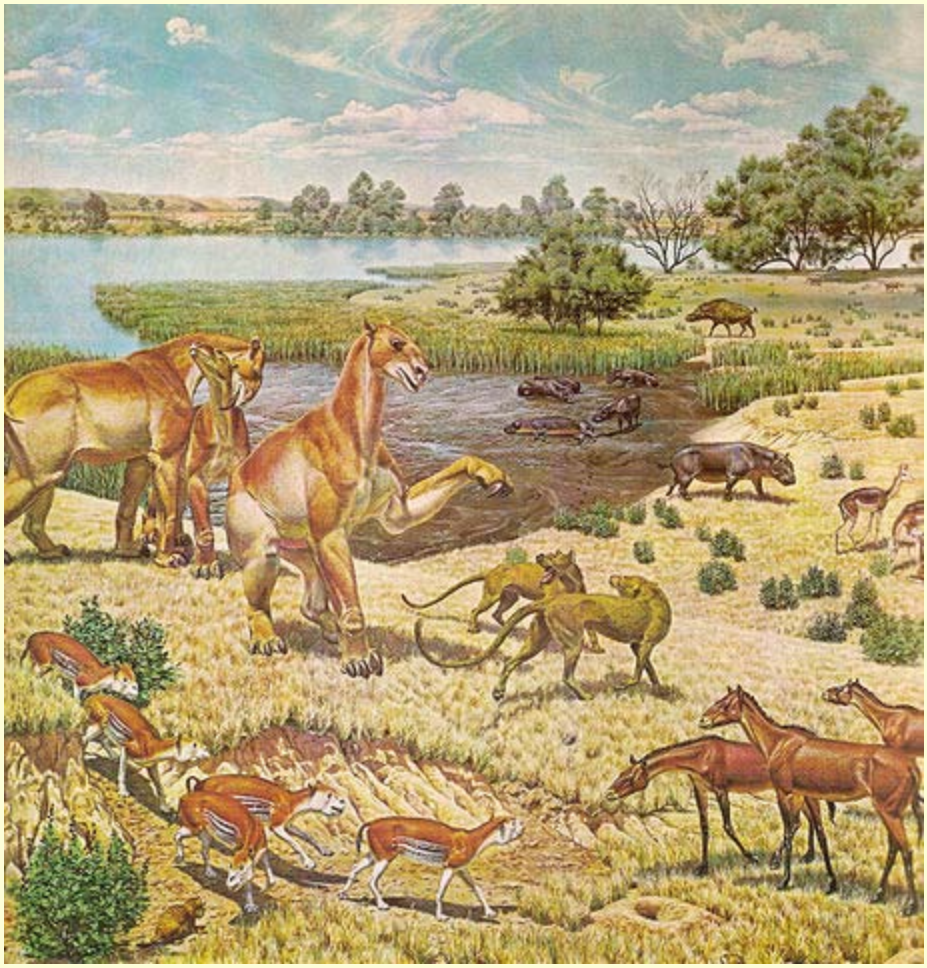
The Cenozoic

Phanerozoic
Cenozoic
Paleogene
Neogene

Cenozoic



Restoration of Miocene fauna of North America, on a mural made for the Smithsonian Museum, as reproduced in the book "North America" (Time-Life). Artwork by Jay Matternes. The illustration as work done for the US Federal Government is in public domain. (Faunal identification pending) (Wikipedia)

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The Cenozoic

The Cenozoic Era of the Phanerozoic Eon: the last 65.5 million years

The Age of Mammals

Phanerozoic
Cenozoic
Paleogene
Paleocene
Eocene
Oligocene
Neogene
Miocene
Pliocene
Pleistocene
Holocene

Geology
Timescale
Climate
Life
Links

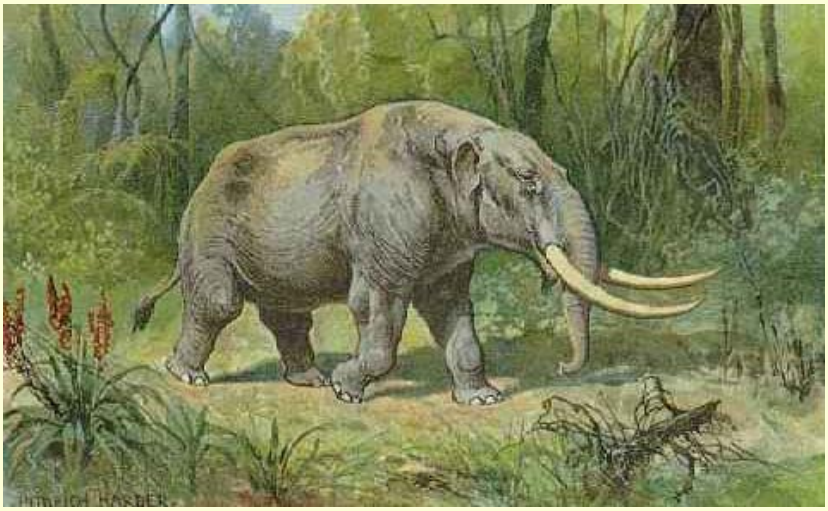


illustration from the former "Early Image" site - public domain images

During the 65 million years of the Cenozoic Era (also spelled "Cainozoic"), or Age of Mammals, the world took on its modern form. Invertebrates, fish, reptiles etc were essentially of modern types, but mammals, birds, protozoa and flowering plants still evolved and developed during this period.

Traditionally, the Cenozoic Era was divided into two very unequal periods, the Tertiary (which made up the bulk of the Cenozoic), and the Quaternary, which is only the last one and a half million years or so. The Tertiary is in turn divided into Paleogene and Neogene. We do not adopt this use of the "Tertiary" as a formal stratigraphic division for the following reasons:

More than 95% of the Cenozoic era belongs to the Tertiary period, an unreasonable division which reflects the arbitrary manner in which the geological epochs were first named. From 1760 to 1770, Giovanni Arduino, inspector of mines in

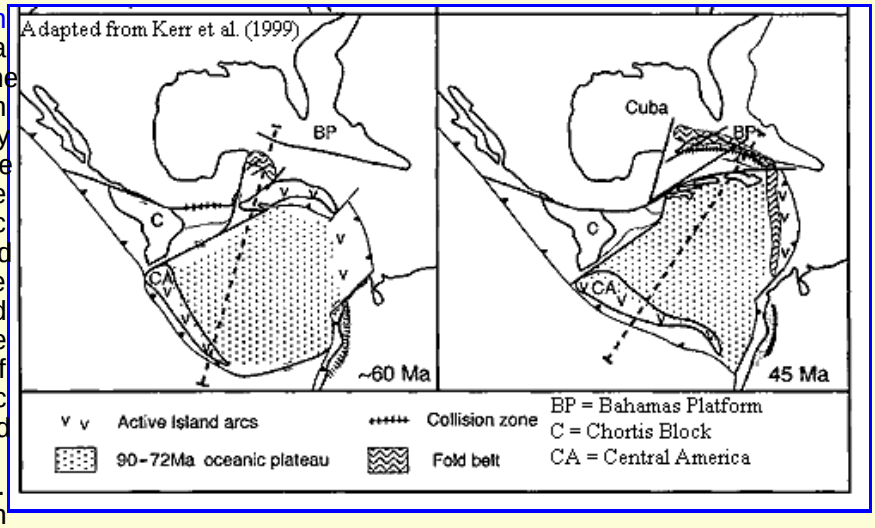
Tuscany and later professor of mineralogy at Padua, set forth the first classification of geological time, dividing the sequence of the Earth's rocks into Primitive, Secondary, and Tertiary. During the 18th century the names Primary, Secondary, and Tertiary were given to successive rock strata, the Primary being the oldest, the Tertiary the more recent. In 1829 a fourth division, the Quaternary, was added by P. G. Desnoyers. These terms were later abandoned, the Primitive or Primary becoming the Paleozoic Era, and the Secondary the Mesozoic. But Tertiary and Quaternary were retained for the two main stages of the Cenozoic. Admittedly, attempts to replace the obsolete "Tertiary" with a more reasonable division of Palaeogene (early Tertiary) and Neogene (later Tertiary and Quaternary) have not been completely successful, but most of the newer geological timelines have rejected the Tertiary.

Revised ATW040925

Geology of the Cenozoic

During the Cenozoic, the fragmentation of continental landmasses continued as the Earth's surface took on its present form. The major geologic events of the Cenozoic can be thought of as two basic processes. First, four different large fragments of the Gondwanan supercontinent moved north and became, to varying degrees, attached to the Laurasian landmass. This resulted in a number of spectacular mountain-building events which climaxed about the Early Miocene. Second, the north-south Atlantic spreading zone continued to widen the Atlantic, contributing to geologic strains in East Africa and the western parts of the Americas, as these continents were pushed into contiguous plates by the growing Atlantic Ocean.

The defecting Gondwanan fragments were South America, Africa, India, and Australia. South America has not pushed far enough north to cause a the geological equivalent of a high speed collision with North America. Instead, the impact was cushioned by a sort of air bag of small plates in what is now the Caribbean Sea. In particular, the approach of the American continents pinched off part of the Pacific crust, a region containing the sea bottom south and west of Cuba. The cushioning effect of these intervening plates delayed the formation of a land bridge between the Americas until the Middle Pliocene (Piacenzian), and has confined the effects of continental collision to relatively mild and sporadic vulcanism around the Caribbean and its southern and western margins. ***See*** image from Kerr ***et al***. (1999). Various other representations can be found at Prof. Manuel Iturralde's wonderful site on the Caribbean plate: Comparison of different opinions...



A similar, but less pneumatic, effect has softened the impact of Africa on Europe. The numerous microplates of the Mediterranean have been repeatedly rearranged and compressed as Africa approached from the south. Nevertheless, Africa's attempt to subduct under the European Plate has been a little like a hippopotamus trying to hide under a bed sheet -- there have been some inevitable little lumps and wrinkles. Some of these, like today's Alps, are difficult to overlook. Other, older ranges which run generally east to west across Europe are also products of this process. In addition, the approach of Africa squeezed shut the old Tethys Seaway, which played such a large part in Early Mesozoic tetrapod history, leaving only a few puddles, such as the Mediterranean Sea and the Black Sea.

The impact of India doesn't seem to have been mitigated at all. A land bridge between India and the Asian mainland was not established until the Eocene. However, the continental shelves of Asia and India had been in contact for some time before this, and elevation of the Himalayas has been ongoing throughout the Cenozoic. Initially, most of the impact was in the East, as India attempted to subduct under Asia to become the basement level of Tibet. In the Miocene, the force of the collision was distributed further west, forming the high plateaus of Afghanistan and Iran, with collateral consequences as far west as Eastern Europe. Perhaps the same fate awaits Australia, the last of the Gondwanan refugees. However, Australia has been dawdling along in the Pacific and has only recently begun to interact with the outlying portions of the Indonesian plates.

While the northern and southern continents have been getting progressively cozier, the Mid-Atlantic spreading ridge has been busy separating east from west. In the north, after splitting Greenland from North America, the rift abruptly changed course in the Paleogene and began to separate Northern Europe from Greenland. As a result, the last land bridge between North America and Europe was broken in the Eocene. The westward pressure on the Americas may well have been responsible for the Laramide Orogeny in the Western United States during the Paleogene, and the seamless merger of the subduction zones of North and South America later on. It is less clear that it has had any role in the more recent events which raised the current complex set of north-south mountain ranges in North America.

On the other side, in East Africa, the eastward pressure of the Mid-Atlantic ridge, combined with the opposite forces

generated by the impact of India, created enormous stresses. As a result, the Arabian peninsula was rotated and torn off the East coast of Africa, and a series of deep faults have begun to fracture the African plate. Late in the Cenozoic, the main rift valley running through Ethiopia, Kenya, and points south, became the home of several species of large, noisy, and nearly hairless apes.

Image: The satellite image is from NASA. It shows the southern part of the rift system in East Africa with a few of the great lakes which have developed in the rift valleys. Part of Lake Tanganyika is in the upper left corner. The lake in the upper central portion is Lake Malawi.

Timescale

The following table gives the component periods and epochs that make up the Cenozoic. In addition to the Neogene and Paleogene Periods below, the helpful folks at the ICS have added a sub-era (or possibly period, subperiod, or supra-age), the Quaternary, which begins at the base of the Gelasian Age and extends through the present day. Obviously, this makes no sense at all, since the same body abolished the "Tertiary" just a year or two ago -- not to mention the fact that the rules on chronostratigraphic units don't seem to allow for a unit which begins in the middle of one epoch and ends in another. It would make much more sense to move the Gelasian Age (a unit which was only created in 1996) to the Pleistocene. Then the Pleistocene would become the age of continental ice sheets, which is precisely the reason it was thought necessary to recognize the "Quaternary." This sensible proposal was actually considered, but it was far too late. The ICS had already established a Subcommission on Quaternary Stratigraphy. Kings may die or abdicate. Nations may be conquered and governments dissolved. Even whole continents may fractured and dispersed by cataclysmic rifting. But committees do not vote themselves out of existence.

