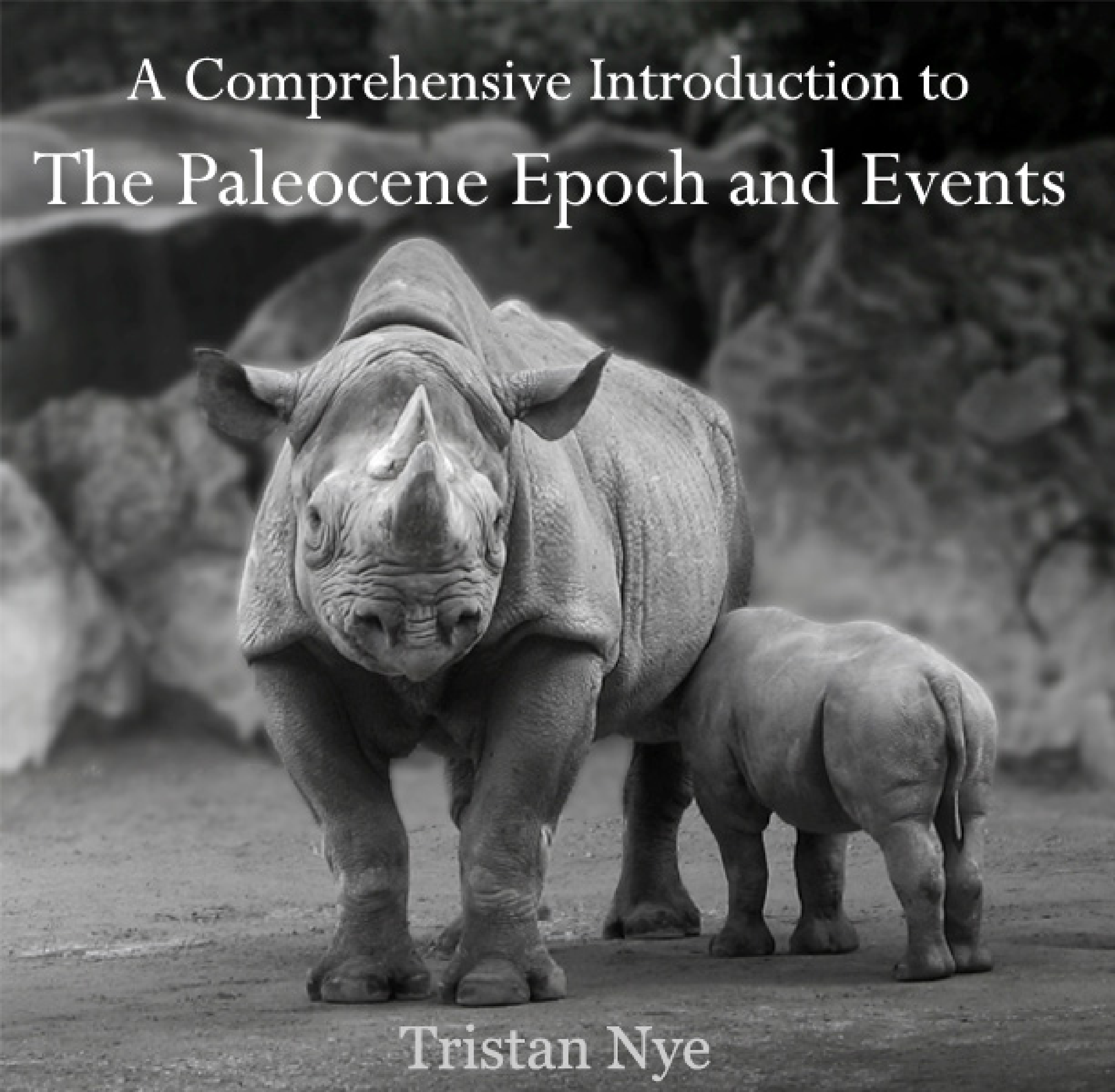
A Comprehensive Introduction to

The Paleocene Epoch and Events



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Chapter- 1

Introduction to Paleocene Epoch

System	Series	Stage	Age (Ma)
Neogene	Miocene	Aquitanian	**younger**
Paleogene	Oligocene	Chattian	23.03–28.4
		Rupelian	28.4–33.9
	Eocene	Priabonian	33.9–37.2
		Bartonian	37.2–40.4
		Lutetian	40.4–48.6
		Ypresian	48.6–55.8
	Paleocene	Thanetian	55.8–58.7
		Selandian	58.7–61.7
		Danian	61.7–65.5
Cretaceous	Upper	Maastrichtian	**older**

Subdivision of the Paleogene Period according to the IUGS, as of July 2009.

The **Paleocene** or **Palaeocene**, the "early recent", is a geologic epoch that lasted from about 65.5 to 56 million years ago (65.5 ± 0.3 to 55.8 ± 0.2 Ma). It is the first epoch of the Palaeogene Period in the modern Cenozoic Era. As with most other older geologic periods, the strata that define the epoch's beginning and end are well identified but the exact date of the end is uncertain.

The Paleocene Epoch immediately followed the mass extinction event at the end of the Cretaceous, known as the K-T boundary (Cretaceous - Tertiary), which marks the demise of the dinosaurs (except their descendants, modern birds) and much other fauna and flora. The die-off of the dinosaurs left unfilled ecological niches worldwide and the name "Paleocene" comes from Greek and refers to the "old(er)" (παλαιός, *palaios*) – "new" (καινός, *kainos*) fauna that arose during the epoch, before modern mammalian orders emerged in the Eocene.

Boundaries and subdivisions

The K-T boundary that marks the separation between Cretaceous and Paleocene 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 flora and fauna. There is some evidence that a substantial but very short-lived climatic change may have happened in the very early decades of the Paleocene. There are several theories about the cause of the K-T extinction event, with most evidence supporting the impact of a 10 km diameter asteroid forming the buried Chicxulub crater on the coast of Yucatan, Mexico.

The end of the Paleocene (55.5/54.8 Ma) was marked by one of the most significant periods of global change during the Cenozoic. The Paleocene-Eocene Thermal Maximum upset oceanic and atmospheric circulation and led to the extinction of numerous deep-sea benthic foraminifera and a major turnover in mammals on land.

The Paleocene is divided into three stages, from youngest to oldest:

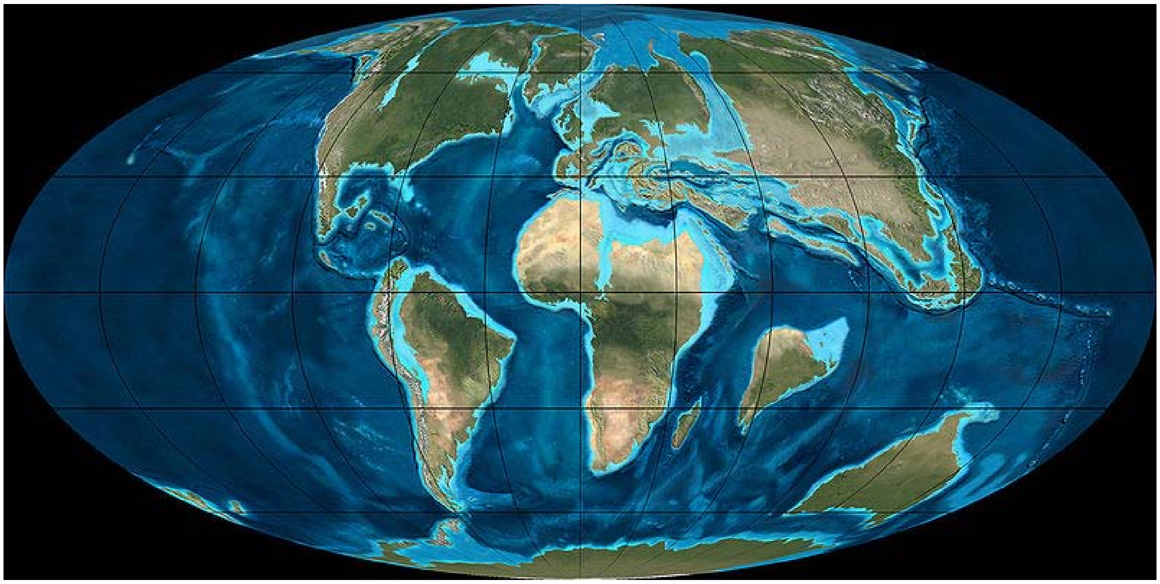
Thanetian (58.7 ± 0.2 – 55.8 ± 0.2 Ma)
Selandian (61.7 ± 0.2 – 58.7 ± 0.2 Ma)
Danian (65.5 ± 0.3 – 61.7 ± 0.2 Ma)

Additionally, the Paleocene is divided into six Mammal Paleogene zones.

Climate

The early Paleocene was cooler and dryer than the preceding Cretaceous, though temperatures rose sharply during the Paleocene–Eocene Thermal Maximum. The climate became warm and humid worldwide towards the Eocene boundary, with subtropical vegetation growing in Greenland and Patagonia, crocodiles swimming off the coast of Greenland and early primates evolving in tropical palm forests of northern Wyoming. The Earth's poles were cool and temperate; North America, Europe, Australia and southern South America were warm and temperate; equatorial areas had tropical climates; and north and south of the equatorial areas, climates were hot and arid.

Paleogeography



Global paleogeographic reconstruction of the Earth 65 million years ago

In many ways, the Paleocene continued processes that had begun during the late Cretaceous Period. During the Paleocene, the continents continued to drift toward their present positions. Supercontinent Laurasia had not yet separated into three continents - Europe and Greenland were still connected, North America and Asia were still intermittently joined by a land bridge, while Greenland and North America were beginning to separate. The Laramide orogeny of the late Cretaceous continued to uplift the Rocky Mountains in the American west, which ended in the succeeding epoch.

South and North America remained separated by equatorial seas (they joined during the Neogene); the components of the former southern supercontinent Gondwanaland continued to split apart, with Africa, South America, Antarctica and Australia pulling away from each other. Africa was heading north towards Europe, slowly closing the Tethys Ocean and India began its migration to Asia that would lead to a tectonic collision and the formation of the Himalayas.

The inland seas in North America (Western Interior Seaway) and Europe had receded by the beginning of the Paleocene, making way for new land-based flora and fauna.

Oceans

Warm seas circulated throughout the world, including the poles. The earliest Paleocene featured a low diversity and abundance of marine life, but this trend reversed later in the epoch. Tropical conditions gave rise to abundant marine life, including coral reefs. With the demise of marine reptiles at the end of the Cretaceous, sharks became the top predators. At the end of the Cretaceous, the ammonites and many species of foraminifera became extinct.

Marine faunas also came to resemble modern faunas, with only the marine mammals and the Carcharhinid sharks missing.

Flora

Terrestrial Paleocene strata immediately overlying the K-T boundary is in places marked by a "fern spike": a bed especially rich in fern fossils. Ferns are often the first species to colonize areas damaged by forest fires; thus the fern spike may indicate post-Chicxulub crater devastation.

