families occurred in the Tertiary.

In the oceans, only the ammonites (relatives of the living chambered nautilus), the marine reptiles (mosasaurs and plesiosaurs,) and a few groups of plankton, and bizarre clams died out at or near the end of the Mesozoic. The vast majority of the dominant marine invertebrates groups (especially clams, snails, corals, sea urchins, and most planktonic organisms) survived with only moderate extinction. During the Tertiary, these groups recovered completely, and continued to diversify, with many new forms emerging (such as more advanced, burrowing snails and clams, and the burrowing sand dollars). Single-celled organisms (the amoeba-like shelled foraminifer and radiolarian, and the shelled algae known as coccolithophorids, and diatoms) also evolved rapidly in the oceans, where they serve as the timekeepers for marine rocks of Cenozoic age.

Occasionally, there were spectacular developments in these groups. During the middle Eocene, the single-celled nummulitic foraminifer grew calcite skeletons the size and shape of coins. They were so numerous in the tropical seas of Eurasia and Africa that they make up huge volumes of limestone, from which the Pyramids of Egypt are built. By the middle Eocene, there were archaic whales over 20 m long. In the middle Miocene, a gigantic relative of the great white shark appeared which was over 18 m long, and probably hunted whales. Seals, sea lions, and walruses also appeared in the Miocene, along with most of the modern groups of bony fishes (in both the marine, and fresh waters).

1.2 Evolution of the Principal Ecosystems in the Tertiary

The terrestrial habitats vacated by the dinosaurs at the end of the Cretaceous were dominated by flowering plants, although mostly represented by archaic groups, such as the magnolias. Gymnosperms such as conifers, and archaic plants such as ferns, had already been forced into restricted habitats by the Cretaceous explosion of flowering plants. During the Tertiary, the spread of flowering plants continued, with many modern groups of plants appearing for the first time. By the early Eocene, tropical jungles prevailed even up to places as far north as Montana and Wyoming, as the "greenhouse" world of high atmospheric carbon dioxide reached its peak. Temperate conditions were found in the Arctic and Antarctic. Although these regions were dark for six months of the year, they were apparently warm enough to sustain the deciduous plants.

The inhabitants of this world were essentially modern groups: mammals, birds, and many types of insects, along with holdovers from the Mesozoic, like the living groups of reptiles (turtles, snakes, lizards, and crocodiles), amphibians, and most modern groups of bony fish. However, the ecological complexity of this more homogeneous, tropical world was not as great as it is today, when we have many more levels of animals in the food web, and we have much more varied climates and vegetation. For example, among the mammals most were either tree-dwelling seed- and fruit-eaters, or ground-dwelling leaf eaters. Since there were no grasslands, there were no grazers. The predatory mammals were rather primitive, with simple unspecialized teeth for eating meat and carrion. In the absence of dominant mammalian carnivores, 2 m tall flightless birds were actually the largest land predator in the middle Eocene.

By the late Eocene and Oligocene Periods, the global climate began to change dramatically, and one with cooler, drier climates, and greater seasonality replaced the warm, tropical "greenhouse" world of high atmospheric carbon dioxide. This climatic transformation was probably triggered by plate tectonic changes, which in turn affected oceanic circulation. Before the late Eocene, Australia and Antarctica were still connected and circulation in the South Pacific and South Atlantic mixed polar waters with equatorial waters, decreasing the temperature extremes from pole to equator. By the late Eocene, Australia had separated enough from Antarctica that cold, deep currents could flow between the two continents for the first time. This established the beginning of the circum-Antarctic current, which spirals around Antarctica and locks in the cold over the Antarctic. This current was completed in the early Miocene, when the separation between Antarctica and South America was complete. Today, the circum-Antarctic current not only locks in the cold polar waters in a spiral around the Antarctic continent, but also generates the cold Antarctic Bottom Waters, which flow north along the ocean floor all the way to the Arctic. The timing of this change is manifested in the first Antarctic ice sheets in the early Oligocene, and the permanent Antarctic ice cap by the middle Miocene.