Period	Epoch	Age	Base (duration)	Geomagnetic Polarity Zone (base)	Approximate Central Paratethys Stage	European Neogene Mammal Zones (base)	South American Land Mammal Ages ("SALMA")	North American Land Mammal Ages ("NALMA") Paleobiology Database (2006)
Neogene	Holocene		0.0118 (0.0118)					
	Pleistocene	Late	0.126 (0.1142)					
		Middle	0.781 (0.655)				Lujanian (0.3)	
		Early	1.81 (1.029)	C1 (1.8)			Ensenadan (1.5)	Irvingtonian (1.8), Rancholabrean (1.02)
	Pliocene	Gelasian	2.59 (0.78)			MN 17 (2.5), MmQ1 (2.0)	Uquian (2.5)	
		Piacenzian	3.60 (1.01)			MN 16 (3.2)	Chapadmalalan (3.0)	
		Zanclian	5.33 (1.73)	C2 (4.2)	Dacian	MN 15 (4.2), MN 14 (4.9)	Montehermosan (5.4)	Blancan (4.9)
	Miocene	Messinian	7.25 (1.92)		Pontian	MN 13 (7.1)		
		Tortonian	11.6 (4.35)	C3 (7.4), C4 (9.7)	Pannonian	MN 12 (7.7), MN 11 (8.7), MN 10 (9.7), MN 9 (11.3)	Huayquerian (9.0), Chasicoan (10)	Hemphillian (10.3)
		Serravallian	13.7 (2.1)		Sarmatian,	MN 7/8 (12.7),	Mayoian (12), Laventenian	Clarendonian

					later Badenian	MN 6 (13.8)	(13.8)	(13.6)
		Langhian	16.0 (2.3)		earlier Badenian	MN 5 (16.0)	Colloncurian (15.5), Friasian (16.3)	Barstovian (16.3)
		Burdigalian	20.4 (4.4)	C5 (19.1)	Karpatian, Ottnangian, Eggenburgian	MN 4 (16.8)	Santacrucian (17.5)	Hemingfordian (20.6)
		Aquitanian	23.0 (2.6)		Egerian		Colhuehuapian (21)	
Paleogene	**Oligocene**	Chattian	28.4 (5.4)	C9 (28.2), C8 (26.5), C7 (24.9), C6 (24.1)		MN 1 (23.9)		Harrisonian (24.8)
		Rupelian	33.9 (5.5)	C11 (30.6), C10 (29.3)			Deseadan (29)	Geringean (30.8), Whitneyan (33.3), Orellan (33.9)
	Eocene	Priabonian	37.2 (3.3)	C17/16 (36.3), C12 (33.0)			Tinguirican (36)	
		Bartonian	40.4 (3.2)	C19 (41.3), C18 (40.4), C17 (37.6)				Chadronian (38)
		Lutetian	48.6 (8.2)	C21 (48.6), C20 (45.1)			Divisaderan (42), Mustersan (48)	Duchesnean (42), Uintan (46.2)
		Ypresian	55.8 (7.2)	C23 (52.6), C22 (50.6)			Casamayoran (54.0-51.0)*	Bridgerian (50.3), Wasatchian (55.4)
	Paleocene	Thanetian	58.7 (2.9)	C24 (56.6)			Ríochican (57.0-55.5)	Clarkforkian (56.8)
		Selandian	61.7 (3.0)	C25 (58.4)			Itaboran (59.0-57.5)	Tiffanian (60.2)
		Danian	65.5 (3.8)	C29 (65.5), C28 (64.6), C27 (63.4), C26 (61.7)			Peligrosan (62.5-61.0), Tiumpampan (64.5-63.0)	Torrejonian (63.3), Puercan (65), Lancian (69.7)

Climate

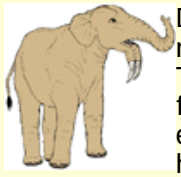
During the Paleogene the climate worldwide was warm and tropical, much as it had been for most of the preceding Mesozoic. The Neogene saw a drastic cooling in the world's climate, possibly caused by the Himalayan uplift (Tibetan plateau) that was generated by the Indian subcontinent ramming into the rest of Asia (and is still going on now). During the Pleistocene, the continuing cooling climate resulted in an ice age, or rather a series of ice ages with interspersed warm periods

Life

With the end Cretaceous extinction event and the extinction of the ammonites and most of the belemnites, teleost fishes dominated neritic (near shore) and pelagic faunas. Plankton recovered and basically belonged to modern groups. Coleoidea, Crustaceans, nudibranch mollusks and polychaete worms make up a large part of the larger zooplankton. The large marine reptiles of the Mesozoic were replaced by cetacean mammals (dolphins, whales and their kin) that first appeared during the Eocene. And while the protostegids (which included giants like Archelon) disappeared with the end-Cretaceous extinction, modern sea turtles survived quite happily.

The Paleogene saw the diversification of many mammalian and bird groups, flourishing in the tropical conditions. During the early Paleogene the continents were isolated by shallow seas, and different lineages of Mammals evolved on each one. Mammals included many giant yet small-brained rhinoceros-like types - the Asiamerican uintatheres, and brontotheres and the African arsinoitheres. There were huge flightless carnivorous birds - the Laurasian

diatrymids (left) and the South American phorusrhacids - 2 meters tall with cruel curved beaks, that mimicked the great theropod dinosaurs of the Mesozoic. All these animals lived in tropical forests. The champsosaurs, crocodile-like "eosuchian" reptiles - living fossils of their time - survived the dinosaurs and the K-T extinction but died out later in the Paleogene. In the seas the first archaic toothed whales appeared. Giant marine protozoa, (foraminifers) the size of lentils evolved during the Eocene. Bivalve and Gastropod molluscs were basically the same type as today. The nautilids experienced their last mild evolutionary radiation. Transitional forms ancestral to modern coleoid cephalopods evolved. Echinoderms, corals, bryozoa and sponges were basically of modern type. On land insects were generally of modern type. Ants were even more numerous then they are today.



During the Neogene modern mammals and flowering plants evolve, as well as many strange mammals that are no longer around. The most astonishing thing to happen during the early Neogene was the evolution of grass. This led to the evolution of long-legged running animals adapted to life on the savanna and prairie. The horse family - Equidae - was an especial success story during the Neogene. Horses and other grazing mammals evolved high-crowned teeth to cope with a diet of abrasive grass. There were still many forest animals however. The Mastodons lived on every continent except Australia. Many strange mammals - litopterns, notoungulates, ground sloths, borhyaenids, etc - continued to evolve in isolation in Hominids appeared in the Africa savannas, the Australopithecines. The oceans were inhabited by whales basically like modern forms, which had replaced the archaic toothed whales. They were the most intelligent animals of their time, but they never developed the use of tools or a memetic noosphere. In the north Pacific were the Desmostylids - a sort of cross between an elephant and a seal. Also in the seas were the largest carnivorous sharks ever to live - the ***Carcharodon megalodon***, a predecessor of the modern White Pointer but much larger and heavier.

Megaceros

The Pleistocene period saw essentially modern flora and invertebrate species. However many mammalian types were of species and genera now extinct, and generally of large size - the various species of mammoth, the Irish "elk" (left), a large diversity of rhinos, the giant ground sloths, the diprotodonts of Australia, and many more. Man evolved as an ice-age mammal in Europe. A combination of human hunting ("stone age overkill") and climatic change served to kill off most worlds megafauna.

Links

Introduction to the Cenozoic - a short introduction at the University of California Museum of Paleontology site

Walking With Prehistoric Beasts -- Discovery Channel -- a non-technical look at the age of mammals, with photo-realistic computer reconstructions of a number of extinct species

Buy the DVD (a wonderful sequel to the ***Walking with Dinosaurs*** DVD - excellent computer special effects recreate the animals of the Cenozoic, from the early Eocene to the Pleistocene)

The Age of Mammals - from Biology 65: Biodiversity and Conservation

Cenozoic Era - a good summary

Cenozoic Mammals: Guilds and Trends - annotated links page from Richard Cowen's History of Life site

Geography and Evolution - annotated links page from Richard Cowen's History of Life site

DVD

Walking With Prehistoric Beasts - DVD also in VHS - by the team that brought you ***Walking With Dinosaurs***

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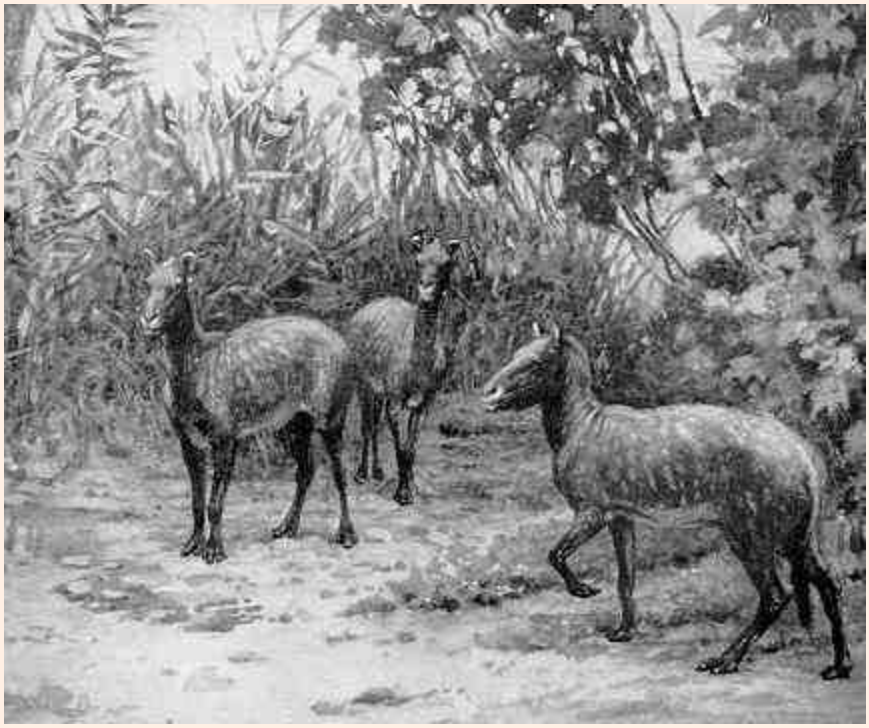
The Paleogene

The Paleogene Period of the Cenozoic Era: 65.5 to 23.0 million years ago

Mesozoic
  Triassic
  Jurassic
  Cretaceous
Cenozoic
  Paleogene
    Paleocene
    Eocene
    Oligocene
  Neogene



Hyracotherium (Eohippus) - a cat-sized ancestor of the horse

The Paleogene is divided into three epochs, the Paleocene, Eocene, and Oligocene. During this relatively short span of time (about as long as the Triassic), the continents began to take on their present form. General cooling and drying began before the end of the Oligocene, but was probably not a major factor until the middle Miocene. The Paleogene might be thought of as an extension of the Mesozoic -- but with mammals.

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The Paleocene

The Paleocene Epoch of the Paleogene Period: 65.5 to 55.8 million years ago

Mesozoic
- Triassic
- Jurassic
- Cretaceous
  - Early Cretaceous I
  - Early Cretaceous II
  - Late Cretaceous I
  - Late Cretaceous II

Cenozoic
- Paleogene
  - Paleocene
    - Paleocene Mammals
  - Eocene
  - Oligocene
- Neogene

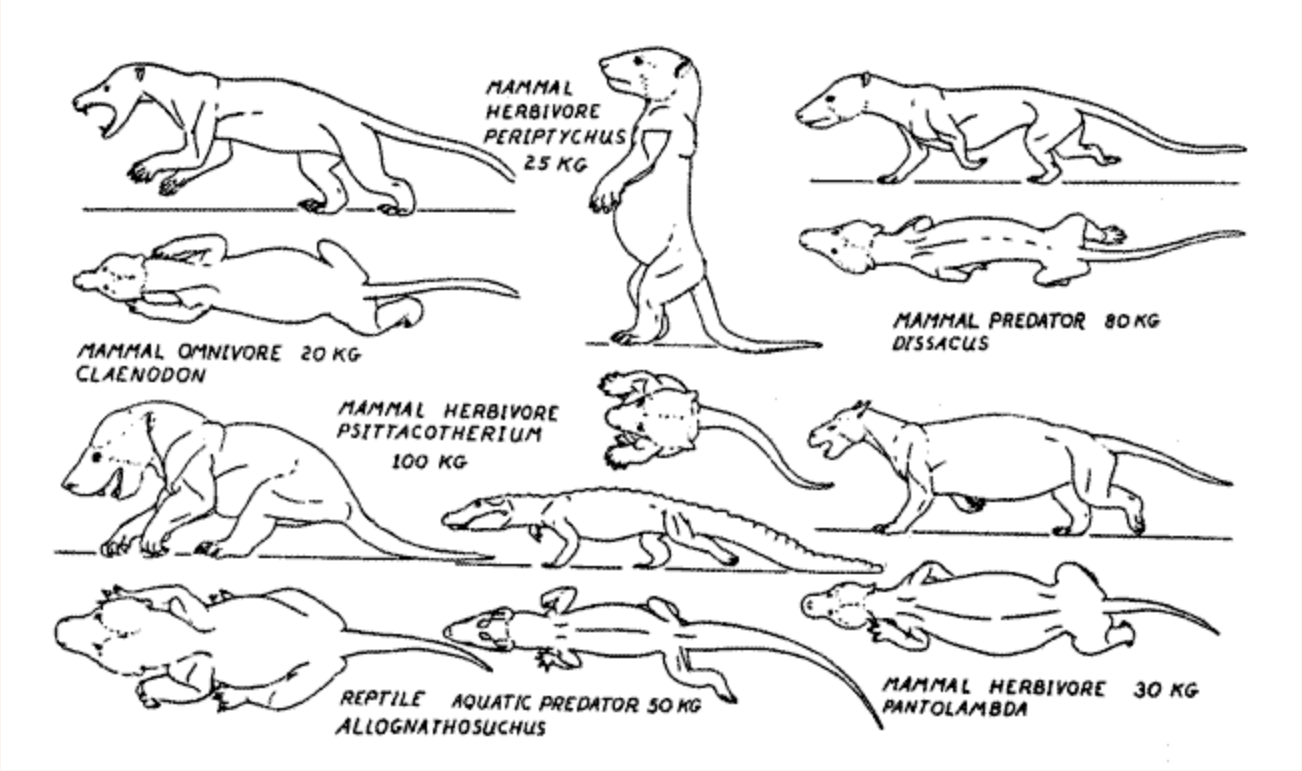
In the early Paleocene, dense forests extended to higher latitudes. This scene is from the Early Paleocene of Wyoming. The vegetation included sequoia trees, with a dense undergrowth of shrubs such as tea and laurel, with the addition of ferns and horsetails. On the ground is *Chriacus*, a racoon-like omnivore. Facing Chriacus on the tree is *Ptilodus*, a surviving member of the multituberculates, primitive mammals often termed the "rodents of the Mesozoic. " Higher up in the tree is Peradectes (the name means "persisting biter"), an early opossum-like marsupial. Marsupials became extinct in North America by the Oligocene, and did not reappear until true opossums invaded from South America in the Pleistocene.

Image and caption both from *The Book of Life: An Illustrated History of the Evolution of Life on Earth*

The Paleocene ("ancient recent life") epoch marks the beginning of the Paleogene Period and the Cenozoic era. The sea-level fell to expose dry land in much of inland North America, Africa, and Australia. South America however was cut adrift with its own unique evolving "ark" of birds, mammals, and reptiles.

At sea, gastropods and bivalves were very similar to modern forms. Soft-bodied squid replaced the hard-shelled ammonites as the leading molluscs. New kinds of sea urchins and foraminifers replaced Mesozoic types that had been killed off in the great terminal Cretaceous extinction. Among fishes, sharks seem to have been particularly plentiful.

On land, many new types of mammals appear in a dramatic evolutionary radiation, filling the ecological roles vacated by the dinosaurs. But compared to the majestic Cretaceous megafauna, these animals were puny. No Paleocene mammal exceeded the size of a small modern bear, and most were a lot smaller. They were all short-legged and plantigrade (walking on the soles of their feet), and they had five toes on each foot, a primitive feature. Most or all have fourty-four low crowned teeth, another primitive feature. Almost all of them had slim heads with narrow muzzles and small brain cavities. In terms of brain to body weight ratios they were well below late Cenozoic mammals. A number of typical Paleocene mammals are shown in the following sketch by Dr Bob Bakker.