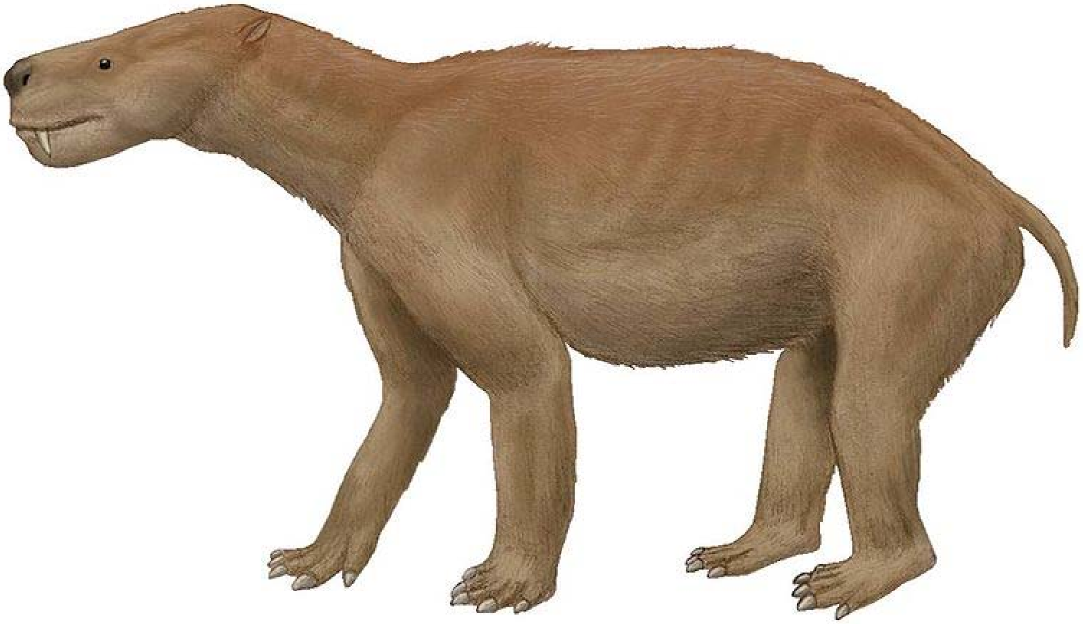
In general, the Paleocene is marked by the development of modern plant species. Cacti and palm trees appeared. Paleocene and later plant fossils are generally attributed to modern genera or to closely related taxa.

The warm temperatures worldwide gave rise to thick tropical, sub-tropical and deciduous forest cover around the globe (the first recognizably modern rain forests) with ice-free polar regions covered with coniferous and deciduous trees. With no large grazing dinosaurs to thin them, Paleocene forests were probably denser than those of the Cretaceous.

Flowering plants (angiosperms), first seen in the Cretaceous, continued to develop and proliferate and along with them coevolved the insects that fed on these plants and pollinated them.

Fauna

Mammals



Life restoration of *Titanoides*

Mammals had first appeared in the Triassic, evolving from advanced cynodonts and developed alongside the dinosaurs, exploiting ecological niches untouched by the larger and more famous Mesozoic animals: in the insect-rich forest underbrush and high up in the trees. These smaller mammals (as well as birds, reptiles, amphibians and insects) survived the mass extinction at the end of the Cretaceous which wiped out the non-avian dinosaurs and mammals diversified and spread throughout the world.

While early mammals were small nocturnal animals that mostly ate soft plant material and small animals such as insects, the demise of the non-avian dinosaurs and the beginning of the Paleocene saw mammals growing bigger and occupying a wider variety of ecological niches. Ten million years after the death of the non-avian dinosaurs, the world was filled with rodent-like mammals, medium sized mammals scavenging in forests and large herbivorous and carnivorous mammals hunting other mammals, birds and reptiles.

Fossil evidence from the Paleocene is scarce and there is relatively little known about mammals of the time. Because of their small size (constant until late in the epoch) early mammal bones are not well-preserved in the fossil record and most of what we know comes from fossil teeth (a much tougher substance) and only a few skeletons.

Paleocene mammals did not yet have specialized teeth or limbs and their brain to body mass ratios were quite low; compared to later forms, they are considered primitive, or archaic. It was not until the Eocene, 55 Ma, that true modern mammals developed.

Mammals of the Paleocene include:

- Monotremes: three species of monotremes have survived to modern times: the Platypus and two species of Echidnas. *Monotrematum sudamericanum* lived during the Paleocene.
- Marsupials: modern kangaroos are marsupials, characterized by giving birth to embryonic babies, who crawl into the mother's pouch and suckle until they are developed. The Bolivian *Pucadelphys andinus* is a Paleocene example.
- Multituberculates: the only major branch of mammals to go extinct since the K-T boundary, this rodent-like grouping includes the Paleocene *Ptilodus*.
- Placentals: this grouping of mammals became the most diverse and the most successful. Members include primates, plesiadapids and hoofed ungulates, including the condylarths and the carnivorous mesonychids.

Reptiles

Section of an *Asiatosuchus* jaw

Because of the climatic conditions of the Paleocene, reptiles were more widely distributed over the globe than at present. Among the sub-tropical reptiles found in North America during this epoch are champsosaurs (aquatic reptiles that resemble modern gharials), crocodilia, soft-shelled turtles, palaeophi snakes, varanid lizards and *Protochelydra zangerli* (similar to modern snapping turtles).

Examples of champsosaurs of the Paleocene include *Champsosaurus gigas*, the largest champsosaur ever discovered. This creature was unusual among Paleocene reptiles in that *C. gigas* became larger than its known Mesozoic ancestors: *C. gigas* is more than twice the length of the largest Cretaceous specimens (3 meters versus 1.5 meters). Reptiles as a whole decreased in size after the K-T event. Champsosaurs declined towards the end of the Paleocene and became extinct during the Miocene.

Examples of Paleocene crocodylians are *Borealosuchus* (formerly *Leidyosuchus*) *formidabilis*, the apex predator and the largest animal of the Wannagan Creek fauna and the alligatorid *Wannaganosuchus*.

Non-avian dinosaurs may have survived to some extent into the early Danian stage of the Paleocene Epoch circa 64.5 Mya. The controversial evidence for such is a hadrosaur leg bone found from Paleocene strata in New Mexico; but such stray late forms may be derived fossils.

Birds

Gastornis

Birds began to re-diversify during the epoch, occupying new niches. Most modern bird types had appeared by mid-Cenozoic, including perching birds, cranes, hawks, pelicans, herons, owls, ducks, pigeons, loons and woodpeckers.

Large carnivorous flightless birds (also called Terror Birds) have been found in late Paleocene fossils, including the fearsome *Gastornis* in Europe.

In the late Paleocene, early owl types appeared, such as *Ogygoptynx* in the United States and *Berruornis* in France.

Chapter- 2

Paleocene Life

Droseridites

Droseridites
Fossil range: Cretaceous?–Miocene

Photomicrographs of *D. echinosporus* pollen taken at 1000x magnification.

Scientific classification

Kingdom:	Plantae
(unranked):	Angiosperms
(unranked):	Eudicots
(unranked):	Core eudicots
Order:	Caryophyllales
Family:	?Droseraceae
Genus:	***Droseridites*** Cookson (1947) *ex* R.Potonié (1960)

Species

D. baculatus Ibrahim (1996)
D. echinosporus R.Potonié (1954)
D. major Krutzsch (1970)
D. parvus Dutta & Sah (1970)
D. senonicus Jardiné & Magloire (1965)
D. spinosus (type) (Cookson) R.Potonié (1960)

Droseridites is a genus of extinct plants of possible droseracean or nepenthacean affinity. It is a form taxon known only from fossil pollen. Species assigned to this genus originate from numerous regions of the world, including Europe (from France to the Caucasus), India, Egypt, the Arabian Peninsula and the Kerguelen Islands.

This genus is characterised by inaperturate and spinose pollen grains that are united in loose tetrahedral tetrads (groups of four). The grains are prolate, striate and tricolpate. The colpi are slender and long, whereas the striae are very fine, densely packed and situated parallel to the polar axis.

Species

Droseridites spinosus, the type species, has been recorded from the Tertiary of the Kerguelen Islands and the Miocene of India, including the Warkalli Formation (Bharathi and Kundra Clay Mines, Kerala) and the Sindhudurg Formation (Mavli Mine at Redi, Sindhudurg District, Maharashtra). It is of possible nepenthacean affinity. Specimens identified in the literature as *D.* cf. *spinosus* have also been reported from Hungarian Miocene deposits.

Droseridites baculatus was described from the Ghazalat-1 Well, Qattara Depression, Egypt.

Droseridites echinosporus has been recorded from European Tertiary strata and is a member of a group of similar species that have been interpreted as belonging to the genus *Nepenthes*.

Sites for *D. major*, a possible nepenthacean species, include the Tertiary of Europe and the Palaeocene-early Eocene Rekmangiri Coalfield of Garo Hills, Meghalaya, India.

Droseridites parvus was originally described from the lower Eocene Cherry Formation of Assam, India. It has also been recorded from the Palaeocene Tura Formation of the "*Retialetes emendatus* zone" in Assam and the Oligocene-Neogene Dharmsala and Siwalik (Dharmsala and Nurpur areas, Kangra District, Himachal Pradesh). The species is characterised by wart-like sculpturing and is "presently impossible to interpret".

Pollen matching the description of *D. senonicus* has been found in formations of the Arabian Peninsula dating to as early as the Middle Cretaceous to late Upper Cretaceous and it has been suggested that this species may represent an early palm taxon.

Unidentified *Droseridites* palynomorphs have been recorded from numerous sites in India, including the Miocene Cuddalore Formation (Neyveli Lignitefield, Tamil Nadu), the Palaeocene Tura Formation (Langrin Coalfield, Khasi Hills, Meghalaya), the Palaeocene Seam No. 1 (Rekmangiri Coalfield, Garo Hills, Meghalaya) and the Oligocene-Neogene Dharmsala and Siwalik (Dharmsala and Nurpur areas, Kangra District, Himachal Pradesh).

Taxonomy

Pollen of a number of species originally described under the genus *Droseridites* has been tentatively assigned to *Nepenthes*. In 1985, Wilfried Krutzsch transferred three species of the "*D. echinosporus* group", creating the new combinations *Nepenthes echinatus*, *N. echinosporus* and *N. major*. However, at more than 40 µm in diameter, the tetrads of *D. major* are larger than those of any known extant *Nepenthes* and within the lower range of extant *Drosera* tetrads. Pollen from the Kerguelen Islands originally described as *D. spinosus* has also been interpreted as belonging to *Nepenthes*.

Some authors consider *D. major* and *D. parvus* as synonyms of ***Nepenthidites laitryngewensis*** of the Palaeocene Lakadong Sandstone in Laitryngew, Khasi Hills, Meghalaya, India.

Montrichardia aquatica

Montrichardia aquatica **Fossil range: Mid - late Paleocene60–58 Ma**	
Scientific classification	
Kingdom:	Plantae
(unranked):	Angiosperms
(unranked):	Monocots
Order:	Alismatales
Family:	Araceae
Subfamily:	Aroideae
Genus:	*Montrichardia*
Species:	***M. aquatica***
Binomial name	
Montrichardia aquatica Herrera *et al*	

Montrichardia aquatica is an extinct species of monocot plant in the Araceae family. *M. aquatica* is related to the living species *M. arborescens* and *M. linifera*. The species is solely known from the Middle to late Paleocene (about 60 to 58 Ma), Cerrejón Formation deposits in Colombia.

History and classification

The species is known only from the holotype specimen, number ING-0904 and the four paratypes ING-0808, ING-0903, ING-0905 and ING-0906. The leaves are currently residing in the collections housed by the Colombian Geological Institute in Bogotá, Colombia. All five fossil specimens were collected from Cerrejón Formation exposures in the Cerrejón coal mine, located in the Rancheria Basin, Colombia. They were first studied by a group of researchers from Florida Museum of Natural History, the Smithsonian Museum of Natural History and lead by Fabiany Herrera from the Smithsonian Tropical Research Institute. Herrera and associates published their 2008 type description in the *American Journal of Botany*. The specific epithet "*aquatica*" a derivation of the Latin "aquaticus" was chosen by the authors in reference to the species having lived near to, or in water.

Description

There are two angiosperm families, Nymphaeaceae and Nelumbonaceae which have leaf shapes very similar to *Montrichardia aquatica*. Though the over all shape of leaves in those families may be similar the vein structure in *M. aquatica* is notably distinct from both. Neither family possesses the collective veins along the margin, naked secondary veins along the basal margin and the distinct higher vein structure that is present in the fossil specimens of *M. aquatica*. This combination of features is found within the family Araceae. *M. aquatica* is placed within the living Araceae genus *Montrichardia* due to the unique combination of leaf morphology characters present in the fossils. Though the fossils are generally similar to the fossil genus *Caladiosoma* the vein structure is very dissimilar and thus is not considered a close relation. Overall the species possesses entire margined leaves with a generally ovate shape. The leaf apex is short and rounded, while the base is heart to arrowhead shaped. Each of the basal lobes is supplied by a secondary vein which forms part of the margin and forks several times. The overall size of the leaves reached up to 56 by 26 centimetres (22 by 10 in).

