Major Geological
and
Biological Events
The **Tertiary** period was once prominent as a major division of the geologic timescale, designating the time from the end of the Cretaceous period about 65 million years ago to the start of the Quaternary period about 1.6 million years ago. While its use has been widespread and continues, the International Commission on Stratigraphy no longer endorses this term as part of the Formal Stratigraphic Nomenclature. Instead the Paleogene and Neogene periods are recommended as the primary subdivisions of the Cenozoic era. The Quaternary likewise has been subsumed into the Neogene. When the term Tertiary is used now, it is generally as a "sub-era" rather than a "period" of geologic time (Hinton 2006).

In common usage, the Tertiary has included five geologic epochs—the Paleocene, Eocene, Oligocene, Miocene, and Pliocene. The Tertiary covers roughly the time span between the demise of the dinosaurs and beginning of the most recent ice age.

Name

The term "Tertiary" for this period was first used by Giovanni Arduino in the 1700s. He classified geologic time into primitive (or primary), secondary, and tertiary periods based on observations of geology in northern Italy. Later the Quaternary was added as a fourth period. In 1828, Charles Lyell incorporated a Tertiary period into his own, far more detailed system of classification. He subdivided the Tertiary period into four epochs according to the percentage of fossil mollusk species resembling modern species found in those strata. He used Greek names: Eocene, Miocene, Older Pliocene, and Newer Pliocene. These designations, albeit adequate for the areas originally applied, were not universally applicable. Therefore, later the use of mollusk species was abandoned from the definition and the epochs were renamed and redefined.

The Primary and Secondary periods have been done away with as periods, and the Tertiary and Quaternary are now generally placed at the level of "sub-era" when used. There is little reference in literature to intervals of time of "sub-era" and thus some consider it logical to also remove the name Tertiary from geologic time (Hinton 2006).
Several important geological events occurred during the Early Tertiary (Harland et al., 1982; Shackleton, 1986; Parrish, 1987). There were two of the boundaries, the Cretaceous / Tertiary (i.e. Maastrichtian / Palaeocene) and the Eocene / Oligocene. Meteoritic impacts have caused profound biological disturbance including ecological disruption with ensuring extinctions. Extraterrestrial impacts have been drawn by the occurrence of anomalously high concentrations of elements like iridium, otherwise rare on earth.

(a) The Cretaceous-Tertiary extinction event

The end of the Cretaceous period and the beginning of the Tertiary period (The Paleogene) was marked by a mass extinction event known as the Cretaceous-Tertiary extinction event. Also known as the K-T extinction event, it was a period of massive extinction of species that occurred about 65.5 million years ago. Many forms of life perished, encompassing approximately 50 percent of all plant and animal families, the most conspicuous being the non-avian dinosaurs. Some recognize this mass extinction now as occurring at the Cretaceous-Paleogene boundary rather than the K-T boundary (Hinton 2006). The last of the pterosaurs also vanished, as well as the great sea reptiles of the Cretaceous, the mosasaurs and plesiosaurs. Mammals suffered as well, and among mollusks, the ammonites, a diverse group of coiled cephalopods, were exterminated. As much as 57 percent of the plant species in North America may have become extinct as well.

The K-T boundary that marks the separation between Cretaceous and Paleogene is visible in the geological record of much of the Earth by a discontinuity in the fossil fauna, with high iridium levels. There is also fossil evidence of abrupt changes in plants and animals. There is some evidence that a substantial but very short-lived climatic change may have occurred in the very early decades of the Paleocene.