A Paleocene bestiary - archaic mammals and a reptile

illustration from Robert T. Bakker, "The Need for Endothermic Archosaurs",

in R.D.K.Thomas and E.C.Olson, eds, ***A Cold Look at the Warm Blooded Dinosaurs***, AAAS Selected Symposium 28, p.366

The predominant mammals of the period were members of groups that are now extinct. These included the flesh-eating Mesonychia, such as ***Dissacus*** (=***Hyaenodictis***) known from the Middle Paleocene Middle Eocene of Europe, East Asia, and North America [family Mesonychidae], which were actually (believe it or not) ancestral to the whales; and Creodonta; and the mostly herbivorous Condylartha (e.g. ***Periptychus*** (top center) - early Paleocene of North America, family Periptychidae)), which first appeared in the guise of the latest Cretaceous ***Protungulatum***, and were light-bodied animals; and the pantodonts such as ***Pantolambda*** (middle Paleocene of North America - family Pantolambdidae) and Dinocerata, which were as yet still small to medium-sized, but heavy-bodied animals, all with small brains. Other Paleocene groups included Cretaceous survivors such as the multituberculates, the marsupials, and several groups of the insectivores and insectivore-like mammals, and the Plesiadapiformes, a group of squirrel-like animals more or less transitional between insectivores and primates. Other Paleocene mammals included two unrelated groups of large clumsy herbivores, the Tillodonts and the Tainodonts, the latter group including ***Psittacotherium*** (bottom left, middle Paleocene of North America, family Stylinodontidae). Also living at this time, but still insignificant, were the first representatives of the rodents and the Miacidae, the ancestors of modern Carnivora.

By the start of the Tertiary the present continental land masses were largely separate, and so independent evolutionary radiations of mammals took place in these relatively isolated areas). This allowed the well-known marsupial fauna of Australia to develop. Until the end of the Tertiary, South America was similarly isolated from the north and likewise developed a unique fauna. Until the middle Tertiary the faunas of Africa were also clearly distinct from those of Eurasia.

Many Paleocene mammals seem to have developed in northern Asia and migrated from there to the rest of Asia, to Europe and to North America, these made up the typical Laurasian fauna of the time. The Paleocene inhabitants of the scattered continents of Gondwana are only poorly known, if at all. As mentioned, South America-Antartica-Australia, New Zealand, India, and Africa, were all isolated from each other and from other parts of the world, and served as island arks and centers of evolution where unique types of placental mammals, marsupials, monotremes, birds, reptiles, and in the case of New Zealand the last surviving Sphenodontia, were able to develop in safety.

The Paleocene carnivorous mammals of Laurasia had to share their world with giant flightless birds of prey like ***Diatryma*** and it's cousins (order Diatrymiformes), which appear suddenly during the late Paleocene and continue through to the Middle Eocene. Standing 2 meters or more in height and weighing in at around 200 kg, these large-beaked birds were the biggest and fiercest animals on land for some five or ten million years. In South America similar giant predatory birds, the Phorusrhacids, are known from the

Eocene but most probably likewise evolved during the Paleocene. These great birds were the last successors of the mighty theropod dinosaurs of the Mesozoic.

Paleocene symmetrodont-like mammal
Chronoperates paradoxus Fox, Youzwyshyn & Krause 1992,
described in *Nature* **358**:233-235.
from The UALVP Collections page (former page)

Originally described as a cynodont (mammal-like reptile), but H.D. Sues found it compares more closely with a symmetrodont mammal

Paleocene Epoch	Thanetian
	Danian

Resources

Web Links

The Paleocene Epoch - best overall intro

Paleocene mammals of the world - Martin Jehle's superb coverage of Paleocene Mammals - **Best on the Web**

Paleocene epoch- mirror - short intro

The Paleocene - short intro

The Fossil Record of North American Mammals: Evidence for a Paleocene Evolutionary Radiation - John Alroy

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Paleocene Mammals

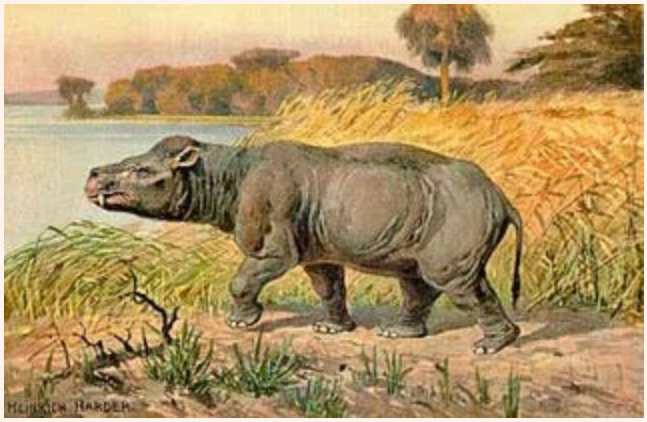
Mesozoic
- Triassic
- Jurassic
- Cretaceous
  - Early Cretaceous I
  - Early Cretaceous II
  - Late Cretaceous I
  - Late Cretaceous II

Cenozoic
- Paleogene
  - Paleocene
    - Paleocene Mammals
  - Eocene
  - Oligocene
- Neogene

Life in the Palaeocene - We Don't Need No Placentalia?

by
Christopher Taylor

from Catalogue of Organisms blog, original url



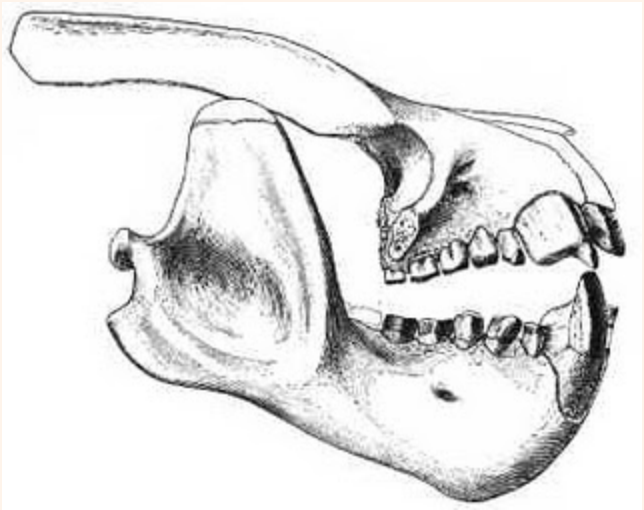
The pantodont Coryphodon***, as reconstructed by Heinrich Harder. At the time of their existence,***

pantodonts were the largest herbivorous mammals. According to Wikipedia, Coryphodon ***reached about a metre in height and a weight of half a tonne, and also had the dubious distinction of having the smallest brain/body weight ratio of any mammal living or extinct.***

Sixty-five million years ago last Tuesday, the mighty dinosaurs went extinct. Well, they didn't ***all*** go extinct, but that's how it's usually expressed because "the mighty dinosaurs went extinct except for a number of volant clades that actually continued to do pretty well for themselves, really" somehow just doesn't have quite the same ring to it. What remains a fact is that something pretty significant happened to the ecosystem at the end of the Cretaceous, leading to a major turnover that's usually represented as out with the dinosaurs, bring in the mammals. It is true that the mammals showed a significant rise in diversity during the Palaeocene, the time period immediately following the Cretaceous. However, few of the prominent mammalian groups of the time would be recognisable today.

Modern mammals are divided between monotreme, marsupials and placentals. It is the Placentalia (the group we ourselves belong to) that have been the most successful of the three groups overall, a success that has generally been attributed to their reproductive system of nourishing developing foetuses for longer periods and giving birth to more developed young*. When the fossil record is actually taken into account, Placentalia are a subset of a larger group called Eutheria. Eutherians are the total group containing placentals and all fossil mammals more closely related to placentals than marsupials, while placentals are the crown group of the eutherian lineages that have survived to the present.

*Whether this is ***really*** the secret of the placentals' success is more debatable than generally let on. For instance, it has been suggested that in highly unpredictable environments such as the arid centre of modern Australia, marsupials, with their lower nutrient commitment to developing offspring, may actually have the edge reproductive system-wise.



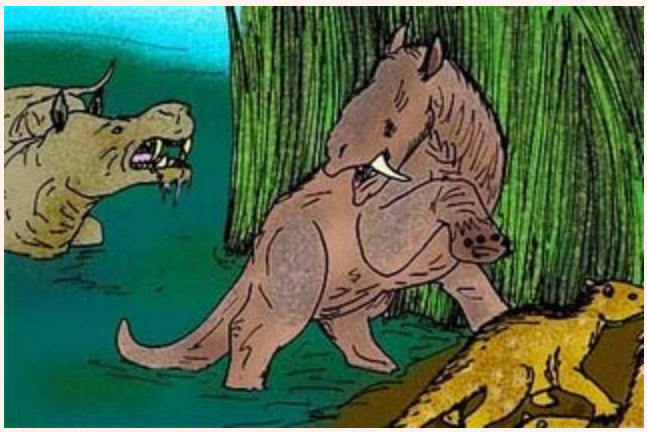
Skull of the taeniodont Psittacotherium***, from Matthew (1937) via Paleocene Mammals. Late Palaeocene taeniodonts developed massively powerful jaws and cutting teeth.*** Psittacotherium ***was one of the most extreme forms, and at a weight of about 50 kg would have been comparable in size to a medium dog.***

The eutherian and marsupial lineages had separated from each other by the early Cretaceous, but the question of when the modern placentals arose has been a hotly debated topic. While a number of Cretaceous lineages have been suggested to belong to the Cretaceous crown group - Zhelestidae as relatives of the ungulates (hoofed mammals), while Zalambdalestidae were close to rodents and lagomorphs (Archibald ***et al.***, 2001) - recent analyses have placed these taxa outside the placental crown, and the fairly comprehensive analysis by Wible ***et al.*** (2007) suggested that none of the fossil eutherians known from the Cretaceous are placentals. This stands in fairly stark contrast to molecular dating studies, which are fairly unanimous in suggesting that the modern placental orders diverged from each other during the Cretaceous. Either the molecular dating is all wrong for some reason, or the placentals were around in the Cretaceous and we just haven't found them yet.

Still, whether it was the ancestors of the placentals or a number of lineages that survived the end of the Cretaceous, the fossil evidence indicates at least four eutherian lineages survived into the Palaeocene. The Cimolestidae and Leptictidae, families present in both the Cretaceous and the Palaeocene, were placed by Wible ***et al.*** (2007) outside the placentals, while the Taeniodonta, a eutherian lineage of unknown

relationships, was represented in the late Cretaceous by the species ***Schowalteria clemensi*** (Fox & Naylor, 2003). Whether the various other lineages known from the Palaeocene diverged from these lines after the end of the Cretaceous or also survived from earlier times is a decidedly open question.

As already indicated, few of the Palaeocene eutherians can be related directly to modern placental orders. Instead, the Palaeocene was the time of a number of lineages that are no longer with use - herbivores such as the pantodonts and dinocerates, small insectivores such as apatemyids and leptictids, carnivores such as creodonts and arctocyonids. Martin Jehle's Paleocene Mammals website has detailed coverage of many such groups. Palaeocene mammals were also quite distinct from modern taxa in the overall range of morphologies - for want of a better way to put it, Palaeocene eutherians tend to look - well - ***lumpier*** than modern species. The broad grasslands that currently dominate the terrestrial part of the world were not yet in existence, and the Palaeocene was a time of forests. As a result, the grassland-adapted cursorial morphologies like modern horses and antelope were also absent, and the low-slung waddler was king.



The early dinocerate Prodinoceras xinjiangensis***, as reconstructed by Stanton Fink.***

So how did these Palaeocene waddlers relate to the modern taxa evolutionarily? The only answer we can really give at this point is, who knows? The relationships between the Palaeocene and the modern eutherian orders remain almost completely unknown, and those few connections that have been accepted in the past have been profoundly shaken. For instance, many of the Palaeocene families have been included in the 'condylarths', a heterogeneous assemblage believed to be related to the modern ungulates. However, it has become well established in recent years that the ungulates represent at least three separate lineages, with the artiodactyls (even-toed hoofed mammals), perissodactyls (horses and rhinoceros) and paenungulates (elephants and hyraxes) all arising from separate ancestors in the placental tree. Which condylarths are related to which modern ungulates? For that matter, are they related to any of them? If the ungulate morphology arose at least three times in lineages that survived to the present, why should we assume that it couldn't have also appeared independently in extinct lineages? Similar issues surround Palaeocene 'insectivoran' families, whose association with possibly polyphyletic modern insectivorans should be regarded as doubtful.

In light of the findings of Wible ***et al.*** (2007), we might even doubt whether many of the Palaeocene eutherians even represent placentals. The classification of McKenna and Bell (1997) united many early eutherians such as Cimolestidae, Pantodonta and Taeniodonta (as well as the modern pangolins) into a group called Cimolesta, which was then included in the Ferae with creodonts and Carnivora. While pangolins may indeed be related to carnivorans, Cimolestidae, as referred to above, are not even placentals. What then becomes of the rest of the "Cimolesta"? Are they also stem-eutherians like Cimolestidae, or are they true placentals?

Such questions are not mere curiosities - the answer could have significant effects on our understanding of Palaeocene ecology. At least some stem eutherians such as the Zalambdalestidae possessed epipubes, bones that support the pouch in marsupials but are absent from placentals (Kielan-Jaworowska, 1975). Because of the restrictions epipubes place on the expansion of the abdomen, they may be incompatible with a placental reproductive system. As a result, we cannot assume that stem eutherians bore well-developed young like modern placentals do. Did pantodonts walk around with pouches slung from their bellies?