Several depositional environments appeared to have hosted *M. aquatica*. The holotype specimen was recovered from a sandstone that probably was an overbank deposits of a fluvial environment. The paratype specimens were recovered from gray siltstones underlying one of the thickest coal sequences in the Cerrejón Formation. These layers are most likely from a swampy to lake like environment.

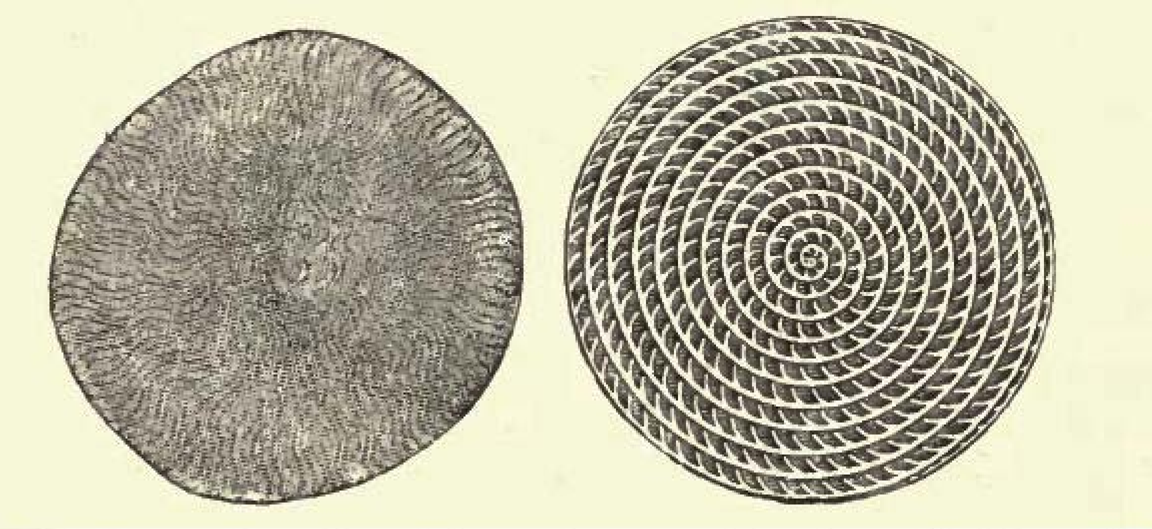
Nummulite

Nummulites **Fossil range: Tertiary**	
Scientific classification	
Kingdom:	Rhizaria
Phylum:	Foraminifera
Class:	Granuloreticulosa
Order:	Rotaliida
Superfamily:	Nummulitacea
Family:	Nummulitidae
Genus:	***Nummulites*** Lamarck, 1801
Species	
Numerous	

Fossil nummulitid foraminiferans showing microspheric and megalospheric individuals; Eocene of the United Arab Emirates; scale in mm.

Fossil Nummulites in Urbasa, Basque Country

A **nummulite** is a large lenticular fossil, characterized by its numerous coils, subdivided by septa into chambers. They are the shells of the fossil and present-day marine protozoan ***Nummulites***, a type of foraminiferan. Nummulites commonly reach 6 cm (2.4 inches) in diameter and are common in Tertiary marine rocks, particularly around the Mediterranean (e.g. Eocene limestones from Egypt). Fossils up to 6 inches wide are found in the Middle Eocene rocks of Turkey.[2] They are valuable as index fossils.



-A Nummulite, viewed from above, and horizontally bisected.

The name "*Nummulites*" is a diminutive form of the Latin *nummulus* meaning "little coin", a reference to their shape. In 1913, Randolph Kirkpatrick published a book, *The Nummulosphere: an account of the Organic Origin of so-called Igneous Rocks and Abyssal Red Clays*, proposing the theory that all rocks have been constructed by the accumulation of forams such as *Nummulites*.

Petrocardium

Petrocardium **Fossil range: Mid - late Paleocene60–58 Ma**	
Scientific classification	
Kingdom:	Plantae
(unranked):	Angiosperms
(unranked):	Monocots
Order:	Alismatales
Family:	Araceae
Subfamily:	*incertae sedis*
Genus:	***Petrocardium*** *Herrera* et al
Species	
• *Petrocardium*	

cerrejonense
- *Petrocardium wayuuorum*

Petrocardium is an extinct genus of monocot plant in the family Araceae. At present it contains only two species ***Petrocardium cerrejonense*** and ***Petrocardium wayuuorum***, the type species. The genus is solely known from the Middle to late Paleocene (about 60 to 58 Ma), Cerrejón Formation deposits in Colombia.

History and classification

The genus is known only from the two holotype specimens, number ING-0902, type specimen for *Petrocardium wayuuorum* and ING-0804, type specimen for *Petrocardium cerrejonense*. The leaves are currently residing in the collections housed by the Colombian Geological Institute in Bogotá, Colombia. Both ING-0902 and ING-0804 were collected from Cerrejón Formation exposures in the Cerrejón coal mine, located in the Rancheria Basin, Colombia. They were first studied by a group of researchers from Florida Museum of Natural History, the Smithsonian Museum of Natural History and lead by Fabiany Herrera from the Smithsonian Tropical Research Institute. Herrera and associates published their 2008 type description in the *American Journal of Botany*.

The generic epithet *Petrocardium* is Greek in derivation and is a combination of the words *petro* meaning "rock" and *cardium* which means "heart" and references the heart shaped nature of the leaf fossils in the rocks. The specific epithet "*wayuuorum*" was chosen by the authors to honor the Wayuu Amerindian tribe which lives in the Rancheria Basin area of Colombia. The specific epithet "*cerrejonense*" is a derivation of Cerrejón and reflects the type locality, the Cerrejón Formation.

Description

Although several angiosperm families, such as Alismataceae and Potamogetonaceae have leaf morphologies similar to *Petrocardium*, its lack of the primary vein structure found in those families excludes them as relatives. *Petrocardium* is placed as *incertae sedis* within the Araceae due to the unique combination of leaf morphology characteristics present in both species. Of the modern Araceae genera, *Petrocardium* is most similar to the modern tropical genus *Anthurium* in tribe Pothoeae. However it is not close in structure to the other three genera in the tribe, *Pedicellarum*, *Pothoidium* and *Pothos*. This disparity lead the research team to leave the genus unplaced as to subfamily and tribe. Overall the genus possesses entire margined leaves with a generally ovate shape. The leaf apex is long and tapers to a point, while the base is heart to arrowhead shaped. The overall depositional environment was that of sedimentation associated with a fluvial channel area formed within a Neotropical rainforest basin.

Petrocardium wayuuorum

The single known specimen of *P. wayuuorum*, ING-0902, was recovered from locality 0315, a 6 metres (20 ft) by 50 centimetres (20 in) lens of fine grained sandstone in the Cerrejón Formation. The specimen is missing the basal portion of the leaf but shows a smooth margin in the preserved regions of the leaf blade and was either cordate or sagittate. The overall size of the leaf was 6.2 by 3.8 centimetres (2.4 by 1.5 in) and has a vein structure similar to that of *Anthurium* species that form secondary veins which group in single cluster of veins parallel to the outer margin of the leaf. This secondary vein structure is used to distinguish *P. wayuuorum* from *P. cerrejonense*.

Petrocardium cerrejonense

As with *P. wayuuorum*, *P. cerrejonense* is known from only one partial leaf and specimen ING-0804, is also from locality 0315. The specimen is incomplete with only portions of the tip and middle area of the leaf blade known. The overall size of the leaf was over 9.5 by 24.3 centimetres (3.7 by 9.6 in), with an acuminate tip and smooth margin. *P. cerrejonense* has a vein structure similar to that of *Anthurium* species which form secondary veins which group into two clusters of veins parallel to the outer margin of the leaf and the secondary vein structure is used to distinguish *P. cerrejonense* from *P. wayuuorum*.

Chapter- 3

Paleocene Plants

Banksieaephyllum

Banksieaephyllum **Fossil range: Paleocene - early Miocene**	
Scientific classification	
Kingdom:	Plantae
(unranked):	Angiosperms
(unranked):	Eudicots
Order:	Proteales
Family:	Proteaceae
Tribe:	*Banksieae*
Genus:	***Banksieaephyllum*** Cookson & Duigan

Banksieaephyllum is a plant genus that encompasses organically preserved fossil leaves that can be attributed to the Proteaceae tribe *Banksieae*, but cannot be attributed to a genus.

Before 1950, many fossil leaves were attributed to the genera *Banksia* and *Dryandra*. In most cases, leaves with triangular lobes were associated with *Dryandra* and leaves with serration were associated with *Banksia*. In 1950, Isabel Cookson and Suzanna Duigan showed this policy to be flawed, by demonstrating that the leaves of the two genera cannot be reliably distinguished. Since these two genera then comprised tribe *Banksieae*, Cookson and Duigan erected *Banksieaephyllum* to contain such leaves.

Since then, *Banksia* and *Dryandra* have been further grouped into subtribe *Banksiinae* and another subtribe, *Musgraveinae*, erected to contain two new genera. Interpretations of *Banksieaephyllum* are now no longer consistent. Some botanists continue to hold that *Banksieaephyllum* is for fossil leaves that can be attributed to *Banksieae* but not to a genus; that is, they include fossils that cannot be excluded from the *Musgravinae*. Others hold that Cookson and Duigan's intentions were for the genus to hold fossil leaves that are known to be *Dryandra* or *Banksia*, but cannot be attributed to either with certainty; thus they now define the genus in terms of *Banksinae* rather than *Banksieae*.

Dryandra has now been transferred into *Banksia*. Although as yet undetermined, the latter interpretation would result in *Banksieaephyllum* becoming a nomenclatural synonym of *Banksia*.

Fossils ascribed to *Banksieaephyllum* have been found in sediments dating from the Paleocene to early Miocene. As of 1998, the most recent synopsis, there are 16 species, including:

- *Banksieaephyllum acuminatum*
- *Banksieaephyllum angustum*
- *Banksieaephyllum attenuatum*
- *Banksieaephyllum cuneatum*
- *Banksieaephyllum elongatus*
- *Banksieaephyllum fastigatum*
- *Banksieaephyllum incisum*
- *Banksieaephyllum longifolium*
- *Banksieaephyllum obovatum*
- *Banksieaephyllum pinnatum*
- *Banksieaephyllum praefastigatum*
- *Banksieaephyllum regularis*
- *Banksieaephyllum urnifome*
- *Banksieaephyllum westdaliense*

Pinus peregrinus

Pinus pereginus **Fossil range: Paleocene (Clarkforkian)**	
Scientific classification	
Kingdom:	Plantae
Division:	Pinophyta
Class:	Pinopsida
Order:	Pinales
Family:	Pinaceae
Genus:	*Pinus*
Species:	†***P. peregrinus***
Binomial name	

†*Pinus peregrinus*

Hickey, 1977

Pinus peregrinus is an extinct species of pine in the Pinaceae family known from Clarkforkian age Paleocene fossils found in western North Dakota, USA.

The species was described from three wing seed specimens found at localities 14051a and 14083 in the Bear Den member of the Golden Valley Formation with associated needles from the Heart River Bluffs area, site 14051a, provisionally assigned to the species also. The Bear Den member outcrops at a number of sites in western North Dakota and is designated the type locality.

The holotype specimen, number *PU 20091*, is preserved in the Princeton University collections and paratype specimens are in the National Museum of Natural History collections of the Smithsonian Institution. The specimens were studied by paleobotanist Leo J. Hickey of the Yale University Geology Department. Dr Hickey published the 1977 type description for *P. peregrinus* in the Geological Society of America memoir 150, *Stratigraphy and Paleobotany of the Golden Valley Formation (Early Tertiary) of Western North Dakota*. Dr Hickey chose the specific name *peregrinus*, which is Latin meaning "stranger" or "newcomer" noting the species to be the first megafossil record for the pine family to be described from Rocky Mountains and Great Plains Paleocene rocks.