(b) Paleocene-Eocene Thermal Maximum

Another major phenomenon during the Paleogene was one of the most significant periods of global change during the Cenozoic, the Paleocene-Eocene Thermal Maximum. At the onset of the Eocene the earth warmed by 4-8 °C over a period of 10-20 ky. This sudden global warming, called the Paleocene-Eocene Thermal Maximum (PETM), lasted approximately 150 ky
and appears to have been caused by the release of ~4,500 Gt of carbon to the atmosphere-ocean system. At the Paleocene-Eocene boundary, this rapid warming event, the Paleocene-Eocene Thermal Maximum (PETM) has been identified in strata by a negative carbon isotopic excursion (CIE) During this time, sea surface temperatures rose between 5 and 8°C over a period of a few thousand years, and in the high Arctic, sea surface temperatures rose to a sub-tropical ~23°C/73°F. This upset oceanic and atmospheric circulation and led to the extinction of numerous deep-sea benthic foraminifera and on land, a major turnover in mammals.

Fig.5: Climate change during the last 65 million years.

The Paleocene-Eocene Thermal Maximum is labeled PETM and is likely to be understated by a factor of two or more due to coarse sampling and averaging in this data set. Leaf margin analysis of the floras shows ~5 °C of warming during the PETM, consistent with the magnitude of warming estimated from oxygen isotope change in continental vertebrates and planktonic foraminifera. Leaf size analysis of PETM floras suggests that precipitation decreased at the beginning of the event, then fluctuated, consistent with paleosol features in the same area. Comparison of PETM plant fossils with latest Paleocene and early Eocene floras in the same area shows a nearly complete turnover in composition over this brief time. Pre- and post-PETM floras are dominated by deciduous plants in Betulaceae, Platanaceae, Cercidiphyllaceae and Taxodiaceae, among others. PETM floras are characterized by a high abundance and/or diversity of Fabaceae and Anacardiaceae among other families, and conifers are absent. The plant fossil record of the PETM demonstrates the large effect of global warming on the composition of mid-latitude vegetation, probably resulting from local extinction and continental-scale change in the geographic ranges of plants over a geologically brief time.
The similarity of pre- and post-PETM, a flora demonstrates that rapid climate change of this magnitude did not result in lineage extinction, implying that cooler-adapted plants survived in higher-latitude or higher-altitude refugia. The Paleogene climate, geography, geology, and biota came on the foundation of previous stages and were itself the foundation for modern life. Lasting 42 million years, the Paleogene period is most notable as being the time in which mammals became very diversified and dominant.

(c) Palaeoclimatic setting:
The warmer global temperatures of the Cenozoic Era occurred in the Early Eocene time, following a warming trend that started in the late Paleocene time. The latest Cretaceous, Palaeocene and Eocene were much warmer at corresponding latitudes than the Oligocene and later Tertiary or the present day. The pattern implies a warming during the Palaeocene with temperature maxima in the late Early or early Middle Eocene. Subsequent cooling accelerated near the Eocene/Oligocene boundary, giving temperature minima at that time. Global temperature gradients were much lower than today, in particular the temperature difference between mid- and high-latitudes was less pronounced. The fall in temperature at the Eocene/Oligocene boundary indicated by isotopic evidence from benthic foraminifera is much more pronounced than that from planktonic forms.

Mechanisms of Climate Warming at the End of the Paleocene -
An abrupt episode of global warming marked the end of the Paleocene epoch. Oxygen and carbon isotope records from two widely separated sites support the notion that degassing of biogenic methane hydrate may have been an important factor in altering Earth's climate. The data show evidence for multiple injections of methane, separated by intervals in which the carbon cycle was in stasis. Correlations between the two sites suggest that even these small-scale events were global in nature. (Santo Bains, Richard M. Corfield, Richard D. Norris)

Climatic and environmental changes through the Paleogene are characterized by some unusual sedimentological and astronomical events. LPTM (Latest Paleocene Thermal Maximum) event is thought to have been produced by an abrupt dissociation of marine sedimentary hydrates along ocean margins. The abrupt warming that took place 55.5 Ma is one of the pronounced climatic events in the geohistory. Sudden climate cooling event at the Eocene-Oligocene boundary might have been caused by multiple or continuous impacts of extraterrestrial materials. Extraordinarily warm climate during the Eocene may have been brought by either vigorous erosion and
connecting modern day camels in the Old World with their close relatives the llamas in South America. Towards the end of the Tertiary, South America also was connected to North America. Antarctica—which was already separate—drifted to its current position over the South Pole. Climates during the Tertiary slowly cooled, starting off in the Paleocene with tropical-to-moderate worldwide temperatures and ending up with extensive glaciations at the end of the period.