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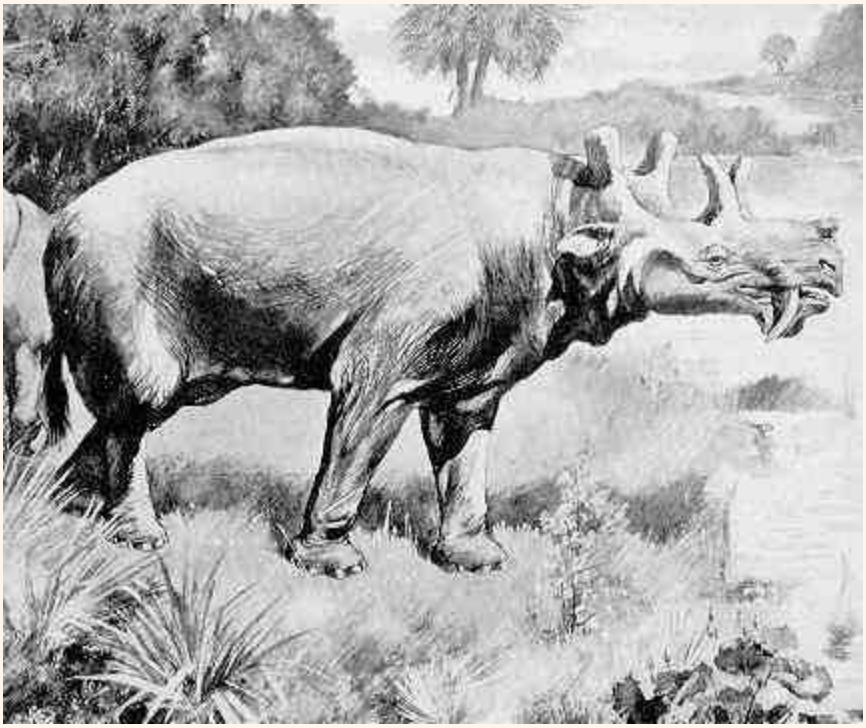
The Eocene

The Eocene Epoch of the Paleogene Period: 38-54 million years ago

Paleogene
  Paleocene
  Eocene
  Oligocene
Neogene



Eobasileus, a 6-horned rhinoceros-like animal that stood 2 meters at the shoulder. It was one of many types of early mammals that flourished in the tropical Eocene. Like the dinosaurs before it, it's brain was tiny in proportion to its massive body.

illustration by Charles R. Knight - from Early Image - public domain images

The name Eocene means the "dawn of recent life" Originally the Eocene was the first epoch of the Cenozoic, but then the Paleocene was erected as an earlier epoch. Life during the Eocene was pretty similar to that of the Paleocene, a warm tropic world, high sea-levels and island continents, invertebrates and plants similar to those today, while mammals continue to evolve and diversify along many lines

Plate Tectonics

The rifting of the North Atlantic cut off North America from Europe, and South America lost links with Antarctica. India and Scotland were home to mountain-building episodes. The sea-level rose and seas invaded much of Africa, Australia, and Siberia.

Climate

Climates were generally warm or mild worldwide. Tropical palms flourished as far north as the London Basin. The unusual mixture of tropical and subtropical elements in the northern latitudes in the Eocene suggests that the mean annual temperature of these regions was not as high as in the present tropics, but that the flora was maintained by a greater rainfall than occurs in these northern latitudes today, with no pronounced seasonality in its distribution, and by the absence of winter frost.

Plant Life

Changes in vegetation during the Eocene epoch were limited chiefly to the migration of types of plants in response to climate changes.

Animal Life

Mesonyx, an early carnivore of the order Creodonta .

illustration from Early Image - public domain images

The mammals continue to diversify, and the various archaic fauna flourished. Creodonts and amblypods (including the spectacular and ungainly Uintatheres of North America and Asia) continued to develop during the epoch

The Eocene saw the appearance of a number of direct evolutionary ancestors of modern animals.

The ancient hoofed condylarths gave way to more modern ungulates, and became extinct before the end of the epoch. The modern hoofed mammals - perissodactyls and artiodactyls - of Europe, Asia and North

America, included proto- horses, tapirs, rhinoceroses, and camels, as well as extinct groups like the pig-like anthracotheres, horse-like chalicotheres, and rhinoceros-like Titanotheres. They were all small to begin with, about the size of a modern domestic cat, but some groups, especially the Titanotheres, quickly grew to huge size, before suddenly dying out in a mass-extinction of archaic forms at the end of the Eocene (it used to be believed that Titanotheres lived on to the Early Oligocene but modern dating shows this to be incorrect).

The rodents replaced the multituberculates in the small gnawing herbivore guild. Bats not unlike modern types appeared, evolving from primitive Insectivora. Primates including forest-dwelling ancestors of today's lemurs and tarsiers flourished in the trees.

The first aquatic mammals, whales and sea cows appeared in the oceans. The whales belonged to an extinct lineage called Archaeocetes, and quickly grew to huge size (***Zeuglodon*** (more correctly ***Basilosaurus***, a confusing name because this was a mammal not a reptile) attained 20 to 25 meters in length.

The Eocene saw the appearance of modern birds such as eagles, pelicans, quail, and vultures, as well as the great flightless Diatrymiformes, 2 meters or more in height, with a huge hooked beak that clearly indicated carnivorous habits. Such giant flightless birds, curiously reminiscent of their ancestors, the great theropod dinosaurs of the bygone Mesozoic, may have been able to develop because carnivorous mammals remained primitive and not very efficient.

Africa was separated by ocean on all sides, which allowed the development of a unique fauna in isolation from Europe, Asia and North America. There evolved not only the ancestors of elephants but also the hyrax, the monkey, and strange extinct forms such as the rhinoceros-like Embrithopods.

South America was another isolated island continent. It became home to a unique zoo of hoofed mammals, edentates, marsupials, and more giant flightless birds (Phorusrhacids).

Australia's fauna at this time is unknown, but would presumably consist of various indigenous marsupials, monotremes, crocodilians and lizards.

<table>
<tr><th>Epoch</th><th>Sub-epoch</th><th>Standard Age (base)</th><th>European Land Mammal Age (approximate correlation)</th><th>North American Land Mammal Age (approximate correlation)</th><th>representative animal</th></tr>
<tr><td>Oligocene</td><td></td><td>Rupelian (33.9)</td><td></td><td>Orellan</td><td></td></tr>
<tr><td rowspan="5">Eocene Epoch</td><td rowspan="2">Late</td><td rowspan="2">Priabonian (37.2)</td><td>Seuvian</td><td rowspan="2">Late Chadronian
Early Chadronian</td><td rowspan="2"> 
Brontotherium</td></tr>
<tr><td>Headonian</td></tr>
<tr><td rowspan="2">Middle</td><td>Bartonian (40.4)</td><td>Bartonian</td><td>Late Duchesnean
Early Duchesnean</td><td>no image yet...</td></tr>
<tr><td>Lutetian (48.6)</td><td>Lutetian</td><td>Late Uintan
Early Uintan</td><td> 
Uintatherium</td></tr>
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Middle Bridgerian
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The Oligocene

The Oligocene Epoch of the Paleogene Period: 33.9 to 23.0 million years ago

Paleogene
- Paleocene
- Eocene
- Oligocene

Neogene
- Miocene
- Pliocene
- Pleistocene
- Holocene

A ***Hoplophoneus***, an early saber-tooth cat, stalks a group of early horses.
The grey somewhat mouse-like (at least in this drawing!) looking animal
to the right is ***Archaeotherium***, an entelodont.
image from American Museum of Natural History - Timelines Exhibit (former page)

The Oligocene Epoch (meaning "slightly recent") was the third and youngest division of the Paleogene, and the characterized by an increasing proportion of "modern" animals.

Plate Tectonics

There was an increase in volcanic activity, and plate tectonic movement, as India collided with Asia. The last remnant of the supercontinent of Gondwanaland broke up as Australia and South America both separated from Antarctica

Climate

The Oligocene also marked the start of a generalized cooling, with glaciers forming in Antarctica for the first time during the Cenozoic. The increase in ice sheets led to a fall in sea level. The tropics diminished, giving way to cooler woodlands and grasslands. Although there was a slight warming period in the late Oligocene, the overall cooling trend was to continue, culminating in the Ice Ages of the Pleistocene.

Plant Life

By the Oligocene the major evolution and dispersal of modern types of angiosperms had occurred. The vegetation of the higher latitudes in the northern hemisphere changed from an essentially broad-leaved tropical evergreen forest such as had typified the Eocene, to a temperate deciduous woodland of evergreen and broad-leaved trees. This type of woodland is seen today only in certain relict areas like the North Island of New Zealand and the tip of the South African Cape. Grasses, which appeared for the first time as plants of water margins in the Eocene, became more common in open habitats.

In North America the flora consisted of a mixture of subtropical elements, such as cashews and lychee trees, with temperate trees such as roses, beech and pine. Leguminous plants of the pea and bean family were common, as were sedges, bulrushes and a variety of ferns.

Animal Life

Mesohippus bairdi, a browsing, short-necked, three-toed Oligocene horse (Perissodactyla, Equidae). It fed on leaves (not grass) stood about 55 cm tall.

illustration from Early Image - public domain images

In the seas the Nummulitid foraminifera continue with some abundance. The genus ***Lepidocyclina*** replaces ***Orthophragmina***. Irregular echinoids such as ***Scutella*** and ***Clypeaster*** first appear

Following the terminal Eocene extinction which took out the Dinocerata, Archaeoceti, and most of the Titanotheres and creodonts, new kinds of mammals evolved and expanded in an evolutionary radiation of many new types. These included the prehistoric ancestors of dogs, cats, rhinoceroses (including both small slender running types and hippo-like semi-aquatic forms), and horses (such as Mesohippus, above).

But the most important transition among terrestrial mammals involved the artiodactyls (even-toed ungulates) taking over from the perissodactyls as the dominant medium-sized herbivores in the middle Tertiary. These included the most common animals of the period, the sheep-like oreodonts which flourished in huge numbers. Meanwhile the omnivorous niches were filled by giant pig-like entelodonts like ***Archaeotherium*** (shoulder height 1 metre), which retained short legs and low-crowned teeth.

While artiodactyls appeared in the late Paleocene, they remained rare, and it was only during the

Oligocene that advanced forms (the first camels) developed a rumen, a complex fore-stomach that aids in the digestion of cellulose. This provided these animals with a great advantage in dealing with a fibrous diet, such as was appearing with the vegetation of the time, and would become even more important during the rest of the Cenozoic as the world continued to become drier and cooler.

illustration by Charles R. Knight - from Early Image - public domain images

The largest animals remained - as in the late Eocene - the perissodactyls. The huge hornless rhinos (***Indricotherium*** - weight 15 to 25 tonnes) of central Asia was the largest land mammals ever to live, matching even the great sauropod dinosaurs in size. These enormous beasts continued for some fifteen million years in Asia, surviving until the Mid Miocene

Meanwhile, ancestral elephant-like forms and the rhinoceros-like Arsinoitheres grew to large size in Africa, where the first anthropoid apes appeared as well.

In South America, completely different herbivores evolved, the Edentates (sloths, armadillos, etc), the strange Meridiungulates, and, in view of the absence of placental carnivores, various lines of marsupial predators and the giant flightless flesh-eating Phorusrhacids birds - 1.5 meters and more in height.

Little is known of life in Australia and Antarctica at this time.

Stratigraphy

Oligocene Epoch	**Chattian**
	Rupelian

Resources

Links

The Oligocene Epoch

Oligocene

Oligocene epoch - mirror

The Terrestrial Eocene-Oligocene Transition in North America **ed. by Donald R. Prothero and Robert J. Emry**

The Eocene-Oligocene Transition **by Donald R. Prothero (The Critical Moments and Perspectives in Paleobiology and Earth History Series)**

The Oligocene Bridge Creek Flora of the John Day Formation, Oregon **by Herbert W. Meyer, Steven R. Manchester (University of California Publications in Geological Sciences, Vol 141)**

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The Neogene

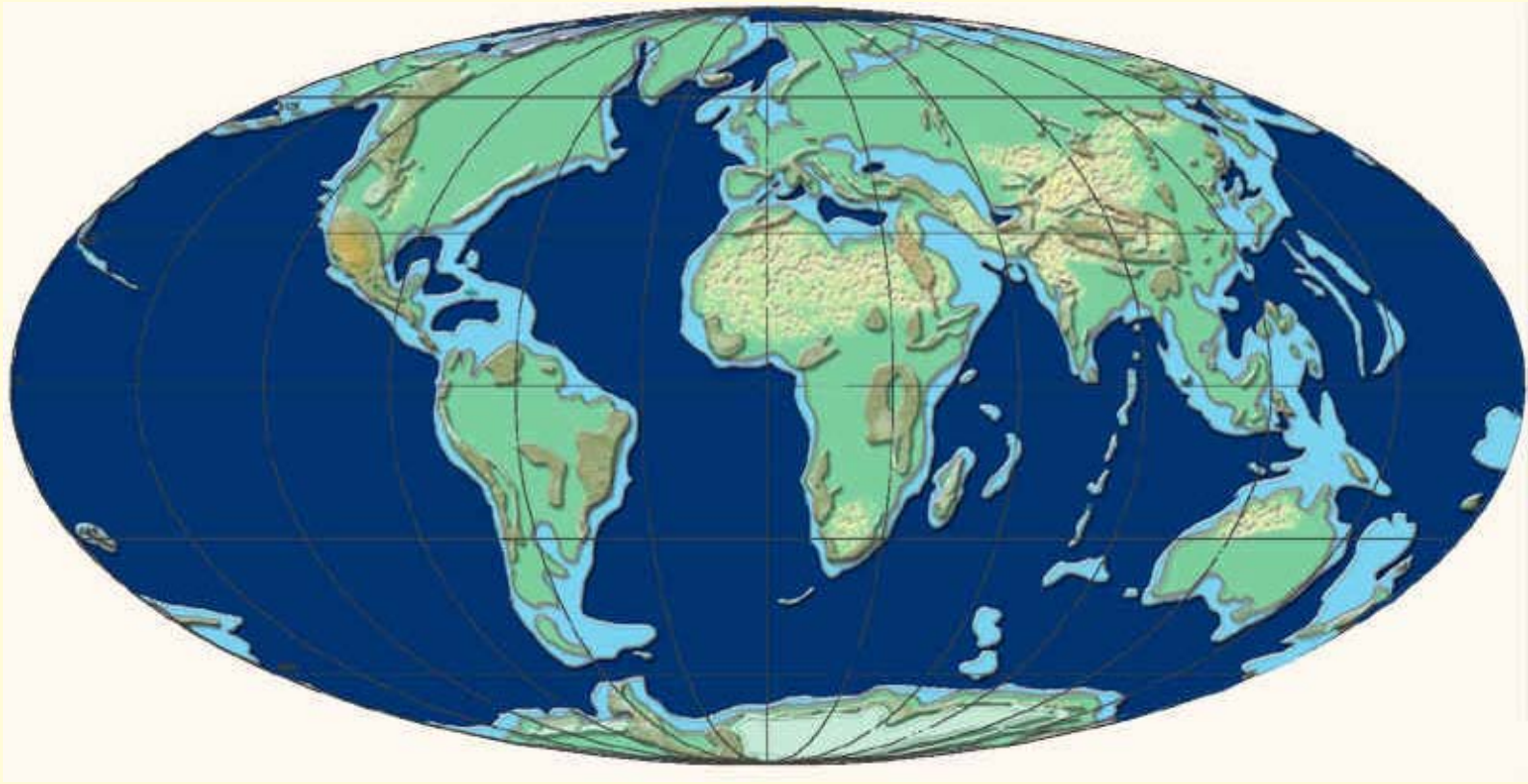
The Neogene Period of the Cenozoic Era: from 23.0 million years ago to the present