The winged seeds of *Pinus peregrinus* are between 20 and 23 millimetres (0.79 and 0.91 in) long and have a nutlet located in the base of the wing to one side of the wing axis. The small, 4 to 5 millimetres (0.16 to 0.20 in) long nutlet is three sided and generally deltoid to ovoid in shape. The wing possesses a thickened inside margin that is straight, while the thin outside margin arches from nutlet to distal tip of the wing. The wing membrane is slightly striated parallel to the wing margins and curving towards the outside margin near the tip. This combination of characters is specific to the genus *Pinus* and the seeds are most similar to the modern *Pinus resinosa* and *Pinus tropicalis*. The needles provisionally included in *P. peregrinus* can reach up to 10 centimetres (3.9 in) long with a distinct midrib.

Chapter- 4

Danian and Landen Formation

Danian

The **Danian** is the oldest age or lowermost stage of the Paleocene epoch or series, the Paleogene period or system and the Cenozoic era or erathem. The beginning of the Danian age (and the end of the precessing Maastrichtian age) is at the Cretaceous-Tertiary extinction event 65.5 ± 0.3 Ma (million years ago). The age ended 61.7 ± 0.2 Ma, being followed by the Selandian age.

Stratigraphic definitions

The Danian was introduced in scientific literature by German-Swiss geologist Pierre Jean Édouard Desor in 1847. It is named after the Latin name for Denmark. The Montian stage from Belgian stratigraphy (named after the city of Mons) is now considered a junior synonym and is no longer in use.

The base of the Danian is defined at the iridium anomaly which characterized the Cretaceous-Paleogene boundary in stratigraphic sections worldwide. A section in El Kef, Tunisia was appointed as a reference profile (GSSP) for this important boundary.

The top of the Danian stage (the base of the Selandian) is close to the boundary between biozones NP4 and NP5 from marine biostratigraphy. It is slighltly after the first appearances of many new species of the calcareous nannoplankton genus *Fasciculithus* (*F. ulii*, *F. billii*, *F. janii*, *F. involutus*, *F. tympaniformis* and *F. pileatus*) and close to the first appearance of calcareous nannoplankton species *Neochiastozygus perfectus*.

The Danian stage overlaps the Puercan and Torrejonian North American Land Mammal Ages and the Shanghuan and lowest part of the Nongshanian Asian Land Mammal Ages. It includes the oldest Mammal Paleogene zones, all included in the 1 - 5 group.

Palaeontology

Though the non-avian dinosaurs were gone, the mammals and other land animals remained small, none bigger than a large domestic cat. But most of the mammals' orders already had appeared. Numerous lineages of modern birds also survived, particularly in the area around Australia but also elsewhere, e.g. *Scaniornis* of the North Sea region. The oceans remained much the same as the Late Cretaceous seas, only that there was less life, no marine reptiles and other lesser known animals.

Landen Formation

The **Landen Formation** (abbreviation: LA) is a lithostratigraphic unit (a set of rock strata) in the subsurface of the Netherlands. This formation shares its name with the Belgian Landen Group, but the Belgian unit is thinner and has different definitions. The Landen Formation consists of shallow marine and lagoonal sediments (mostly clay, sandy clay and marl) from the late Paleocene to early Eocene (between 58 and 54 million years old).

Lithology

The Landen Formation can be maximally 150 meters in thickness. It is subdivided into five only regionally recognized members:

- The Swalmen Member, lagoonal clay, sometimes with small lignite layers;
- The Reusel Member, green sandy clay, loam and sand;
- The Liessel Member, mica, pyrite and glauconite bearing clay, containing plant fossils;
- The Orp Member, greenish grey sand;
- The Gelinden Member, calcareous clay.

Some of the sandy layers can have been made into sandstone by diagenetic processes. The whole formation is interpreted as one megacycle: the lower parts (Swalmen and Orp) represent a marine transgression, while the upper parts (Reusel and Liessel) represent a regression.

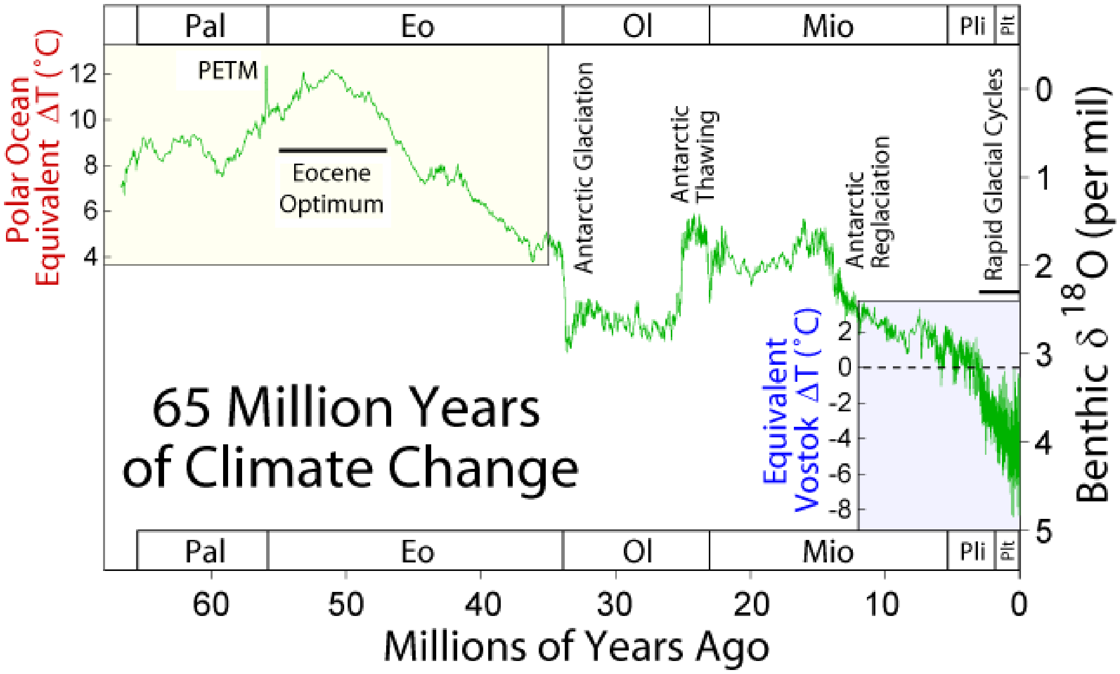
Stratigraphy

The Dutch Landen Formation is not totally equal with the Belgian Landen Group. In Belgium, the Orp and Gelinden Members are seen as one separate formation, the Heers Formation. The Dutch Landen Formation correlates with the Belgian Heers Formation, Hannut Formation, Tienen Formation and parts of the Opglabbeek Formation.

The Landen Formation lies normally on top of a nonconformity with the Dutch Chalk Group, which is usually represented by the early Paleocene Houthem Formation. In most places the early Eocene Dongen Formation is found on top of the Landen Formation.

Chapter- 5

Paleocene–Eocene Thermal Maximum



Climate change during the last 65 million years as expressed by the oxygen isotope composition of benthic foraminifera. The Paleocene-Eocene Thermal Maximum (PETM) is characterized by a brief but prominent negative excursion, attributed to rapid warming. Note that the excursion is understated in this graph due to the smoothing of data.

The most extreme change in Earth surface conditions during the Cenozoic Era began at the Paleocene/Eocene boundary, 55.8 million years ago. This event, the **Paleocene–Eocene Thermal Maximum** (**PETM**, alternatively "**Eocene thermal maximum 1**" (**ETM1**) and formerly known as the "**Initial Eocene**" or "**Late Paleocene Thermal Maximum**", (**IETM/LPTM**)), was associated with rapid (in geological terms) global warming, profound changes in marine and terrestrial ecosystems and major perturbations in the carbon cycle.

Global temperatures rose by about 6°C (11°F) at the start of the PETM, which appears to have occurred within 20,000 years. At nearly the same time, many deep-sea benthic foraminifera went extinct and mammalian life on land experienced a major turnover, which marks the emergence of numerous modern mammalian orders. The event is linked to a prominent negative excursion in carbon stable isotope ($\delta^{13}C$) records from across the globe and dissolution of carbonate deposited on the seafloor of all ocean basins. The latter observations strongly suggest that a massive input of 13C-depleted carbon entered the ocean or atmosphere at the start of the PETM. The event has become a focal point of geoscience investigations because it is perhaps the best past analog in which to understand the fate and consequences of current fossil fuel emissions on an intermediate time-scale (>1000 years).

Setting

The configuration of oceans and continents was somewhat different during the Eocene. The Panama Isthmus did not yet connect North and South America, which allowed circulation between the Pacific and Atlantic oceans. Further, the Drake Passage was closed, perhaps preventing the thermal isolation of Antarctica. Although various proxies for past atmospheric CO_2 levels in the Eocene do not agree in absolute terms, all suggest that levels then were much higher than at present. In any case, there were no significant ice sheets during this time.

Earth surface temperatures increased by about 6°C from the late Paleocene through the early Eocene, culminating in the "Early Eocene Climatic Optimum" (EECO). Superimposed on this long-term, gradual warming were at least two (and likely more) "hyperthermals". These can be defined as geologically brief (<200,000 year) events characterized by rapid global warming, major changes in the environment and massive carbon addition. Of these, the PETM was the most extreme and perhaps the first (at least within the Cenozoic). Another hyperthermal clearly occurred at approximately 53.7 Ma and is now called ETM-2 (also referred to as H-1, or the Elmo event). However, additional hyperthermals likely occurred at about 53.6 Ma (H-2), 53.3 (I-1), 53.2 (I-2) and 52.8 Ma (informally called K, X or ETM-3). The number, nomenclature, absolute ages and relative global impact of the Eocene hyperthermals are the source of considerable current research. Whether they only occurred during the long-term warming and whether they are causally related to apparently similar events in older intervals of the geological record (e.g., the Toarcian turnover of the Jurassic) are open issues.

Evidence for global warming

Average global temperatures increased by ~6°C (11°F) within about 20,000 years. This is based on several lines of evidence. There is a prominent (>1‰) negative excursion in the $\delta^{18}O$ of foraminifera shells, both those made in surface and deep ocean water. Because there was a paucity of continental ice in the early Paleogene, the shift in $\delta^{18}O$ very likely signifies a rise in ocean temperature. The temperature rise is also supported by analyses of foraminifera Mg/Ca and ratios of certain organic compounds (TEX_{86}).

Due to the positive feedback effect of melting ice reducing albedo, temperature increases would have been greatest at the poles, which reached an average annual temperature of

10 to 20 °C (50 to 68 °F); the surface waters of the northernmost Arctic ocean warmed, seasonally at least, enough to support tropical lifeforms requiring surface temperatures of over 22°C.

Evidence for carbon addition

Clear evidence for massive addition of ^{13}C-depleted carbon at the onset of the PETM comes from two observations. First, a prominent negative excursion in the carbon isotope composition ($\delta^{13}C$) of carbon-bearing phases characterizes the PETM in numerous widespread locations from a range of environments. Second, carbonate dissolution marks the PETM in sections from the deep-sea.

The total mass of carbon injected to the ocean and atmosphere during the PETM remains the source of debate. In theory, it can be estimated from the magnitude of the $\delta^{13}C$ excursion, the amount of carbonate dissolution on the seafloor, or ideally both. However, the shift in the $\delta^{13}C$ across the PETM depends on the location and the carbon-bearing phase analyzed. In some records of bulk carbonate, it is about 2‰; in some records of terrestrial carbonate or organic matter it exceeds 6‰. Carbonate dissolution also varies throughout different ocean basins. It is extreme in parts of the north and central Atlantic Ocean but far less pronounced in the Pacific Ocean. With available information, estimates of the carbon addition range from about 2500 to over 6800 gigatons

The timing of the PETM $\delta^{13}C$ excursion has been calculated in two complementary ways. The iconic core covering this time period is the ODP's Core 690 and the timing is based exclusively on this core's record. The original timing was calculated assuming a constant sedimentation rate. This model was improved using the assumption that ^{3}He flux is constant; this cosmogenic nuclide is produced at a (roughly) constant rate by the sun and there is little reason to assume large fluctuations in the solar wind across this short time period. Both models have their failings, but agree on a few points. Importantly, they both detect two steps in the drop of $\delta^{13}C$, each lasting about 1,000 years and separated by about 20,000 years. The models diverge most in their estimate of the recovery time, which ranges from 150,000 to 30,000 years. There is other evidence to suggest that warming predated the $\delta^{13}C$ excursion by some 3,000 years.