During the Oligocene and Miocene, this long-term cooling and drying trend had a significant effect on life. On land, the jungles of the Eocene were replaced by a more mixed woodland-scrubland habitat in the Oligocene, and by the late Miocene, by true grasslands and savannas across most temperate and tropical regions. Land animals responded to these changes as well. The mostly tree-dwelling seed and fruit eaters of the Eocene nearly vanished as the dense forests were decimated, as did the archaic hoofed mammals that fed primarily on leaves. In their place were mammals adapted for more open habitats, and by the late Miocene, there were many herbivores adapted for grazing, with ever-growing molars that can stand the abrasion this gritty diet, and long legs for rapid escape from predators across the open plains. The Oligocene and Miocene saw the origination or diversification of most of the modern groups of land herbivores (especially rhinos, camels, horses, peccaries, and pronghorns in North America, and rhinos, horses, mastodons, pigs, and ruminants such as deer, antelopes, giraffes, and cattle in Eurasia). It also witnessed the radiation of more specialized predators, the order Carnivora (including the first true cats, dogs, and bear and weasel relatives), which replaced the archaic carnivorous mammals and giant flightless predatory birds of the middle Eocene. Finally, the archaic small mammals of the Eocene jungles (such as the archaic lemur-like primates and the egg-laying multituberculates) were replaced by the rodents and rabbits, which underwent a huge diversification in the Tertiary to become the most numerous, and diverse mammals on Earth.

In the marine realm, the overall structure of the ecological communities was not much changed since the early Mesozoic, when the sea floor dominated by snails, clams, and sea urchins was first established. However, the effects of the long-term cooling trend were dramatic. The high diversity of tropical mollusks, and echinoderms of the Eocene gradually diminished by the Oligocene and Miocene, with many tropical groups replaced by a less diverse assemblage of temperate and cold-tolerant groups. As the "icehouse" world of the Oligocene and Miocene took effect, oceanic circulation also became more vigorous and complex, with stratification of warm surface currents, intermediate currents, and cold bottom waters. This is in contrast to the warm Eocene ocean, which was relatively unstratified and sluggish in circulation. Complex oceanic circulation triggered evolution and diversification in marine organisms (especially the plankton, which track specific water masses). By the Miocene, it also stimulated the revival of modern hermatypic coral reefs, which are adapted to surviving in low-nutrient conditions typical of modern oceans.

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Biographical Sketch

Donald R. Prothero is Associate Professor of Geology at Occidental College, Los Angeles, California, U.S.A. Born in Glendale, California, he was a double major in geology and biology at the University of California at Riverside, graduating in 1976 with highest honors, Phi Beta Kappa, and recipient of the College Award for outstanding senior in the natural and agricultural sciences. He received a 3-year NSF graduate fellowship to attend graduate school. He earned his M.A. (1978), M.Phil. (1979) and Ph.D. (1982) from Columbia University and the American Museum of Natural History in New York, specializing in fossil mammals and in magnetostratigraphy. He taught at Vassar College in Poughkeepsie, New York (1979–1981), then at Knox College in Galesburg, Illinois (1982–1985). Since 1985, he has taught at Occidental College in Los Angeles.

In 1989, he was a Guggenheim Fellow, and in 1991 he received the Schuchert Award of the Paleontological Society for the outstanding paleontologist under the age of 40. He has served as Associate Editor of Paleobiology and Technical Editor of *Journal of Paleontology*. He is currently Vice-President of the Pacific Section SEPM (Society of Sedimentary Geology), and Program Chair of the Society of Vertebrate Paleontology. His research has long focused on the evolution of mammals (especially hoofed mammals, including rhinos, horses, and camels), and on the use of magnetic stratigraphy for dating the climatic changes of the Eocene and Oligocene. He is the author of 11 books (including textbooks in physical geology, historical geology, paleontology, sedimentary geology, and stratigraphy) and over 150 scientific papers.