An Age of Grasses

Cenozoic
Paleogene
Neogene
Miocene
Pliocene
Pleistocene
Holocene

Geography
Climate and adaptations
Links

Neogene Geography



The Neogene world (Middle Miocene)
after DinoData: Maps of Jan Golonka

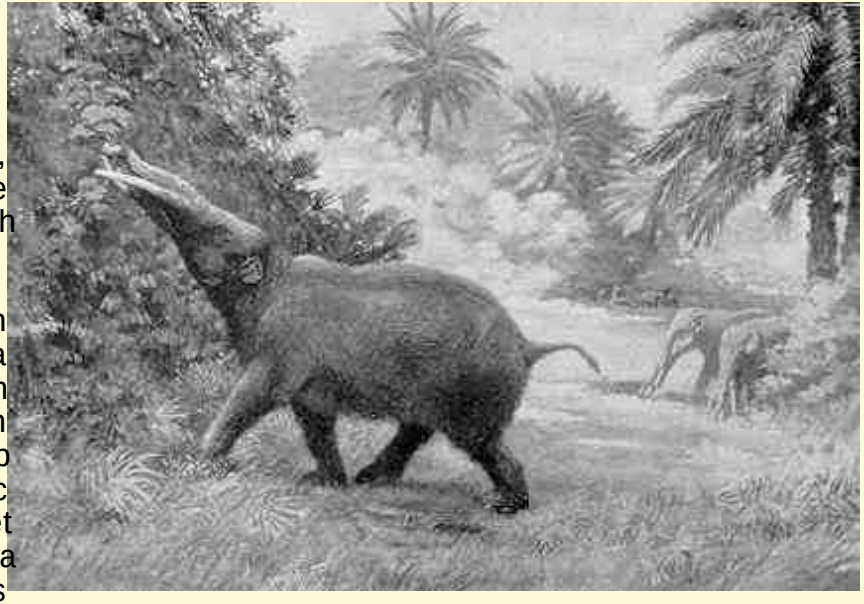
The Neogene Period traditionally comprised the Miocene and Pliocene Epochs. Recent changes by the ICS appeared to eliminate the Quaternary, so that the Neogene included the Pleistocene and Holocene. Even more recently (2005-06), the ICS has indicated it will reanimate the Quaternary as a sort of stratigraphic Frankenstein assembled from ill-fitting spare parts, "gigantic in stature, yet uncouth and distorted in its proportions." However, in doing so, the ICS proposes to preserve the extension of the Neogene to the Present.

Not surprisingly, the Neogene globe looks much like our own. However, the relatively similar topology masks some dramatic changes. One of the best known is the Messinian salinity crisis at the Miocene Pliocene boundary. In the Western Mediterranean, the Alboran Arc, a small subsea plate, drifted west, up against both Spain and North Africa. At the same time, deep magmatic upwelling slightly raised the profile of the entire region. As geologic events go, this was not front-page news. However, the collision sealed the western end of the Mediterranean for about 600,000 years. During this time, the Mediterranean Sea virtually dried up. On the other side of the African continent, three major rifts opened in roughly an east to west sequence: the Aqaba-Levant rift (today's Gulf of Aqaba), the Red Sea, and, late in Neogene time, the Afar Rift Valley where our own genus was born in the Late Pliocene.

These events were probably related to the counterclockwise rotation of the Arabian Plate and the continuing impact of India. During the Neogene, the Indian Plate was deflect from its northerly drift towards the north-west. Presumably the turn resulted from its impact with China and Asia. Crustal thickening under the Himalayas reached a maximum during the Pliocene, although the mountains continued to grow (as they are still growing today). The Neogene westerly component caused mountain building forces in Central Asia, raising the Caucasus and eventually draining most of the Caspian Ocean.

To some degree these events were mirrored in Europe, where Calabria (Italy) apparently underwent some complex combination of clockwise rotation and northeasterly translation, opening the Tyrrhenian Sea and stapling the Italian peninsula to the European mainland. At the same time, an important episode of mountain-building created the Alps to the north, and completed the Carpathians and Zagros mountains to the northeast.

To the other side of India, Late in the Neogene, the Australian plate finally made contact with Asia, eventually raising the island of New Guinea. Jostling among other microplates accreting to the Asian



mainland resulted in the formation of Taiwan, various Indonesian islands, the Kuril Islands, and the Philippines, as well as contributing to the growth and rotation of Japan.

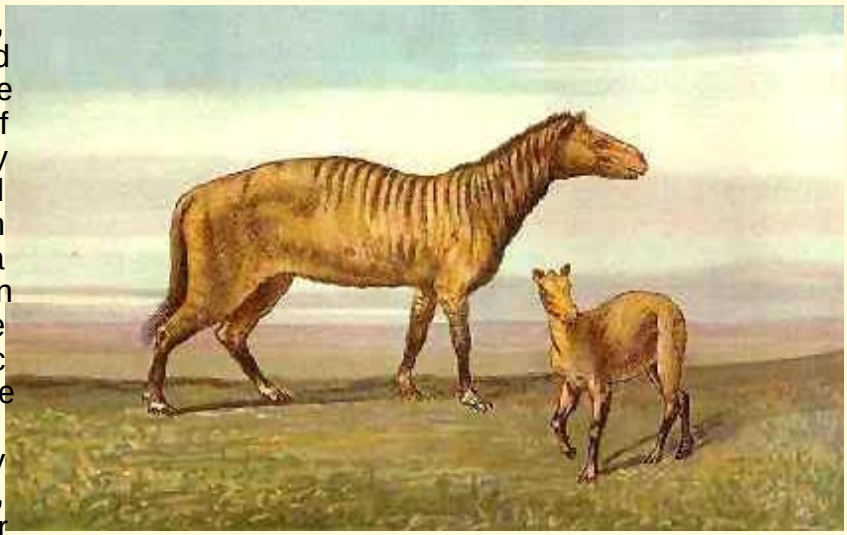
In North America, low sea levels, particularly in the Mid-Miocene, and the accumulation of a permanent North Polar ice cap allowed at least an intermittent bridge to remain between North America and Greenland. The North Polar ice cap was restricted to the shallow waters of arctic Canada and Greenland and probably did not yet reach the pole itself. Iceland emerged from a North Atlantic volcanic hot spot late during this interval. In western North America, north-south faulting, with east-west stretching and thinning of the crust occurred through a basin in Nevada, Arizona and Southern California. The resulting vulcanism is associated with the uplift of the Rocky Mountains on the east and the Sierra Nevadas on the west. The formation of the Sierras, in turn, was associated with the opening of the Gulf of California and major subsidence in the California Central Valley.

Both North and South America were drifting northward. However, South America was moving somewhat faster, and a permanent land bridge between the Americas developed late in the Neogene, probably by the Middle Pliocene. The closing of the Isthmus of Panama isolated the waters of the Gulf of Mexico and separated the marine biota of the east and west coasts.

Part of the reason that South America was moving more rapidly may have been that the Andes were passing over a crustal hot spot. In any event, South America experienced a prolonged period of mountain-building during the Neogene. The earlier stages of Andean mountain building had created a system of lagoons, and later lakes, in the South American interior, and a system of islands in the south. The further development of the mountains in the Neogene drained the lakes and linked most of the islands with the mainland. ATW030901, revised ATW060905.

Neogene Climate and Adaptations:

"Such Strange Creatures"



The Neogene Period spans 22 million years, during which the world became much drier and cooler, culminating in the biotic disaster of the Pleistocene ice ages and the harsh conditions of our own day. During this interval, the relatively uniform and stable climatic regime which had cradled the world's ecosystems for 200 million years, since the Late Triassic, came to a comparatively quick end. Conditions had been deteriorating since the end of the Mesozoic. The Paleogene included times of marked climatic instability that are poorly understood, and the waters near the poles had begun to cool. However, the Paleogene world was still -- by today's standards, at least -- thickly forested, warm, humid, and without strong regionalism or wide seasonal temperature swings.

By the end of the Pliocene, this had all come to an end. The drift of the continents had sealed off the

waters of the far arctic, as the northern margins of Asia and North America crowded together. In the south, Antarctica, now out of contact with any other landmass, was circled by a continuous circum-polar current. Thus both poles were thermally isolated from warm equatorial waters; and (perhaps for the first time since the Ordovician) both poles accumulated heavy coverings of ice. The ice sheets, in turn reflected more sunlight (increased albedo) and lowered sea levels, further reducing temperatures and warm-water circulation. At the same time, the virtual closing of east-west circulation through the Mediterranean Sea and between the Americas isolated those waters, allowing the build-up of hot, circulating currents, conducive to monsoon seasonality.


"... a wide repetoire of behavioral adaptations ..."

The world dried out. Huge deserts developed in North Africa and Central Asia. The deep forests of the continental interiors of the Americas, Asia, Europe, and even Australia were replaced by arid plains, steppe, prairie and tundra. Grasses appeared at the beginning of the Miocene and quickly replaced the thinning forests. But grasses are poor fodder: tough, low in nutrients, high in tooth-destroying silicates. They die back to their roots in cold weather. Under the triple hammers of drought, starvation and cold, herbivorous species were smashed or utterly changed. Their predators followed them into extinction or transformation. The later Neogene saw the creation of an entirely new guild of hunters, the pursuit predator, able to follow scarce prey across miles of open country rather than waiting for the easier opportunity which might never come. The pursued developed their own responses: herd behaviors, seasonal migrations, and big bodies, adapted for speed and endurance.

Another line of adaptation led to small-bodied generalists -- rodents, raccoons, rabbits, and possums -- and their predators, the foxes, cats, dogs and snakes. These generalists were mainly unspecialized herbivores or omnivores, with partially fossorial habits, strong territoriality and high reproductive rates. Theirs was the ability to exploit many resources within small, locally or temporarily favorable conditions, excluding competition and using rapid reproduction as a defense to predation, to quickly take new territory, or to recover from local disasters. These organisms often developed seasonal torpor as a method for surviving seasonal extremes.

A few species do not fall neatly into any of these categories. Humans are one. Bears are another. In one sense, these are hyper-generalists, able to use a wide repertoire of behavioral adaptations to compensate for a conspicuous absence of genetically-endowed talents. In another sense, they are throw-backs to a style of life more common in the Paleogene or the Late Mesozoic. The survival of this group is hard to explain, with so many other, robust lineages disappearing. One wonders what fate an unbiased Pliocene biologist would have predicted for such strange creatures. ATW030901.

Resources

Links

Neogene Marine Biota of Tropical America home page - an online biotic database containing images and data for taxa used in analyses of Tropical American biodiversity over the past 25 million years.

Tertiary Paleogeography: maps and commentary from Robert Blakey on the tectonics of the American Southwest.. Also, don't miss Dr. Blakey's new (2003) **Miocene paleoglobes**.

DVD

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The Miocene

The Miocene Epoch of the Neogene Period: 23.0 to 5.33 million years ago

Paleogene
- Paleocene
- Eocene
- Oligocene

Neogene
- Miocene
- Pliocene
- Pleistocene
- Holocene

Miocene megafauna - horses, rhinos, and (center background) mastodons

image from American Museum of Natural History - Timelines Exhibit (former page)

The Miocene or "less recent" is so called because it contains fewer modern animals than the following, Pliocene, epoch. The Miocene lasted from 18 million years, making it the longest epoch of the Cenozoic era. This was a huge time of transition, the end of the old prehistoric world and the birth of the more recent sort of world. It was also the high point of the age of mammals

Plate Tectonics and Geography

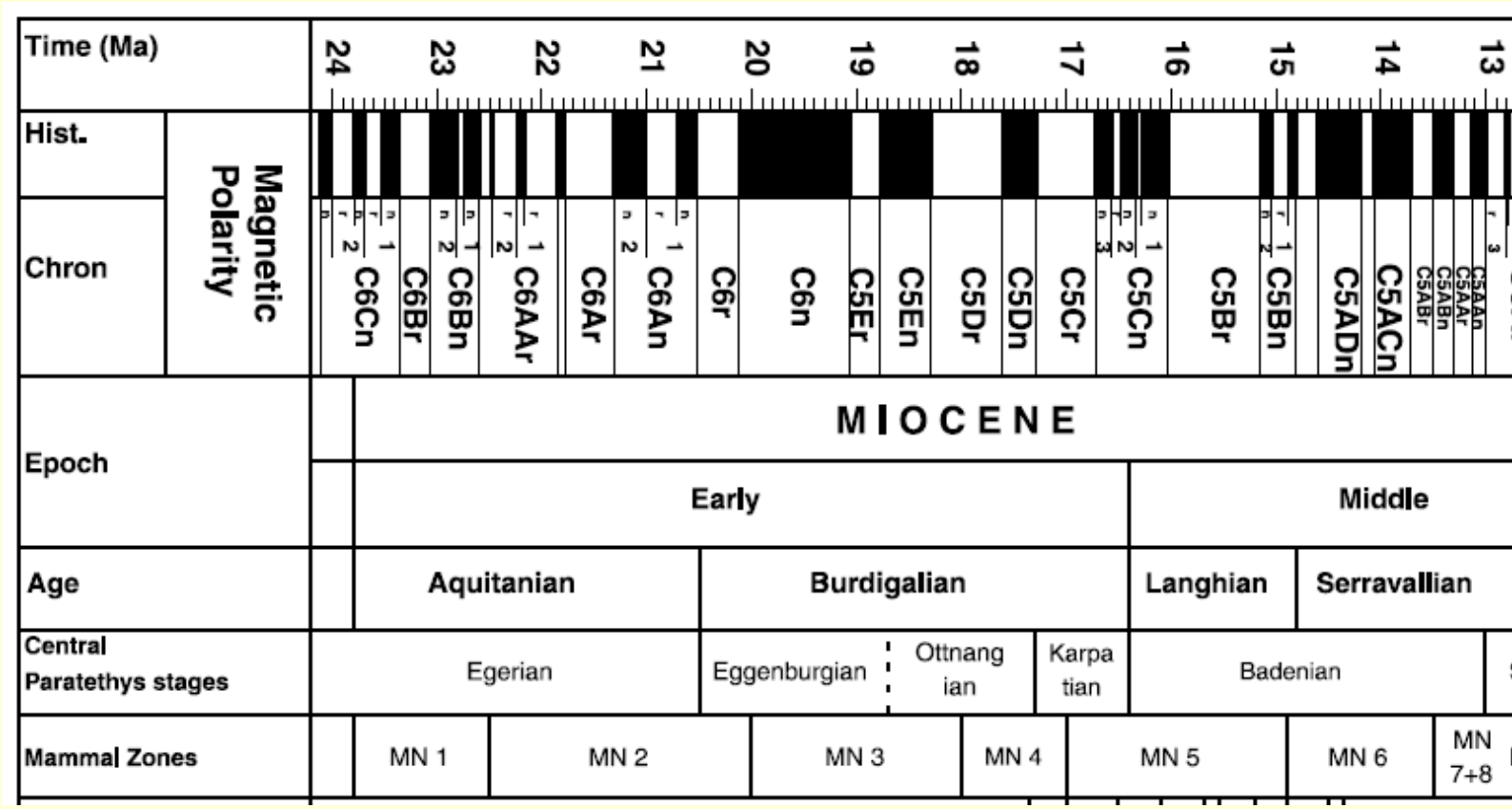
During the late Miocene the island continent of India slammed into Asia, pushing up the Himalayas and triggering a global cooling that was to culminate in the Pleistocene ice ages. Elsewhere the Rockies, and Andes rose as well.