Effects

The climate would also have become much wetter, with the increase in evaporation rates peaking in the tropics. Deuterium isotopes reveal that much more of this moisture was transported polewards than normal. This would have resulted in the largely isolated Arctic ocean's taking on a more freshwater character as northern hemisphere rainfall was channelled towards it.

Sea level

Despite the global lack of ice, the sea level would have risen due to thermal expansion. Evidence for this can be found in the shifting palynomorph assemblages of the Arctic ocean, which reflect a relative decrease in terrestrial organic material compared to marine organic matter.

Circulation

At the start of the PETM, the ocean circulation patterns changed radically in the course of under 5,000 years. Global-scale current directions reversed; for example, deep water in the Atlantic flowed from north to south instead of the usual south to north. This "backwards" flow persisted for 40,000 years. Such a change would transport warm water to the deep oceans, enhancing further warming.

Lysocline

The lysocline marks the depth at which carbonate starts to dissolve (above the lysocline, carbonate is oversaturated): today, this is at about 4 km, comparable to the median depth of the oceans. This depth depends on (among other things) temperature and the amount of CO_2 dissolved in the ocean. Adding CO_2 initially shallows the lysocline, resulting in the dissolution of deep water carbonates. This deep-water acidification can be observed in ocean cores, which show (where bioturbation has not destroyed the signal) an abrupt change from grey carbonate ooze to red clays (followed by a gradual grading back to grey). It is far more pronounced in north Atlantic cores than elsewhere, suggesting that acidification was more concentrated here, related to a greater rise in the level of the lysocline. In parts of the southeast Atlantic, the lysocline rose by 2 km in just a few thousand years.

Anoxia?

In parts of the oceans, especially the north Atlantic Ocean, bioturbation is absent. This may be due to bottom-water anoxia, or by changing ocean circulation patterns changing the temperatures of the bottom water. However, many ocean basins remain bioturbated through the PETM.

Life

The PETM is accompanied by a mass extinction of 35-50% of benthic foraminifera (especially in deeper waters) over the course of ~1,000 years - the group suffering more than during the dinosaur-slaying K-T extinction. Contrarily, planktonic foraminifera diversified and dinoflagellates bloomed. Success was also enjoyed by the mammals, who radiated profusely around this time.

The deep-sea extinctions are difficult to explain, as many were regional in extent (mainly affecting the north Atlantic). General hypotheses such as a temperature-related reduction in oxygen availability, or increased corrosiveness due to carbonate-undersaturated deep waters, are insufficient as explanations. The only factor which was global in extent was an increase in temperature and it appears that the majority of the blame must rest upon its shoulders. Regional extinctions in the North Atlantic can be attributed to increased deep-sea anoxia, which could be due to the slowdown of overturning ocean currents, or the release and rapid oxidation of large amounts of methane.

In shallower waters, it's undeniable that increased CO_2 levels result in a decreased oceanic pH, which has a profound negative effect on corals. Experiments suggest it is also very harmful to calcifying plankton. However, the strong acids used to simulate the natural increase in acidity which would result from elevated CO_2 concentrations may have given misleading results and the most recent evidence is that coccolithophores (*E. huxleyi* at least) become *more*, not less, calcified and abundant in acidic waters. Interestingly, no change in the distribution of calcareous nanoplankton such as the coccolithophores can be attributed to acidification during the PETM. Acidification did lead to an abundance of heavily calcified algae and weakly calcified forams.

The increase in mammalian abundance is intriguing. There is no evidence of any increased extinction rate among the terrestrial biota. Increased CO_2 levels may have promoted dwarfing – which may (perhaps?) have encouraged speciation. Many major mammalian orders – including the Artiodactyla, horses and primates – appeared and spread across the globe 13,000 to 22,000 years after the initiation of the PETM.

Possible causes

Discriminating between different causes of the PETM is difficult. Temperatures were rising globally at a steady pace and a mechanism must be invoked to produce a sudden spike which may have been accentuated by positive feedbacks. The biggest aid in disentangling these factors comes from a consideration of the carbon isotope mass balance. We know the entire exogenic carbon cycle (i.e. the carbon contained within the oceans and atmosphere, which can change on short timescales) underwent a −0.2 % to −0.3 % perturbation in $\delta^{13}C$ and by considering the isotopic signatures of other carbon reserves, can consider what mass of the reserve would be necessary to produce this effect. The assumption underpinning this approach is that the mass of exogenic carbon was the same in the Paleogene as it is today - something which is very hard to confirm.

Volcanic activity

In order to balance the mass of carbon and produce the observed $\delta^{13}C$ value, at least 1,500 gigatons of carbon would have to have been degassed from the mantle via volcanoes over the course of the two 1,000 year steps. To put this in perspective, this is about 200 times the background rate of degassing for the rest of the Paleogene. There is no indication that such a burst of volcanic activity has occurred at any point in Earth's history. However, substantial volcanism had been active in East Greenland for around the preceding million years or so, but this struggles to explain the rapidity of the PETM. Even if the bulk of the 1,500 gigatons of carbon was released in a single pulse, further feedbacks would be necessary to produce the observed isotopic excursion.

On the other hand, there are suggestions that surges of activity occurred in the later stages of the volcanism and associated continental rifting. Intrusions of hot magma into carbon-rich sediments may have triggered the degassing of isotopically light methane in sufficient volumes to cause global warming and the observed isotope anomaly. This hypothesis is documented by the presence of extensive intrusive sill complexes and thousands of kilometer-sized hydrothermal vent complexes in sedimentary basins on the mid-Norwegian margin and west of Shetland. Volcanic eruptions of a large magnitude can impact global climate, reducing the amount of solar radiation reaching the Earth's surface, lowering temperatures in the troposphere and changing atmospheric circulation patterns. Large-scale volcanic activity may last only a few days, but the massive outpouring of gases and ash can influence climate patterns for years. Sulfuric gases convert to sulfate aerosols, sub-micron droplets containing about 75 percent sulfuric acid. Following eruptions, these aerosol particles can linger as long as three to four years in the stratosphere. Further phases of volcanic activity could have triggered the release of more methane and caused other early Eocene warm events such as the ETM2. It has also been suggested that volcanic activity around the Caribbean may have disrupted the circulation of oceanic currents, amplifying the magnitude of climate change.

Comet impact

A briefly popular theory held that a ^{12}C-rich comet struck the earth and initiated the warming event. A cometary impact coincident with the P/E boundary can also help explain some enigmatic features associated with this event, such as the iridium anomaly at Zumaya, the abrupt appearance of kaolinitic clays with abundant magnetic nanoparticles on the coastal shelf of New Jersey and especially the nearly simultaneous onset of the CIE and the thermal maximum. Indeed, a key feature and testable prediction of a comet impact is that it should produce virtually instantaneous environmental effects in the atmosphere and surface ocean with later repercussions in the deeper ocean. Even allowing for feedback processes, this would require at least 100 gigatons of extraterrestrial carbon. Such a catastrophic impact should have left its mark on the globe. Unfortunately, the evidence put forward does not stand up to scrutiny. An unusual 9-meter-thick clay layer supposedly formed soon after the impact, containing unusual amounts of magnetism, but it formed too slowly for these magnetic particles to have been a result of the comet's impact - it turns out they were created by bacteria. Further, an iridium anomaly - often an indicator of extraterrestrial impact - observed in Spain is far too small to denote a comet impact.

Burning of peat

This combustion of prodigious quantities of peat was once postulated, because there was likely a greater mass of carbon stored as living terrestrial biomass during the Paleocene than there is today since plants in fact grew more vigorously during the period of the PETM. This theory was refuted, because in order to produce the δ^{13}C excursion observed, over 90% of the Earth's biomass would have to have been combusted. However, the Paleocene is also recognized as a time of significant peat accumulation worldwide. A comprehensive search failed to find evidence for the combustion of fossil organic matter, in the form of soot or similar particulate carbon.

Orbital forcing

The presence of later (smaller) warming events of a global scale, such as the Elmo horizon (aka ETM2), has led to the hypothesis that the events repeat on a regular basis, driven by maxima in the 400,000 and 100,000 year eccentricity cycles in the Earth's orbit. The current warming period is believed to last another 50,000 years due to a minimum in the eccentricity of the Earth's orbit. Orbital increase in insolation (and thus temperature) would force the system over a threshold and unleash positive feedbacks.

Methane release

None of the above causes are alone sufficient to cause the carbon isotope excursion or warming observed at the PETM. The most obvious feedback mechanism that could amplify the initial perturbation is that of clathrates. At certain temperature and pressure conditions, methane – which is being produced continually by decomposing microbes in sea bottom sediments – is stable in a complex with water, which forms ice-like cages trapping the methane in solid form. As temperature rises, the pressure required to keep this clathrate configuration stable increases, so shallow clathrates dissociate, releasing methane gas to make its way into the atmosphere. Since biogenic clathrates have a $\delta^{13}C$ signature of −60 ‰ (inorganic clathrates are the still rather large −40 ‰), relatively small masses can produce large $\delta^{13}C$ excursions. Further, methane is a potent greenhouse gas as it is released into the atmosphere, so it causes warming and as the ocean transports this warmth to the bottom sediments, it destabilises more clathrates. It would take around 2,300 years for an increased temperature to diffuse warmth into the sea bed to a depth sufficient to cause a release of clathrates, although the exact time-frame is highly dependent on a number of poorly constrained assumptions. Ocean warming due to flooding and pressure changes due to a sea-level drop may have caused clathrates to become unstable and release methane. This can take place over as short of a period as a few thousand years. The reverse process, that of fixing methane in clathrates, occurs over a larger scale of tens of thousands of years.

In order for the clathrate hypothesis to work, the oceans must show signs of having been warmer slightly before the carbon isotope excursion, because it would take some time for the methane to become mixed into the system and $\delta^{13}C$-reduced carbon to be returned to the deep ocean sedimentary record. Until recently, the evidence suggested that the two peaks were in fact simultaneous, weakening the support for the methane theory. But recent (2002) work has managed to detect a short gap between the initial warming and the $\delta^{13}C$ excursion. Chemical markers of surface temperature (TEX_{86}) also indicate that warming occurred around 3,000 years before the carbon isotope excursion, but this does not seem to hold true for all cores. Notably, deeper (non-surface) waters do not appear to display evidence of this time gap.

Analysis of these records reveals another interesting fact: planktonic (floating) forams record the shift to lighter isotope values earlier than benthic (bottom dwelling) forams. The lighter (lower $\delta^{13}C$) methanogenic carbon can only be incorporated into the forams' shells after it has been oxidised. A gradual release of the gas would allow it to be oxidised in the deep ocean, which would make benthic forams show lighter values earlier. The fact that the planktonic forams are the first to show the signal suggests that the methane was released so rapidly that its oxidation used up all the oxygen at depth in the water column, allowing some methane to reach the atmosphere unoxidised, where atmospheric oxygen would react with it. This observation also allows us to constrain the duration of methane release to under around 10,000 years.

Ocean circulation

The large scale patterns of ocean circulation are important when considering how heat was transported through the oceans. Our understanding of these patterns is still in a preliminary stage. Models show that there are possible mechanisms to quickly transport heat to the shallow, clathrate-containing ocean shelves, given the right bathymetric profile, but the models cannot yet match the distribution of data we observe. "Warming accompanying a south-to-north switch in deepwater formation would produce sufficient warming to destabilize seafloor gas hydrates over most of the world ocean to a water depth of at least 1900 m." (K. Bice and J. Marotzke) This destabilization could have resulted in the release of more than 2000 gigatons of methane carbon from clathrate zone of the ocean floor.