Due to continental drift, north-east India came into direct contact with the Asian Plate and a substantial part of it was subducted under it. Due to upliftment of the Himalaya many hills came into existence in this area with an access to the open sea on the south and south-eastern side. Shillong Plateau was a high land surrounded by sea in the Early Tertiary time.

Himalayas and Tibet

The subcontinent proper is a part of the Indian plate. It is a shield area of Pre Cambrian age. It is traversed by a number of major rifts. Some of these are filled with Precambrian sediments (Vindhyan and older), Gondwana sediments and tertiary sediments (in the north). In pre collision times it was bounded on the north by the Tethys sea. In the course of continental drift the Tethys sea disappeared under the Eurasian plate in the north leading to a continental collision between the Indian and Eurasian continents. Subsequent pressure led to the fracture of the northern part of the shield and its piling up on the part south of it. This led to the crustal thickening now observed. In effect the rifted Indian Pre-Cambrian shield is thus over thrust by a part to the north of it. One would therefore expect the down thrust part to retain its rifted character. The presence of large faults in that part has to be traced.

The northward pressure from the SE Indian ocean ridge led to the Indian continent drifting in that direction and the extinction of the Tethys ocean. It finally resulted in the continental collision between the Indian and Eurasian plates. The pressure has however not ceased and one should expect a new subduction zone to be formed to the south of the Brahmaputra suture. The obvious position is the junction of the southern boundary of the Indian subcontinent and the oceanic crust below the Bay of Bengal and the Bengal Basin (particularly at the Dauki fault south of Shillong plateau). Subduction under the Indonesian arc is well known. Subduction of the Indian plate under Burma has also been illustrated. In the circumstances subduction under the Shillong plateau need hardly be doubted.
Due to continental drift, the India Plate split from Madagascar and collided with the Eurasian Plate resulting in the formation of the Himalayas.

The India or Indian Plate is a tectonic plate that was originally a part of the ancient continent of Gondwanaland from which it split off, eventually becoming a major plate. About 50 to 55 million years ago, it fused with the adjacent Australian Plate. It is today part of the major Indo-Australian Plate, and includes the subcontinent of India and a portion of the basin under the Indian Ocean.

In the late Cretaceous Period about 90 million years ago, subsequent to the splitting off from Gondwanaland of conjoined Madagascar and India, the India Plate split from Madagascar. It began moving north, at about 20 cm/yr (8 in/yr), and began colliding with Asia between 50 and 55 million years ago, in the Eocene epoch of the Cenozoic Era. During this time, the India Plate covered a distance of 2,000 to 3,000 km (1,200 to 1,900 mi), and moved faster than any other known plate. In 2007, German geologists determined that the reason the India Plate moved so quickly is that it is only half as thick as the other plates which formerly constituted Gondwanaland.
The collision with the Eurasian Plate along the boundary between India and Nepal formed the orogenic belt that created the Tibetan Plateau and the Himalaya Mountains, as sediment bunched up like earth before a plow.

The India Plate is currently moving northeast at 5 cm/yr (2 in/yr), while the Eurasian Plate is moving north at only 2 cm/yr (0.8 in/yr). This is causing the Eurasian Plate to deform and the India Plate to compress at a rate of 4 mm/yr (0.15 in/yr).

![Tectonic map in correlation with LISS-3 imagery](image)

*Fig.6: Tectonic map in correlation with LISS-3 imagery (modified after Nandy, Murthy et al., and Kaval and De).*