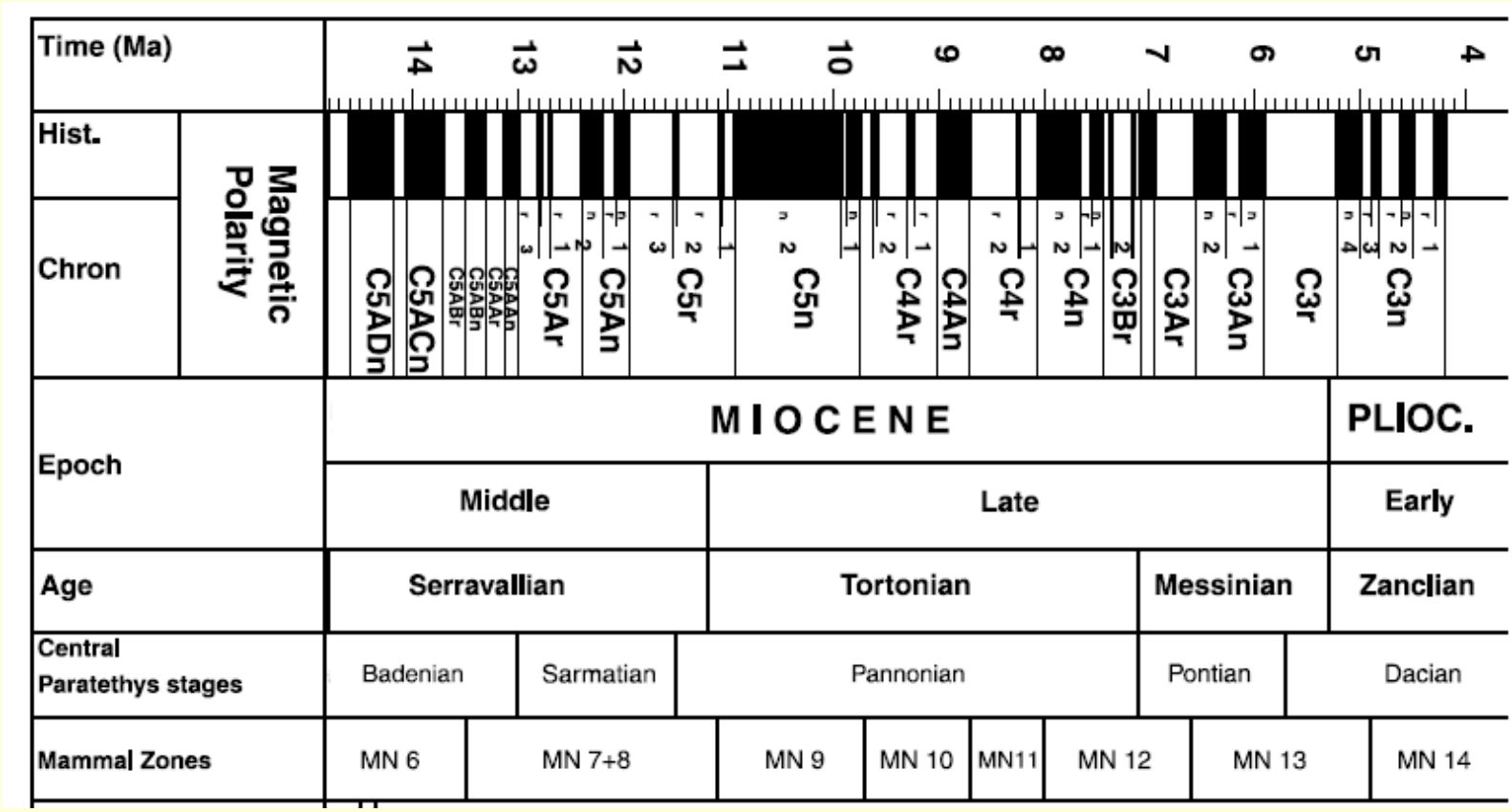
Climate

The Miocene was a time of warmer global climates than those in the preceding Oligocene, or the following Pliocene. During this time modern patterns of atmospheric and ocean circulation formed. The isolation of Antarctica from Australia and South America meant the establishment of the circum-polar ocean circulation, which significantly reduced the mixing or warmer tropical water and cold polar water, and further led to the buildup of the Antarctic ice cap.

Stratigraphy

Miocene stratigraphy is complex because a great many different measures are in common use. These include ICS stages, absolute dates, magnetic polarity reversals ("chrons"), land mammal stages (which differ between continents), and local geological zonation schemes (which differ even more). Below is a table from Böhme (2003), which correlates the systems for Europe. The land mammal stages (MN1 through MN 14) are also used in Africa, and are frequently found in the literature on human evolution. This system is continued through the end of the Pliocene (MN17). For details and definitions, ***see*** Agustí ***et al.*** (2001).





The land mammal schemes for South America and North America are shown, in somewhat less detail, on the Cenozoic Timescale page.

Plant Life

Two major ecosystems first appeared during the Miocene: kelp forests and grasslands. The expansion of grasslands is correlated to a drying of continental interiors and a global cooling. Later in the Miocene a distinct cooling of the climate resulted in the further reduction of both tropical and conifer forests, and the flourishing of grasslands and savanna in their stead.

Animal Life

In Eurasia and North America, the spread of grasslands forced an evolutionary change in herbivorous mammals, with the forest browsers giving way to the prairie grazers. Grass is a very tough and abrasive material, and herbivores like horses evolved very high-crowned teeth to cope with the wear. Both the perissodactyls and artiodactyls underwent a period of rapid evolution during the Miocene. During the Oligocene artiodactyls had developed an advanced digestive systems (the rumen), which was now helping them deal with this new food source.

Mammal diversity reached its peak during the Miocene. Many were hoofed grazers or browsers. The epoch was marked by further evolution of horses, which became plains type animals as large as ponies, the chalicotheres, camels, rhinoceroses and anthropoid apes, including the ***Dryopithecus*** which inhabited Southern Europe, Asia, and Africa. Also this period saw the appearance of the mastodons, raccoons, and weasels. The first deer and giraffes also appear, along with the first hyenas. The slow clumsy creodonts, well adapted to the jungle thickets, were replaced by the swift intelligent cat and dog type Carnivora as the dominant predators. There were many eccentric browsing types as well - the chalicotheres - think of a horse crossed with a gorilla - were able to rear up on their hind legs and pull down the branches of trees. The Asian indricotheres and the American entelodonts both flourished then died out during this epoch.

In the seas whales, dugongs and extinct elephant-like desmostylida flourished. Giant sharks such as ***Carcharodon megalodon*** reached 13 to 15 metres in length and preyed on the early whales.

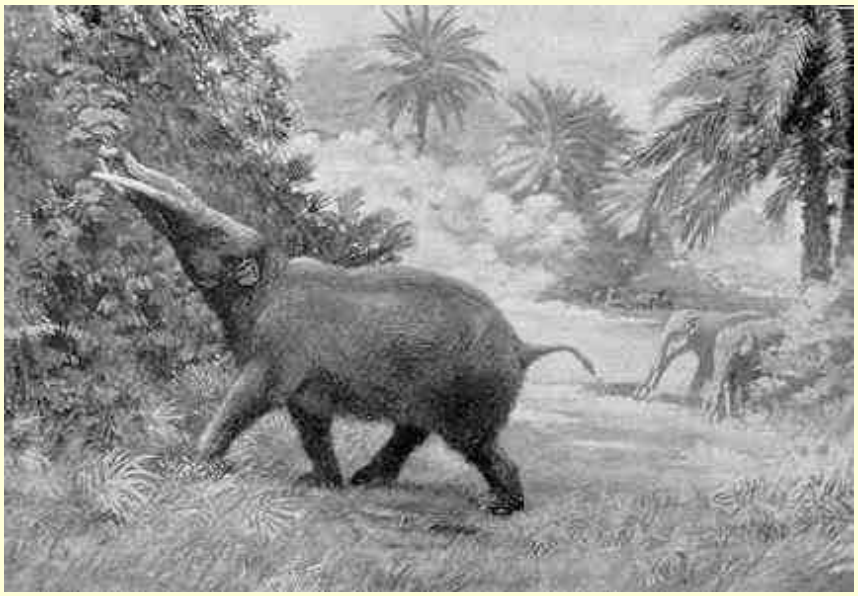
Bioregionalism and Migration

The Miocene saw the continuation of bioregional provinces in some instances, and great mammal migrations in other cases, as animals that had evolved on different continents during the Eocene and Oligocene spread via land-bridges.

Giant carnivorous ground bird (*Phorusrhacus*), 1.5 meters tall. These creatures were wholly indigenous to South America (apart from a brief period during the Plio-pleistocene when they wandered as far north as Florida)

illustration by Charles R. Knight - from Early Image - public domain images (former site)

North America was home to three-toed horses, sheep-like oreodonts, several types of rhinoceroses, pronghorns, camels, protoceratids, and horse-like chalicothere herbivores, with bear-dogs and saber-toothed cats among the carnivores, and the pig-like entelodonts as successful omnivores. In Eurasia the fauna included early deer and giraffes, the giant indricotheres and chalicotheres that were quite different from the American types. African mammals included elephants and mastodons, apes, and Old World monkeys. Australia was a lush tropical rainforested land with an amazing abundance of marsupials, while South America was home to glyptodonts, armadillos, anteaters, New World monkeys, and horse-like litopterns, and a range of marsupial carnivores, giant carnivorous birds (Phorusrhacids), and strange crocodiles (sebecosuchids).



Four tusked Mastodon (*Trilophodon*). These large animals spread widely across Eurasia during the Miocene and Pliocene

illustration by Charles R. Knight - from Early Image (former page) - public domain images

Great migrations saw mastodontids spread out from Africa to Eurasia and North America. Cats, giraffes, pigs, and cattle went the opposite direction, from Eurasia to Africa. Horses and camels spread out from North America into Eurasia.

Resources

Links

The Miocene Epoch - excellent intro

References

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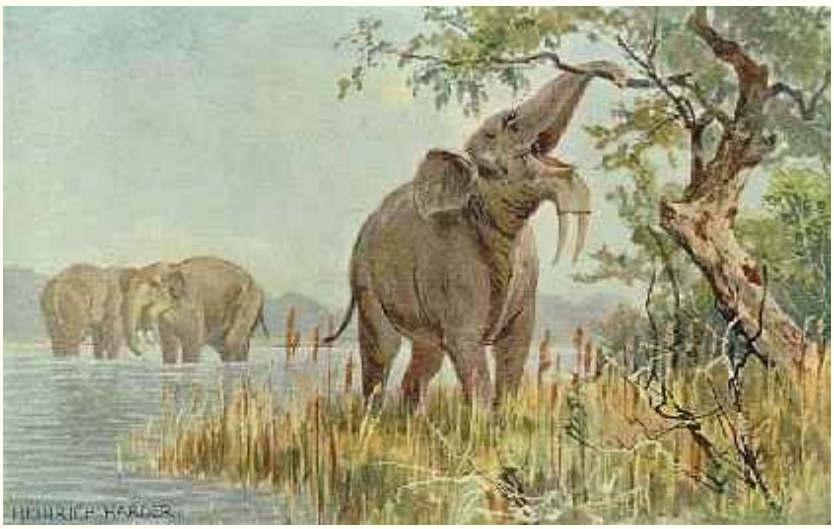
The Pliocene

The Pliocene Epoch of the Neogene Period: 5.33 to 1.81 million years ago

Neogene
- Miocene
- Pliocene
  - Zanclean
  - Piacenzian
  - Gelasian
- Pleistocene
- Holocene

Geology
Stratigraphy
Climate
Life
- Mollusks
- Vertebrates

References
Links



Deinotherium, only distantly related to elephants proper, these animals are distinguished by its downturned tusks. Appearing during the Miocene, they grew progressively larger, and continued through to the early Pleistocene, where they grew as big as the biggest elephant. They flourished in Africa, Europe, and parts of Asia, but became extinct long before the rest of megafauna died out (possibly due to climatic change in the early ice age)

illustration from Early Image - public domain images

The name Pliocene means "more recent", and this was the most recent epoch of Tertiary period, lasting from about 5 to 2 million years ago. Compared to previous epochs this was a relatively brief period, "only" 3 million years. During this time the world became much more like it is today, with ice caps, modern

mammals, relatively modern geography, and the evolution of prehistoric man ("ape man").

Geology

By the Pliocene the world was approaching that of today, and continents had taken up their present-day positions. A shift in the Caribbean tectonic plate, brought about the joining of North and South America, creating a land bridge for mammals to migrate across. The Mediterranean sea (the last remnant of the once mighty Tethys ocean) dried out, and was to remain dry plains and grassland for several million years. During this time, India collided with Asia and gave rise to the Himalayan Mountains, the Himalayan uplift triggering a great global cooling (or accelerating the already unfolding cooling process)

Stratigraphy

Period	Epoch	Age	Base (Mya)	Duration (My)
Neogene	**Pleistocene**	**Early Pleistocene**	**1.81**	**1.03**
	Pliocene Epoch	Gelasian	2.59	0.78
		Piacenzian	3.60	1.01
		Zanclean	5.33	1.73
	Miocene	**Messinian**	**7.25**	**1.92**

The Pliocene is often subdivided into two roughly equal parts, the Early Pliocene (= Zanclean) and Late Pliocene (Piacenzian + Gelasian).

Climate

The Pliocene saw the continuation of the climatic cooling that had began in the Miocene, with subtropical regions retreating equatorially, the beginning of the large ice caps, especially in Antarctica, and the northern hemisphere lands and ocean cooling likewise.