Recovery

The $\delta^{13}C$ record records a duration of around 170,000 to 120,000 years, relatively rapid compared to the residence time of carbon in the modern atmosphere (100-200 thousand years). A satisfactory explanation of this rapid recovery must incorporate a feedback system.

The most likely method of recovery invokes an increase in biological productivity, transporting carbon to the deep ocean. This would be assisted by higher global temperatures and CO_2 levels, as well as an increased nutrient supply (which would result from higher continental weathering due to higher temperatures and rainfall; volcanics may have provided further nutrients). Evidence for higher biological productivity comes in the form of biogenic Barium. However, this proxy may instead reflect the addition of Barium dissolved in methane. Diversifications suggest that productivity increased in near-shore environments, which would have been warm and fertilized by run-off - outweighing the reduction in productivity in the deep oceans.

Chapter- 6

Selandian and Thanetian

Selandian

The **Selandian** is in the geologic timescale an age or stage in the Paleocene. It spans the time between 61.7 ± 0.2 Ma and 58.7 ± 0.2 Ma (million years ago). It is preceded by the Danian and followed by the Thanetian. Sometimes the Paleocene is subdivided in subepochs, in which the Selandian forms the "Middle Paleocene".

Stratigraphic definition

The Selandian was introduced in scientific literature by Alfred Rosenkrantz in 1924. It is named after the Danish island of Zealand (Danish: *Sjælland*).

The base of the Selandian is close to the boundary between biozones NP4 and NP5. It is slighltly after the first appearances of many new species of the calcareous nannoplankton genus *Fasciculithus* (*F. ulii*, *F. billii*, *F. janii*, *F. involutus*, *F. tympaniformis* and *F. pileatus*) and close to the first appearance of calcareous nannoplankton species *Neochiastozygus perfectus*. At the original type location in Denmark the base of the Selandian is an unconformity. The official GSSP was established in the Zumaia section (43° 18'N, 2° 16'W) at the beach of Itzurun, Pais Vasco, northern Spain.

The top of the Selandian (the base of the Thanetian) is laid at the base of magnetic chronozone C26n.

The Selandian stage overlaps with the lower part of the Tiffanian North American Land Mammal Age, the Peligran, Tiupampan and lower Itaboraian South American Land Mammal Ages and part of the Nongshanian Asian Land Mammal Age. It is coeval with the lower part of the Wangerripian stage from the Australian regional timescale.

Thanetian

The **Thanetian** is, in the ICS' Geologic timescale, the latest age or uppermost stratigraphic stage of the Paleocene Epoch or series. It spans the time between 58.7 ± 0.2 Ma and 55.8 ± 0.2 Ma (million years ago). The Thanetian is preceded by the Selandian age and followed by the Ypresian age (part of the Eocene). The Thanetian is sometimes referred to as the Late Paleocene sub-epoch.

Stratigraphic definition

The Thanetian was established by Swiss geologist Eugène Renevier in 1873. The Thanetian is named after the area of Kent (southern England) known as the Isle of Thanet. It shares this name with the Thanet Sand Formation, the oldest Cenozoic deposit of the London Basin.

The base of the Thanetian stage is laid at the base of magnetic chronozone C26n. The references profile (Global Boundary Stratotype Section and Point) is in the Zumaia section (43° 18'N, 2° 16'W) at the beach of Itzurun, Pais Vasco, northern Spain.

The top of the Thanetian stage (the base of the Ypresian) is defined at a strong negative anomaly in $\delta^{13}C$ values at the global thermal maximum at the Paleocene-Eocene boundary.

The Thanetian stage is coeval the lower Neustrian European Land Mammal Mega Zone (it spans the Mammal Paleogene zone 6 and part of zones 1 through 5.), the upper Tiffanian and Clarkforkian North American Land Mammal Ages, the Riochican and part of the Itaboraian South American Land Mammal Ages and the upper Nongshanian and Gashatan Asian Land Mammal Ages. The Thanetian is contemporary with the middle Wangerripian regional stage of Australia and the upper Ynezian regional stage of California. It overlaps the obsolete regional stages Landenian and Heersian of Belgium.

Palaeontology

The *Sézanne flora* is a fossil assemblage preserved in freshwater limestone deposits at Sézanne, laid down during the Thanetian age, when Europe enjoyed a tropical climate. In the lagerstätte, leaves, entire flowers and seeds are minutely preserved.

Chapter- 7

Paleocene Impact Craters

Boltysh crater

Crater characteristics

Planet	Earth
Coordinates	48°54′N 32°15′E / 48.9°N 32.25°ECoordinates: 48°54′N 32°15′E / 48.9°N 32.25°E
Diameter	24 km
Depth	550 m

Location of the Boltysh Crater

The **Boltysh Crater** is an impact crater in the Kirovohrad Oblast province of Ukraine. The crater is 24 km in diameter and its age of 65.17 ± 0.64 million years, based on argon dating techniques, is within error of that of Chicxulub Crater in Mexico and the KT boundary. The Chicxulub impact is believed to have caused the mass extinction at the end of the Cretaceous era, which included the extinction of the dinosaurs. The Boltysh impact likely occurred several thousand years before Chicxulub, suggesting the extinction event may have been driven by multiple meteor strikes over an extended period of time about 65 million years ago.

Overview

Boltysh Crater is located in central Ukraine, in the basin of the Tiasmyn River, a tributary of the Dnieper River. It is 24 km in diameter and is surrounded by an ejecta blanket of breccia preserved over an area of 6500 km². It is estimated that immediately after the impact, ejecta covered an area of 25,000 km² to a depth of 1 m or greater and was some 600 m deep at the crater rim.

The crater contains a central uplift about 6 km in diameter, rising about 550 m above the base level of the crater. This uplift currently lies beneath about 500 m of sediment deposited since the impact and was discovered in the 1960s during oil exploration.

Age

When first identified, the age of the crater could only be roughly constrained between the age of the impacted rocks (the target) and the age of overlying sediments. The target rocks date from the Cenomanian (98.9 to 93.5 million years ago) and Turonian (93.5 to 89 million years ago) epochs. Bore samples of sediments overlying the crater contain fossils dating from the Paleocene epoch, 65 to 54.8 million years ago. The age of the crater was thus constrained to between 54.8 and 98.9 million years.

Subsequent radiometric dating reduced the uncertainty. The concentration of uranium-238 decay products in impact glasses from the crater were used to derive an age of 65.04 ± 1.10 million years. Analysis of argon radioactive decay products yielded an age of 65.17 ± 0.64 million years. These ages are similar to that of Chicxulub Crater. An August 2010 study of ancient fern spikes suggests the Boltysh impact likely occurred several thousand years before Chicxulub.

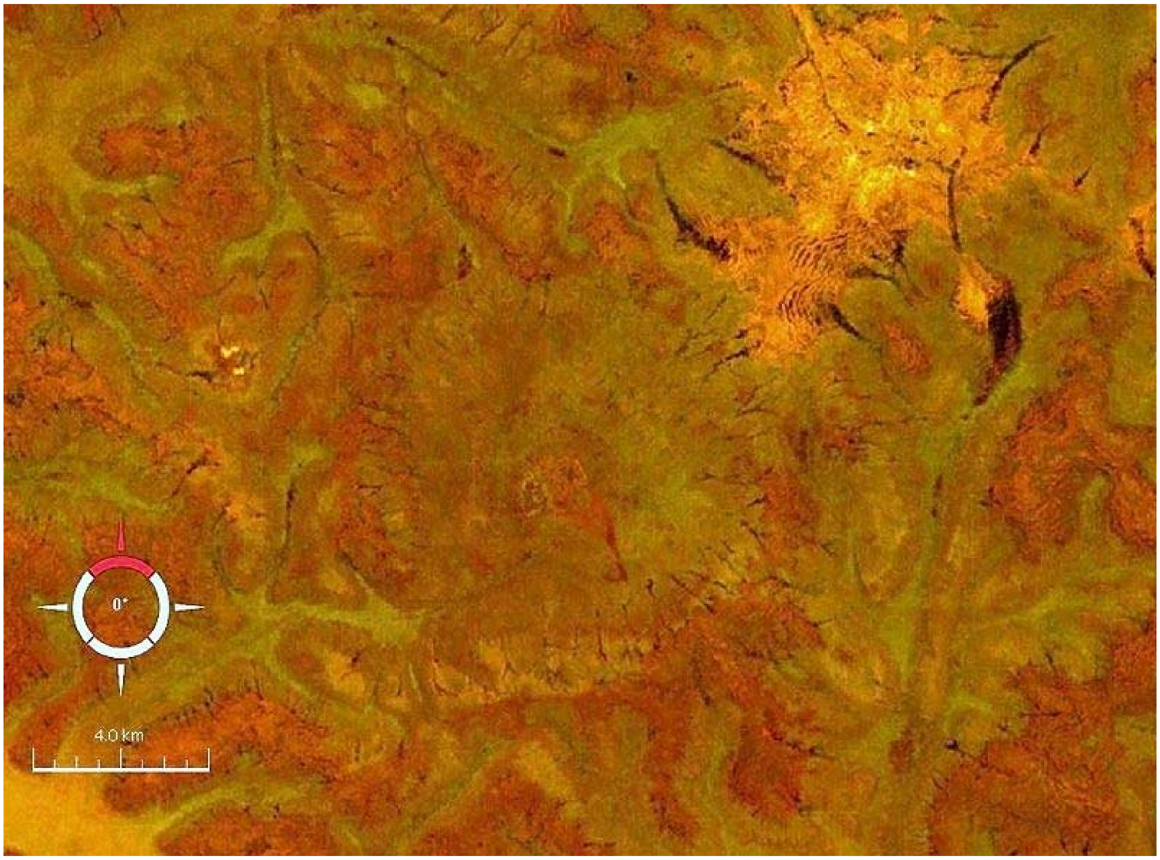
Likelihood of multiple impact

Although the ages derived for Chicxulub and Boltysh are the same to within their statistical errors, it does not necessarily follow that they formed at exactly the same time. At the estimated rate of impacts on the Earth, it would not be extremely unusual for a Boltysh-sized crater to be formed within half a million years of Chicxulub. The dating of these impact craters is not yet accurate enough to establish whether the impactors arrived thousands of years apart, perhaps as part of a generally elevated rate of impacts at that time, or were almost simultaneous, like the impacts of the fragments of Comet Shoemaker-Levy 9 on Jupiter in 1994.

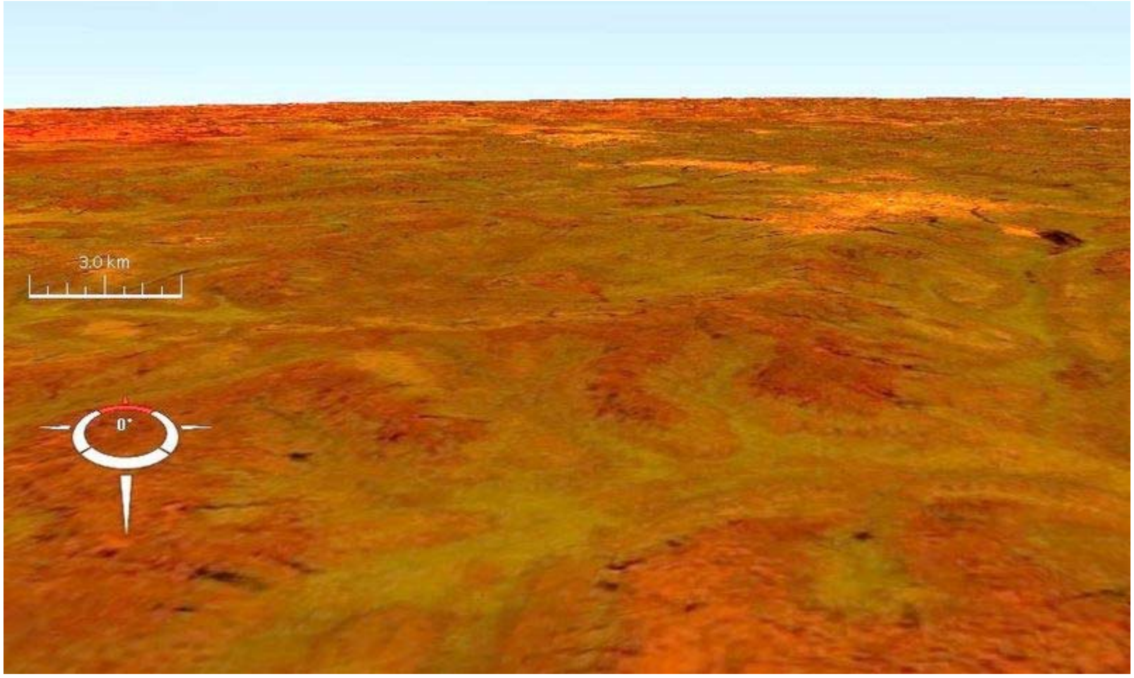
The discovery of the unconfirmed Silverpit crater and the early report of its age as 65 – 60 million years initially gave greater weight to the hypothesis that the Earth was struck by multiple impactors at this time, however, the age estimate has now been broadened to 74 – 45 million years.