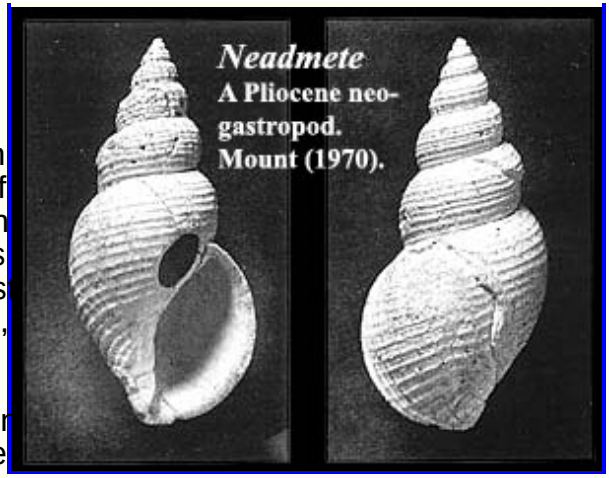
Antarctica was not yet completely frozen. Throughout the Pliocene, ***Nothofagus*** remained common, as indicated by pollen microfossils from this time.

In the northern hemisphere there is a gradual southward migration of marine invertebrates. Reflecting the cooling trend, Arctic species appear in Britain, and later, in the Mediterranean. So much so that the horizon of a normal marine bed can be determined by the percentage of species that (a) are extinct, (b) survive in more northern latitudes, and (c) are today found in more southern latitudes.

Pliocene Life

Pliocene Mollusks

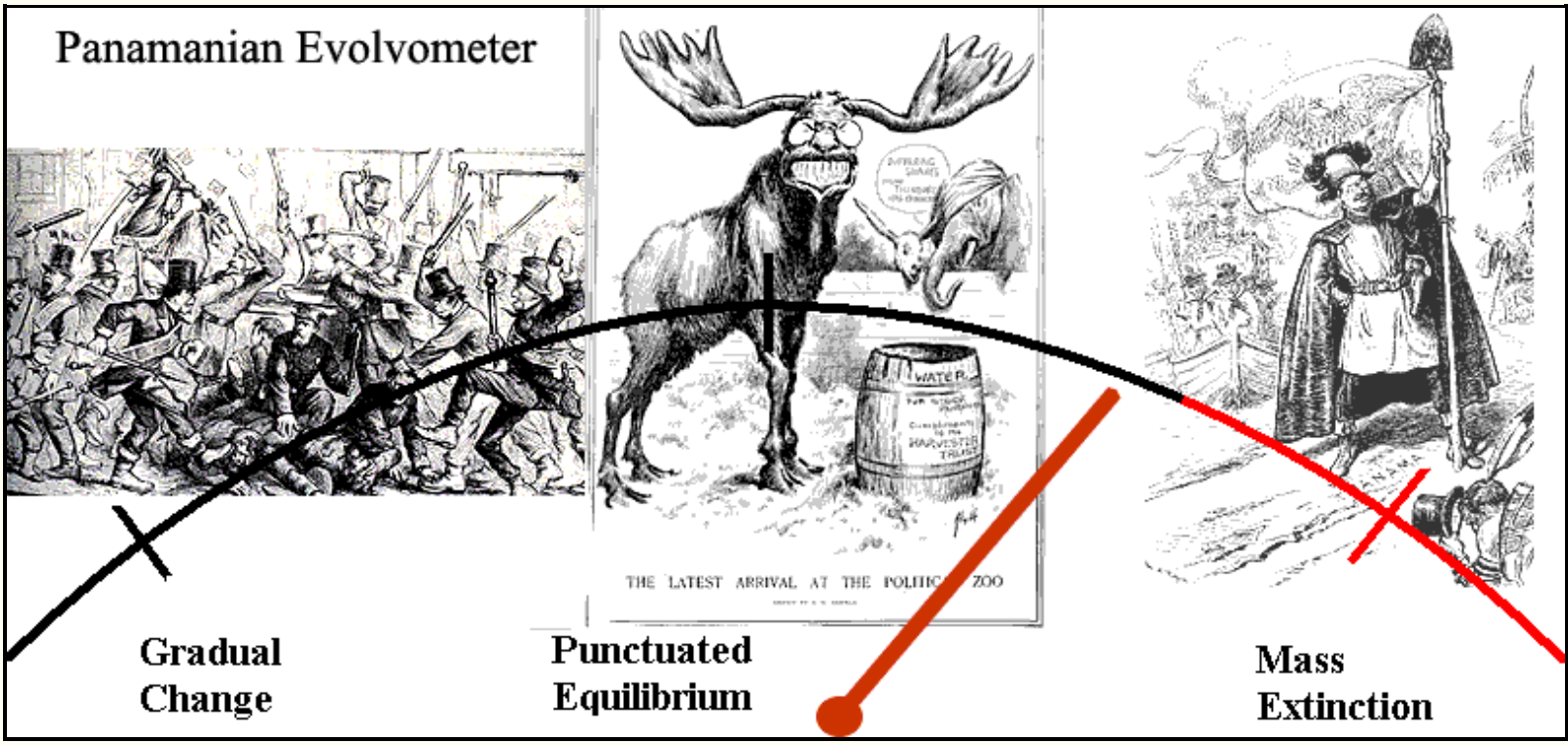
The Pliocene saw an almost complete turnover of molluscan species in numerous locations. This is not to say that extinction rates approached 100% on the species level. In many cases, species ranges simply flowed back and forth with shifting climate.



This is particularly noticeable in regions with long north-south coastlines, as in North America. As the ice sheets spread, many of the endemic mollusks of the California coast during the Zanclean were replaced in the Gelasian by ***existing*** cold-adapted species from Canada and Alaska. Some of the Zanclean Pacific coas species simply relocated to the Gulf of California in the Gelasian, since the Gulf remained semitropical throughout the Pliocene.

This is not to underestimate the effects of the Ice Ages or molluscan diversity. However, an admittedly cursory glance at the literature suggests that the net reductions in molluscan diversity occurred later, during the Pleistocene. A recent, very large-scale study of molluscan turnover by Todd ***et al***. (2002) is worth special emphasis. This work focuses on the Caribbean Basin from the Late Miocene (12 Mya) to the Recent. Todd's group finds that the driving factor in Plio-Pleistocene molluscan turnover was not temperature change, but a steep reduction in nutrient levels associated with the formation of the Isthmus of Panama and isolation of the Caribbean from the Pacific. This was associated with a remarkable increase in molluscan turnover throughout the Pliocene. However, there is no ***net*** decline in diversity until the Pleistocene. Further, the decline in diversity is explained almost entirely by a reduction in the number of gastropod genera. Bivalve diversity remained largely constant. The authors explain that reduction in overall nutrient levels favored reef-based filter-feeders over gastropod carnivores.

The Todd study underlines some points worth the emphasis. First, not everything in the Pliocene can be explained by temperature reductions associated with the Ice Age. The temperature in the Caribbean was constant and may actually have increased slightly. Equally important were the changes in ocean circulation. These changes may have had a role in creating the continental ice shelves of the Gelasian. However, quite apart from arguably converting most of Laurasia into hemispheric ***gelato***, changes in ocean circulation had very important effects in other ways.



Second, the Todd study sets up an interesting line of speculation. Because it is one of a mere handful of really large-scale, well-constrained diversity studies, we may have confidence that our rampant speculations are at least grounded in reality. The authors do not stress the point, but the delay between species turnover and ecological collapse which appears in their data might be a general phenomenon which would explain some of the inconsistent results in "Punctuated Equilibrium" studies. Punctuated Equilibrium holds that evolution happens in bursts, rather than at a continuous, rather constant clip. Now, let us impose a few hypothetical changes in the isolation of the Caribbean from the Pacific.

(1) Suppose that shortly after the isthmus of Panama formed, some Pliocene Teddy Roosevelt had gone down and dug the whole thing up. The brief isolation of the Caribbean from the Pacific would then end, and Recent geologists would never learn of the land bridge between North and South America. Three million years later, we would observe, in the paleontological record, a rapid burst of molluscan evolution, followed by a likely return to a more static state, but with entirely new species, and without any obvious change in the environment or ecosystem. In short, we'd see a punctuation episode. (2) Now, take it a step further. Suppose Teddy had been delayed, perhaps by a run-in with a bull moose, so that he didn't arrive in Panama until after the collapse of the gastropods. However, he still digs up the Isthmus so that we never learn about it. What we now observe is an "inexplicable" mass extinction. (3) Finally, suppose that instead of Roosevelt, we dispatched a horde of lawyers to Panama. The whole business would then be tied up in litigation and nothing would get done properly. The land bridge would be enjoined and never quite get finished, the digging up process would bog down in permit applications, and everyone would ultimately run out of money and patience. For the next 3 My, while the whole thing slowly sleazed its way up to the Court of Geological Appeals, the Caribbean and Pacific would be ***partially*** isolated -- perhaps only meeting at high tide, or on alternate weekends and for three weeks in the summer. In that case, it is likely that the gastropod clan would have time to adapt to this change in its fortunes without ecological collapse. That is, we would see a long, continuous process of more leisurely species turnover.

So, then, the question: are mass extinction, punctuated equilibrium, and classical Darwinian gradualism simply three points on a single spectrum?

As is all too often the case, we have wandered so far off the intended path, that it would now be hopeless to attempt any remarks concerning Pliocene mollusks. Accordingly we will simply leave abruptly, salvaging whatever shards of dignity may remain for some happier occasion

Pliocene Vertebrates

Terrestrial Ecosystems

The fauna of the Pliocene does not differ much from that of the Miocene, although the period is regarded by many zoologists as the climax of the Age of Mammals. This epoch is characterized by the appearance of all of the presently existing orders and families, and many of the existing genera of mammals.

Pliocene Vegetation was very like today's. Grasslands replaced forests, so grazing mammals spread at the expense of browsers. Cattle, sheep, antelopes, gazelles, and other bovids reached their peak. North American mammals included horses, camels, deer, pronghorns, peccaries, mastodonts, beavers, weasels, dogs, and saber-toothed cats. Rhinoceroses and protoceratids died out in North America. The one-toed horse appears for the first time.

Animal migrations

The Pliocene was a time of great migration, owing to the appearance of new land bridges.

The North American three-toed ***Hipparion*** horse crossed the Bering Straits land bridge and entered Asia and Europe, while mastodonts entered the Americas from Asia.

During the late Pliocene, about 3 million years ago, the isthmus of Panama ended South America's isolation. The armadillo, ground sloth, opposums, and phorusrhacid birds were among the animals that migrated North from South America. And dogs, cats, bears, horses, mastodonts, and others animals invaded South America from the north. This was catastrophic for some of the local animals, especially the big marsupial carnivores. Even today more than half the genera of South American mammals are descended from northern species.

Australia, still isolated, saw rodents rafting in on mats of vegetation drifting south from Indonesia.

Hominid Evolution

Australopithecus robustus

illustration by Zdenek Burian, from *Life Before Man*

In Africa the emerging savanna grasslands and retreating forests caused some apes to come down from the trees and take up life in the open, where they co-existed with early elephants, antelopes, and other types of animals. An erect posture was necessary for these vulnerable creatures to watch for predators, which also freed the hands for the use of makeshift tools (sticks etc). Thus the hominid lineage appeared in the rift valleys of north-east Africa during Early Pliocene. As with the bovids, the hominids underwent an evolutionary radiation, with a number of lines of gracile and robust Australopithecines inhabiting Ethiopia and Tanzania, and probably spreading throughout most of Africa. The large-brained australopithecine ***Homo habilis*** continued on into the Early Pleistocene, giving rise to ***Homo erectus*** , the common ancestor of both Neanderthal and modern man during the late Pleistocene.

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Resources

Links

The Pliocene Epoch - good basic intro

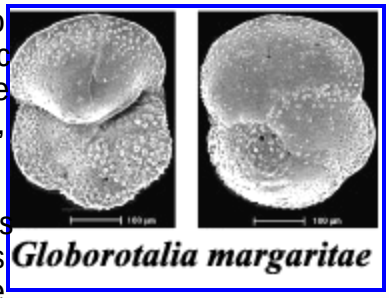
The Pliocene epoch - from Earth history resources

Evolving Toward Humans - links page, from Howcomyoucom

The Piacenzian

The Piacenzian Age of the Pliocene Epoch: 3.60 to 2.59 million years ago

Pliocene
  Zanclean
  Piacenzian
  Gelasian
Pleistocene


Globorotalia margaritae

The Piacenzian Age is the first half of the Late Pliocene, a sub-epoch that we do not cover as a separate unit. Its base is defined by the bottom of magnetic polarity zone C2An (called the "Gauss Normal" chron) and the extinction of the forams ***Globorotalia margaritae*** and ***Pulleniatina primalis*** at Punta Piccola, in Sicily.

The Piacenzian is also referred to as the "Middle Pliocene" by ICS. This is unnecessarily confusing, since this period has, under various names, always been regarded as Late Pliocene. However, it may also be necessary. The Gelasian Age was carved out of the Piacenzian by ICS quite recently (in 1996). References to the "Piacenzian" in the literature, even in the last few years, refer to the ***entire*** Late Pliocene, ***i.e.*** the Piacenzian + Gelasian. ***See, e.g.,*** McKinney & Taylor (2001).

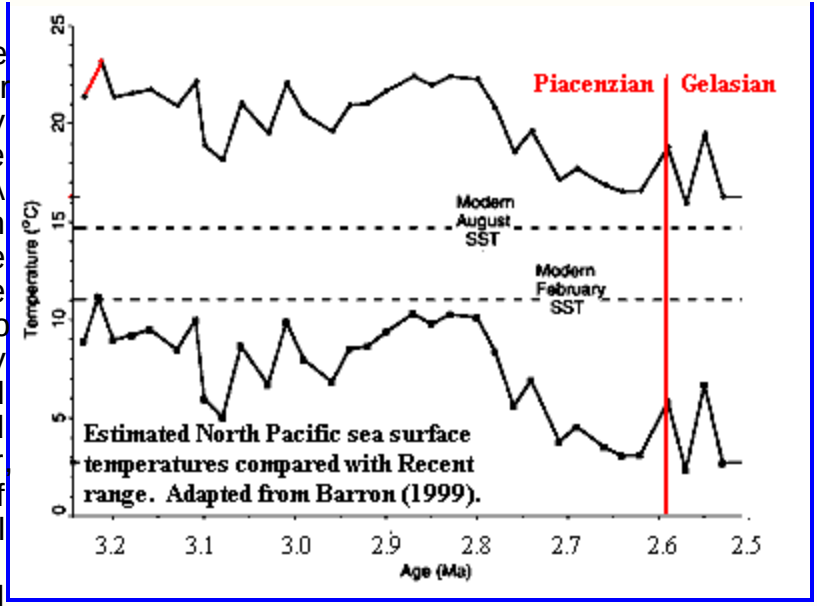
While only one million years long, the Piacenzian was an eventful age, particularly for our own ancestors. The Piacenzian saw the run-up to the first Ice Age and the formation of the land bridge between North and . This was also the age of "Lucy," ***Australopithecus afarensis,*** and the radiation of robust and gracile hominids which produced the genus ***Homo***. All over the globe, species turnover was accelerated, as high latitude temperatures dropped, the ice sheets gathered, and ocean circulation patterns approached their present form.