The controversial Shiva crater is claimed to have formed around the same time, but its status as an impact crater is disputed.

Connolly Basin crater



Landsat image of the Connolly Basin crater (circular feature in centre); screen capture from NASA World Wind



Oblique Landsat image draped over digital elevation data (x10 vertical exaggeration), Connolly Basin crater (circular depression in centre).

Connolly Basin is a 9 km-diameter impact crater located in the Gibson Desert of central Western Australia. It lies adjacent to the Talawana Track 45 km west of the junction (Windy Corner) with the Gary Highway, but is difficult to access due to the remoteness of the area. Originally thought to be a diapir (salt dome), an impact origin was first proposed in 1985.

The depression has a topographic rim 25–30 m high, while the centre displays a slight circular rise about 1 km in diameter and 5 m high exposing strongly deformed and steeply dipping bedrock interpreted as a central uplift.' Sedimentary rocks comprising the rim are of Early Cretaceous to Palaeogene age, while uplifted rocks in the centre are likely of Early Permian age, all part of the Canning Basin; the impact event itself is inferred to be of Paleocene (early Paleogene) age or later.

Eagle Butte crater

Eagle Butte is an impact crater in Alberta, Canada, named for a rural area west of the Cypress Hills.

It is 10 km in diameter and the age is estimated to be less than 65 million years (Paleocene or earlier). The crater is not exposed at the surface.

Chapter- 8

Paleocene Extinctions

Acheronodon

Acheronodon	
Conservation status	
Fossil	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Multituberculata
Family:	Microcosmodontidae
Genus:	***Acheronodon***
Species:	***A. garbani***
Binomial name	
Acheronodon garbani Archibald J.D., 1982	

Acheronodon is a genus of herbivorous arboreal mammal which belongs to the family *Microcosmodontidae* and which was endemic to North America during the Early Paleocene subepoch (65—56.8 mya) and in existence for approximately 8.2 million years.

It is a member of the extinct order *Multituberculata* and lies within the suborder *Cimolodonta.*

The species *Acheronodon garbani* is known from fossils found in the Puercan (Paleocene)-age formations of Tullock Formation in Montana (USA) and possible specimens from the Porcupine Hills in Alberta, Canada. The holotype was found in Montana.

Ankalagon saurognathus

Ankalagon saurognathus
Fossil range: Early Paleocene

Ankalagon saurognathus

Scientific classification

Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	†Mesonychia
Family:	†Mesonychidae
Genus:	***†Ankalagon*** Van Valen, 1980
Species:	***†A. saurognathus***

Binomial name

†Ankalagon saurognathus
(Wortman, in Matthew, 1897)

Synonyms

Dissacus saurognathus

Ankalagon saurognathus is an extinct carnivorous mammal of the family *Mesonychidae*, endemic to North America during the Paleocene epoch (63.3—60.2 mya), existing for approximately 3.1 million years.

Known from the Paleocene of New Mexico, *Ankalagon* is the largest mesonychid known from the Paleocene of North America and it provides the best evidence for sexual dimorphism in mesonychids.

Description

The main feature that distinguishes *A. saurognathus* from the ancestral *Dissacus* species is its size: *Ankalagon* grew to be as large as a bear, as compared to the coyote or jackal-sized species of *Dissacus*. In fact, the only North American mesonychids that surpassed *Ankalagon* in size were the larger species of the Early Eocene genus, *Pachyaena*, such as *P. gigantea* and *P. ossifraga*, which, too, grew to the size of bears.

Evidence of sexual dimorphism comes from the fact that some jawbones were larger and had more massive molar teeth better suited to crushing bones than other jawbones, suggesting that the males crushed bones.

Ecology

The strong jaws, sharp, hooked canines and triangular molars that form a shearing edge typical of other mesonychids suggest that *A. saurognathus* was a hypercarnivorous apex predator. The massive molars of the males suggest that the males were also scavengers that ate bones.

Etymology

The generic name refers to the dragon Ancalagon, who was mentioned in the Silmarillion by J.R.R. Tolkien. In the Silmarillion, Ancalagon was described as being one of the more powerful servants of the malevolent being, Morgoth, having been bred to be the fiercest, mightiest and largest dragon in all of Middle Earth. According to Tolkien, "Ancalagon" translates from Sindarin as being *anc* 'jaw', *alag* 'impetuous'.

Leigh Van Valen studied the New Mexico mesonychid *Dissacus saurognathus* and eventually came to the conclusion that *D. saurognathus* differed enough from the sympatric *D. navajovius* and from other members of the genus to merit its own genus. Van Valen intended to erect the genus "*Ancalagon*," but found that it was already occupied by a Middle Cambrian priapulid described by Simon Conway Morris, *Ancalagon minor*, a possible ancestor of the parasitic acanthocephalids.

Baiotomeus

Baiotomeus **Fossil range: Paleocene**	
Scientific classification	
Kingdom:	Animalia
Class:	Mammalia

Order: Multituberculata
Family: Ptilodontidae
Genus: ***Baiotomeus***

Species

B. douglassi
B. lamberti
B. russelli

Baiotomeus is a genus of mammals from the extinct order of Multituberculata. It is known from the Paleocene of North America.

The genus *Baiotomeus* was formally named by Krause in 1987 (Krause, 1987) and has also been known as *Mimetodon* (partly), *Neoplagiaulax* (partly) and *Ptilodus* (partly).

Species

B. douglassi

Baiotomeus douglassi is a fairly substantial multituberculate weighing almost 200 g. Remains have been found in Montana and Wyoming in the United States, in strata of the Gidley Quarry dated to the Torrejonian stage of the Paleocene.

The species was originally named *Ptilodus douglassi* by Simpson in 1935 (Simpson, 1935), but it has been reclassified several times:

- *Mimetodon douglassi* in 1940, by Jepsen
- *Neoplagiaulax douglassi* in 1974, by Schiebout

It was finally assigned to *Baiotomeus* by Hartman in 1986 — which is *before* Krause formally established the genus in 1987.

B. lamberti

Remains of *Baiotomeus lamberti* have been discovered in Montana in the United States, in the Medicine Rocks of the Tongue River Formation, which have been dated to the Paleocene.

Several specimens, including the holotype, are at the Peabody Museum of Natural History at Yale. Collected in 1958 and 1965, these were originally described as belonging to *Mimetodon*. It was given its current name in 1987 by Krause (Krause, 1987). *B. lamberti* has also been confused with *Ptilodus montanus*.

B. russelli

Baiotomeus russelli has been discovered in Alberta, Canada, in Cochrane 2 of the Paskapoo Formation, which has been dated to the lower Tiffanian stage of the Paleocene.

Remains consist of nine upper premolars, (P4), which average nearly 2.5 mm in length. This is smaller than the teeth of other genus members; from front to back, approximately 45% less than *B. douglassi* and 40% less than *B. lamberti*. The rows of cusps also display a strong curvature and the cuspate anterolabial lobe is better developed. There is more variation in the height of the cusps among the middle row. These particular premolars — P4s — have three rows of cusps, of which there seem to be about 15 or so in all. In addition, "the enamel is weakly wrinkled on all specimens". (Scott *et al.*, 2002)

According to the same authors:

At present, P4s are the only specimens from Cochrane 2 that we can identify as pertaining to *B. russelli*. Although knowledge of this species is limited, we consider its naming to be justified based on the diagnostic morphology of ultimate fourth premolars in ptilodontids generally (Krause 1982, 1987) and the unique structure of these teeth.

The species name honours L. S. Russell "for his pioneering research on the mammals from Cochrane 2". All presently identified remains are part of the collection of the University of Alberta.

Cochrane 2 has also been interpreted as correlating to the Porcupine Hills Formation, but recent studies suggest that it is part of the Paskapoo, as originally concluded by Russell in 1929.

Bisonalveus browni

Bisonalveus browni	
Conservation status	
Fossil	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Cimolesta
Family:	Pentacodontidae
Genus:	***Bisonalveus***

Species:	***B. browni***

Binomial name

Bisonalveus browni
Gazin, 1956

Bisonalveus browni is an extinct mammal, once believed to be related to the modern pangolin.

It was discovered in 1956 in Alberta, Canada. It is known primarily from fossil jaws dating back 60 million years ago, during the Palaeocene epoch. This ancient mammal was probably something like our modern shrews.

Interestingly, the canine teeth in *Bisonalveus* have grooves that may have been used for delivering a venomous bite. The canines that would contain venom do not correspond with the lower jaw, rendering these teeth as deadly fangs, as in many species of poisonous snakes. There are few modern mammals that are venomous. The male platypus has a hollow foot spur attached to a venom sac. The only other venomous mammals are four species of shrew and the two species of solenodon which have venomous saliva and the slow loris which has poison glands on its arms. Possibly like the modern solenodon, *Bisonalveus* bit its victims to inject its toxic saliva and buried the remains in a cache for later consumption. However, because other nonvenomous mammals, such as baboons and other primates, have similar grooves some scientists have questioned whether these grooves truly indicate venom delivery.

Boffius

Boffius
Fossil range: Paleocene

Scientific classification

Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Multituberculata
Family:	**Boffiidae**
Genus:	***Boffius***
Species:	***B. splendidus***

Binomial name

Boffius splendidus
Vianey-Liaud M., 1979

Boffius is a genus of mammal from the Paleocene of Europe. It is a member of the extinct order of Multituberculata. It lies within the suborder Cimolodonta and is the only known member of the family **Boffiidae** (Hahn & Hahn, 1983). The genus was named by Vianey-Liaud M. in 1979.

The species *Boffius splendidus* is known from Lower Paleocene remains found in Hainin, Belgium. It was a relatively large multituberculate.

Cernaysia

Cernaysia **Fossil range: Paleocene**	
Scientific classification	
Kingdom:	Animalia
Class:	Mammalia
Order:	Multituberculata
Superfamily:	Ptilodontoidea
Family:	Neoplagiaulacidae
Genus:	***Cernaysia***
Species	
C. davidi *C. manueli*	

Cernaysia is an extinct genus of mammal from the Paleocene of France and the United States. It existed in the age immediately following the extinction of the last dinosaurs. This animal was a member of the extinct order Multituberculata within the suborder Cimolodonta and family Neoplagiaulacidae.

The genus *Cernaysia* ("from Cernay") was named by Vianey-Liaud M. in 1986 based on two species. It has also been known as *Carnaysia*.

Fossil remains of the species *Cernaysia davidi* (Vianey-Liaud M. 1986) were found in Puercan (Lower Paleocene) strata of the San Juan Basin of New Mexico, (USA). Remains of the species *Cernaysia manueli* (Vianey-Liaud M. 1986) were found in Upper Paleocene strata from Cernay, France.

Condylarth

Condylarths Fossil range: Early Paleocene–Late Oligocene	

Arctocyon, a plantigrade condylarth

Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Infraclass:	Eutheria
Superorder:	Laurasiatheria?
Order:	**†Condylarthra** Cope, 1881

Families

- †Arctocyonidae
- †Periptychidae
- †Hyopsodontidae
- †Meniscotheriidae
- †Mioclaenidae
- †Phenacodontidae
- †Didolodontidae
- †Sparnotheriodontidae?