Image: ***Globorotalia*** from Li ***et al***. (2003).

Life in the Piacenzian

In Europe, mammoth, tapirs, and the little bear,

Ursus minimus, died out along with rodents, like ***Mimomys***, which were adapted to temperate or subtropical climates and open woodlands. They were replaced in the Gelasian by species more suited for colder and more open environments. A similar change is seen throughout the Northern Hemisphere in what is referred to as the "Elephant-***Equus*** Event," named for the conspicuous change from Piacenzian elephants to Gelasian horses as the dominant open-country ungulate. Azzaroli (1995). This event is reflected by rapid changes in pollen, foraminifera, and mollusk indicators from the same time. However, these indicators also suggest that a number of shorter "cold spells" preceded the final temperature plunge at the end of the Piacenzian. Serrano ***et al***. (1999). The same pattern occurred over most of the world, ***See, e.g.,*** the graph from Barron (1999).



This drying trend was even more pronounced in East Africa, where the global aridification was augmented by regional uplifts (caused by the cracks which appeared in the African craton) casting rain shadows over parts of the area. Partridge ***et al***. (1995). On the other hand, a detailed study of the fauna at Omo fails to demonstrate any large turnover connected with the Piacenzian, despite rapid evolution of bovids in other parts of the continent. Wesselman (1995).

Faunal changes in Americas were marked by the Great American Interchange related to the formation of the interamerican land bridge. The formation of the Isthmus of Panama allowed the long-isolated North and South American vertebrates to mix. The land bridge allowed the armadillo, porcupine, opossum, and ground sloths to colonize the north, as well as the unique South American notoungulates. The sloths and, to a lesser extent, the notoungulates, prospered, but are now extinct. The others were initially restricted to the most southerly parts of North America but are now expanding their ranges. The Northern immigrants to South America included the rodents, Carnivora (bears, cats, dogs, etc.), llamas and horses, bovids (particularly deer), and the tapirs and elephants.

Our understanding of the Interchange has changed greatly in recent years. It was originally viewed as a conquest of the South by the North. It now appears to have been a more even-handed and less catastrophic event. Many of the extinctions originally attributed to the Interchange, particularly the unique endemic South American ungulates, occurred either earlier, in the Late Miocene, or later, in the Pleistocene.

Links

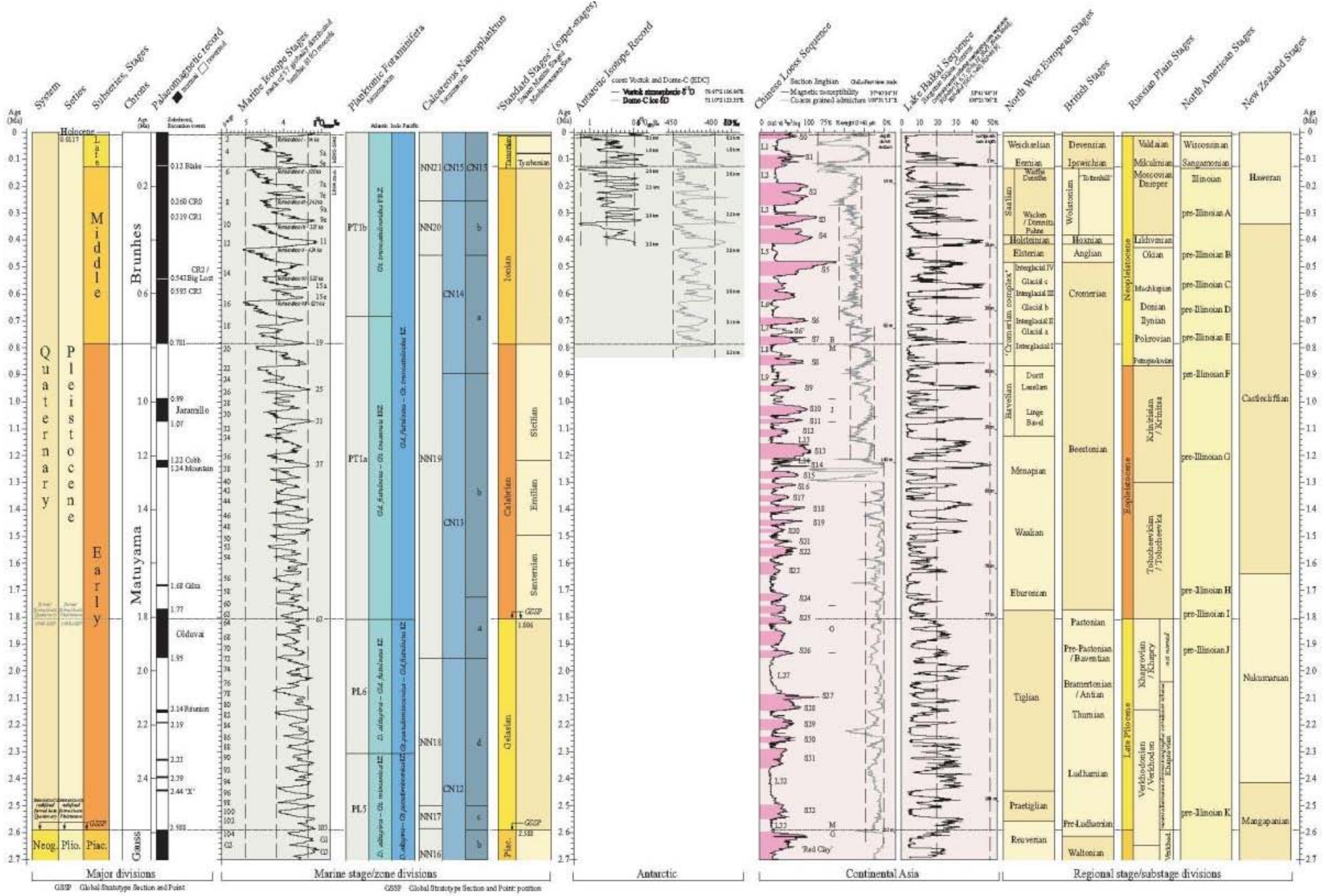
Base of Piacenzian Stratotype: stratigraphic definition and markers. The full description and rationale can be found in Castradori, D, D Rio, FJ Hilgen & LJ Lourens (1998), ***The global standard stratotype-section and point (GSSP) of the Piacenzian Stage (Middle Pliocene)***. **Episodes** 21: 88-93. Better versions of some of the images can be found at base Piacenzian.

Quaternary

Time Main Page
- Cosmological time
- Geological Time
- Quaternary Time
- Historical Time
- Future Time

Quaternary
- Chronostratigraphic chart
- Links
- Pleistocene
- Holocene
- References

Quaternary Time



Quaternary global chronostratigraphical correlation table for the last 2.7 million years. The timescale is based on the internationally-recognised subdivisions of Phanerozoic Eon, Cenozoic Era, Quaternary System or Period; Pleistocene and Holocene Epochs or Series, and finally the Early/Lower, Middle, Late/Upper Pleistocene Subseries, stages or ages, which curerntly are not formalised. So far, two Global Stratotype Section and Points (GSSP) have been ratified within the last 2.7 million years. Chart from Stratigraphical charts for the Quaternary (includes also previous versions), Subcommission on Quaternary Stratigraphy. Reference Cohen & Gibbard 2011

Links

Links: The Quaternary is dead, long live the Quaternary - Current status and some possible options for formalizing the ﷺQuaternaryﷺ interval of Earth history. Durations of stages, epochs and ﷺQuaternaryﷺ on the geologic time scale are according to their span in millions of years. The Neogene Period begins at ~23 Ma (after OGG 2004). - David Bressan, Cryology & co.; Quaternary Palaeoenvironments Group (QPG) Wikipedia; National Geographic; Prehistoric Animals--Quaternary Period MAK111015

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Cohen K.M. & Gibbard, P. 2011 Global chronostratigraphical correlation table for the last 2.7 million years. Subcommission on Quaternary Stratigraphy (International Commission on Stratigraphy), Cambridge, England.

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The Pleistocene

The Pleistocene Epoch of the Neogene Period: 1.81 to 0.012 million years ago

The Ice Age

Neogene
- Miocene
- Pliocene
- Pleistocene
- Holocene

Coleodonta, the Woolly Rhinoceros of the last ice-age, was a contemporary of early man
illustration by Charles R. Knight - from Early Image - public domain images

The Pleistocene Epoch covers a little over one and a half million years. This epoch witnessed a continued

cooling, culminating in a series of ice ages. The great mammalian megafauna are flourishing, and the hominid primates have become increasingly skilled at the use of fire and tool-making.

Historical

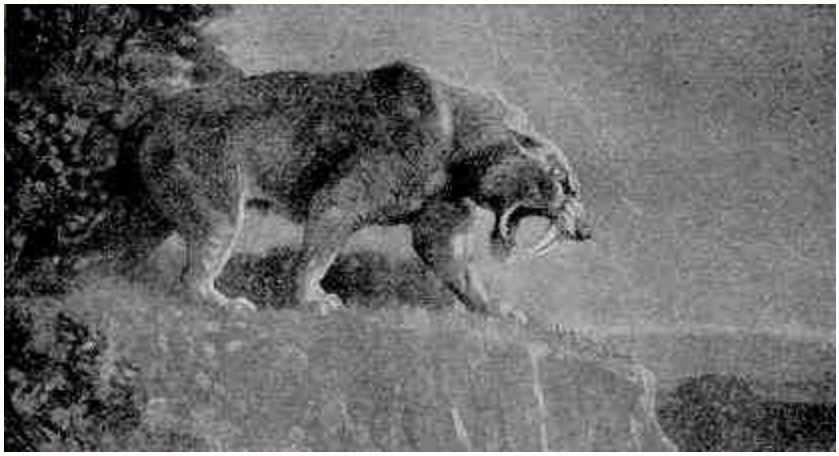
The term Pleistocene ("most recent") was coined by Charles Lyell in 1839, on the basis of a section of type strata in eastern Sicily, according to the proportion of extinct to living species of mollusk shells in the sediment. Strata with 90 to 100% present day species were designated Pleistocene. Clearly this is a somewhat arbitrary arrangement, and in any cases many strata do not contain mollusk shells.

The present definition of the Pleistocene is based on radiometric dating of 1.8 million years or more recent, the presence of cooler water mollusks and foraminifers, the absence of marine micro-organisms called ***discoasters***, and on land the fossil remains of modern horses and true elephants (in the past more widespread than they are today).

Geography and Climate

About a third of the way into the Pleistocene the first Ice Age hit. Therewere a series of advances and retreats of the ice as the climate fluctuated between cold (glacial) and warm (interglacial) periods. The sea level rose during the melting of the glaciers, then dropped again during the next long cold spell (ice formation). The lowered sea levels formed land bridges that enabled the migration of animals and humans across continents.

Biosphere



Smilodon, the great saber-tooth cat, lived in North America and was as large as a lion
illustration by Charles R. Knight - from Early Image - public domain images

The Pleistocene saw the age of mammals is at its height, with both small and giant forms living alongside each other. Animals and plants are basically modern species, although distributions were unusual; e.g. hippos and elephants in what is now London during the warm interglacial periods. There were however many giant mammals - the so called ***megafauna*** - which evolved and lived on all the worlds continents. In Australia for example there were giant kangaroos and wombats (as well as a number of forms with no living relatives), in Europe the mammoth and woolly rhinos, in America the mastodon, camels, and dire wolves, in South America elephant-sized ground sloths and giant armadillo-like creatures called glyptodonts.

Intelligence

During the Pleistocene the hominid tendency to increase brain size and hence intelligence continued. ***Homo erectus***, ***Homo neanderthalis***, and finally modern man (***Homo sapiens***) succeeded each other in time (although modern man and neanderthals lived alongside each other in Europe for a short period, an event popularized in fiction by writers like William Golding (***The Inheritors***) and Jean Aeul (***Clan of the Cave Bear***). Interestingly, neanderthal man had a larger brain capacity than modern man, but still died out. As one of my university tutors once quipped when this was mentioned, a race of philosophers?

Stratigraphy

Pleistocene Epoch	Late Pleistocene
	Middle Pleistocene
	Early Pleistocene

Resources

Links

The Pleistocene

Land of the Mammoth - Discovery Channel

Evolving Toward Humans - annotated links page from Richard Cowen's History of Life site - mirror at Howcomyoucom

The Pleistocene Ice Age - annotated links page from Richard Cowen's History of Life site - mirror at Howcomyoucom

Humans and the Ice Age - - annotated links page from Richard Cowen's History of Life site - mirror at Howcomyoucom

The Pleistocene

Books

The following is highly recommended:

Quaternary Extinctions : A Prehistoric Revolution by Paul S. Martin and Richard G. Klein (Editors) - essays by different writers on the mystery of the Pleistocene extinctions.

DVD

Land of the Mammoth

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checked ATW030930

The Holocene

The Holocene Epoch of the Neogene Period: The Last 12,000 Years

Neogene
- Miocene
- Pliocene
- Pleistocene
- Holocene

The term Holocene means "completely recent" This refers to the present geological era. In fact it is hardly even worth defining in geological terms as an epoch, because it is so brief.. The boundary between the Pleistocene and the recent is set at around 10,000 years BCE (12,000 years ago), which represented a marked climatic warming phase and the beginning of the present interstadial (warm period between glaciations). The change is well established in a number of sediments, especially in Scandinavia, and corresponds to the boundary between the European Pollen Zones III/IV, the Younger Dryas/Preborial, and also the Late Glacial/Postglacial.

All other ages, epochs, and eras are represented by natural evolutionary and geological phenomena. The Holocene in contrast is distinguished by being the Age in which human activities have had a marked, and for the most part extremely detrimental, effect on the rest of the biosphere. Yetat the same time this age has witnessed the rise of civilization and the exponential development of the Noosphere. The ten thousand years of its extent are too short to see much in the way of the evolution of species and ecosystems, but natural processes of erosion and sedimentation have been supplemented by human activities and geographical impacts; the rise of towns, fields, roads, etc. And there has been an exponential growth in human population and knowledge.

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