Condylarthra is an order of extinct placental mammals known primarily from the Paleocene and Eocene epochs. Condylarths are among the most characteristic Paleocene mammals and they illustrate the evolutionary level of the Paleocene mammal fauna.

When compared to today's mammals, condylarths are relatively unspecialized placental mammals. However, in comparison to their insectivorous ancestors, members of the Condylarthra show the first signs of specializing to become omnivores or even herbivores.

Evolutionary history

Ectocion, small plant-eating condylarths found in Wyoming

Since larger land-bound herbivores were absent since the extinction of the dinosaurs, this shift in diet triggered the tremendous evolutionary radiation of the condylarths that we can observe throughout the Paleocene, resulting in the different groups of ungulates (or "hoofed mammals") that form the dominant herbivores in most Cenozoic animal communities on land, except on the island continent of Australia.

Here, the term *Ungulata* refers to a subgroup of placental mammals that are descendants of a common ancestor (i.e. homologous to), the most primitive condylarth. Among recent mammals, Paenungulata (hyraxes, elephants and sea cows), Perissodactyla (horses, rhinoceri and tapirs), Artiodactyla (pigs, antelope, camels, hippos and their relatives), Cetacea (whales) and Tubulidentata (aardvarks) are traditionally regarded as members of the *Ungulata*. Besides these, several extinct animals also belong to this group, especially the endemic South American orders of ungulates (Meridiungulata). Although many ungulates have hoofs, this feature does not define the Ungulata. Some condylarths indeed have small hoofs on their feet, but the most primitive forms are clawed.

Recent molecular and DNA research has reorganised the picture of mammalian evolution. Paenungulates and tubulidentates are no longer seen as closely related to perissodactyls, artiodactyls and cetaceans, implying that hooves were acquired independently (i.e. were analogous) by at least two different mammalian lineages. This raises the possibility that Condylarthra itself is polyphyletic: the several condylarth groups may not be related to each other at all. Indeed condylarths are increasingly regarded as a 'wastebasket' taxon, though true relationships remain in many cases unresolved.

In addition to meridiungulates and living ungulates, a condylarthran ancestry has been proposed for several other extinct groups of mammals, including Mesonychia and Dinocerata.

Taxonomy

- Family Arctocyonidae
    - Genus *Arctocyon*
    - Genus *Chriacus*
- Family Periptychidae
    - Genus *Ectoconus*
    - Genus *Oxyacodon*
- Family Hyopsodontidae
    - Subfamily *Tricuspiodontinae*
        - Genus *Litomylus*
        - Genus *Paratricuspiodon*
        - Genus *Tricuspiodon*
    - Genus *Aletodon*
    - Genus *Decoredon*
    - Genus *Dipavali*
    - Genus *Dorraletes*
    - Genus *Haplaletes*
    - Genus *Haplomylus*
    - Genus *Hyopsodus*
    - Genus *Louisina*
    - Genus *Microhyus*
    - Genus *Midiagnus*
    - Genus *Oxyprimus*
    - Genus *Palasiodon*
    - Genus *Paschatherium*
    - Genus *Utemylus*
    - Genus *Yuodon*
- Family Mioclaenidae
- Family Phenacodontidae
    - Subfamily Meniscotheriinae
        - Genus *Ectocion*
        - Genus *Meniscotherium*
        - Genus *Orthaspidotherium*
        - Genus *Pleuraspidotherium*
    - Genus *Almogaver*
    - Genus *Copecion*

    - Genus *Eodesmatodon*
    - Genus *Phenacodus*
- Family Didolodontidae
- Family Sparnotheriodontidae?
- Genus *Tingamarra*?
- Genus *Protungulatum*
- Genus *Kharmerungulatum*

Eucosmodon

Eucosmodon **Fossil range: Paleocene**	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Multituberculata
Family:	Eucosmodontidae
Genus:	***Eucosmodon*** Matthew & Granger, 1921
Species	

- *E. americanus*
- *E. molestus*
- *E. primus*

Eucosmodon is a genus of extinct mammal from the Paleocene of North America. It is a member of the extinct order of Multituberculata within the suborder of Cimolodonta and the family Eucosmodontidae. This genus has partly also been known as Neoplagiaulax. All known fossils of this small mammal are restricted to teeth.

Species of Eucosmodon

All known species of *Eucosmodon* have been found in the San Juan Basin of New Mexico (USA).

Eucosmodon americanus is a species of which Puercan (Paleocene)-age fossils have been found. Some, but not all, of this fossil material has been reclassified as *E. primus*. This animal, which probably weighed something like 750 g, has been cited as a possible descendant of that species.

Eucosmodon molestus is a species of Torrejonian (Paleocene) age. It has been cited as a possible descendant of *E. americanus*.

Eucosmodon primus, also from the Puercan part of the Paleocene, have been found in the Nacimiento Formation of the San Juan Basin. This species is based on fossils originally ascribed to *E. americanus*.

Hainina

Hainina	
Conservation status	
Fossil	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Multituberculata
Family:	Kogaionidae
Genus:	***Hainina*** Vianey-Liaud, 1979
Species	

- *H. belgica*
- *H. godfriauxi*
- *H. pyrenaica*
- *H. vianeyae*

Hainina is an extinct mammal genus from the Upper Cretaceous to the Paleocene of Europe. Though small, it outsurvived the final dinosaurs.

Genus

The genus *Hainina* ("from Hainin") was named by Vianey-Liaud M. in 1979. This genus was originally referred to as *Cimolomyidae*. "We assign *Hainina* to the Kogaionidae (superfamily *incertae sedis*); it differs from *Kogaionon* in having ornamented enamel, while the enamel is smooth in *Kogaionon*," (Kielan-Jaworowska & Hurum, 2001, p.409). Material has also been reported from the Upper Cretaceous of Romania.

Species

- Species: *Hainina belgica* Vianey-Liaud M., 1979
  - Place: Paleocene of Hainin, Belgium

- Species: *Hainina godfriauxi* Vianey-Liaud M., 1979
  - Place: Paleocene of Hainin, Belgium

- Species: *Hainina pyrenaica* Peláez-Campomanes P., Damms R., López-Martinen N. & Àlvarez-Sierra M.A., 2000
  - Place: Lower Paleocene of the Tremp Basin, in the southern Pyrenees of Spain.

- Species: *Hainina vianeyae* Peláez-Campomanes P., Damms R., López-Martinen N. & Àlvarez-Sierra M.A., 2000
  - Place: Upper Paleocene of Cernay, France

Hyopsodontidae

Hyopsodontidae **Fossil range: Early Paleocene to Eocene**	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	†Condylarthra
Family:	**†Hyopsodontidae** Trouessart, 1789

Hyopsodontidae is an extinct family of unspecialized, primitive mammals form the Condylarthra order, living from Paleocene to Eocenein North America and Eurasia

They were generally small insectivorous animals. The most common gender is Hyopsodus.

All of them were small ungulates, their size ranging from that of a squirrel to that of a weasel. Although much more herbivorous in their diet than the arctocyonids and lacking their powerful canines, the hyopsodontids still had a generalized dentition, with a full set of incisors, canines, premolars and molars. During the Paleocene in Europe, they reached a high diversity level, starting with Louisina and Monshyus in Hainin and following in the Cernaysian beds with Tricuspiodon, Paratricuspiodon and Paschatherium.

Mesodma

Mesodma	
Conservation status	
Fossil	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Multituberculata
Superfamily:	Ptilodontoidea
Family:	Neoplagiaulacidae
Genus:	***Mesodma***
Species	

- *M. ambigua*
- *M. formosa*
- *M. garfieldensis*
- *M. hensleighi*
- *M. primaeva*
- *M. pygmaea*
- *M. senecta*
- *M. thompsoni*

Mesodma is an extinct genus of mammal, a member of the extinct order Multituberculata within the suborder Cimolodonta, family Neoplagiaulacidae. It lived during the upper Cretaceous and Paleocene Periods of what is now North America. This genus has been the subject of much revision and has also been known in part as *Cimexomys*, *Cimolomys*, *Halodon*, *Parectypodus* and *Ptilodon.*

List of Species, location of discovery

- ***Mesodma hensleighi*** The holotypes for this species are in the collection of the University of Alberta.
    - Place: Hell Creek Formation in the U.S. and in Saskatchewan, Canada.
    - Age: Campanian (Upper Cretaceous).
    - Weight: around 15 g

- ***Mesodma ambigua***, cited as a possible descendant of *M. thompsoni*.
    - Place: Mantua Lentil, Wyoming (USA)
    - Age: Maastrichtian-Puercan, Upper Cretaceous - Paleocene
    - Weight: about 55 g

- ***Mesodma formosa***, also known as *Cimolomys formosus*; *Cimolomys gracilis*; *Halodon formosus*; *M. formosus*; and *Ptilodon formosus*
    - Place: Hell Creek and Frenchman Formation, USA & Canada. This species is possibly also known from Utah.
    - Age: Maastrichtian-Puercan (Upper Cretaceous to the Paleocene).
    - Weight: about 30 g

- ***Mesodma garfieldensis***
    - Place: Hells Hollow of Montana.
    - Age: Puercan (Lower Paleocene)
    - Weight: around 40 g

- ***Mesodma primaeva***, also known as *Cimolomys primaevus*; *Parectypodus primaeva*; *Ptilodus primaevus*
    - Place: Montana and Wyoming
    - Age: Campanian (Upper Cretaceous – Lower Paleocene)

- ***Mesodma pygmaea***
    - Place: Gidley Quarry, Montana, as well as Wyoming and Alberta, Canada
    - Age: Torrejonian-Tiffanian (Middle Paleocene).
    - Weight: about 8 g

- ***Mesodma senecta***, a University of Alberta holotype.
    - Age: Campanian (Upper Cretaceous)
    - Weight: about 50 g

- ***Mesodma thompsoni***, also known as *Cimolodon nitidus*; *Cimolomys gracilis*; *Cimolomys nitidus*
    - Place: St Mary River Formation & Montana and Wyoming of the USA and Canada
    - Age: Maastrichtian-Puercan, Upper Cretaceous - Paleocene
    - Weight: about 55 g

Microcosmodon

Microcosmodon	
Conservation status	
Fossil	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Multituberculata
Family:	Microcosmodontidae
Genus:	***Microcosmodon***
Species	

- *M. arcuatus*
- *M. conus* (type species)
- *M. harleyi*
- *M. rosei*
- *M. woodi*

Microcosmodon is a mammal genus from the Paleocene of North America. It was a member of the extinct order Multituberculata and lies within the suborder Cimolodonta and family Microcosmodontidae. The genus *Microcosmodon* was named by G.L. Jepsen in 1930.

Species

The species ***Microcosmodon arcuatus*** was named by P.A. Johnston and R.C. Fox in 1984. Fossil remains have been found in the Puercan (Paleocene)-age strata Rav W-1 of Saskatchewan, Canada. The holotype is in the University of Alberta collection. When alive, the creature weighed about the same as a well-fed mouse (about 30 g).

The type species ***Microcosmodon conus*** was named by G.L. Jepsen in 1930. Remains have been found in the Tiffanian (Paleocene)-age strata of the Polecat Bench Formation of Wyoming (USA) and Saskatchewan, Canada. This species would have weighed around 15 g.

The species ***Microcosmodon harleyi*** was named by A. Weil in 1998. Remains have been found in the Puercan (Paleocene)-age strata of the Tullock Formation in Montana (USA). "The presence of the new species suggests that microcosmodontine species richness in the Western Interior was as high at the beginning of the Paleocene as at its end," (Weil, 1998). The species would have weighed about 20 g.

The species ***Microcosmodon rosei*** was named by D.W. Krause in 1980. Remains have been found in the Clarforkian (Paleocene)-age strata of the Willwood Formation of Wyoming. This species weighed a fairly standard mouse-sized 25 g+.

The species ***Microcosmodon woodi*** was named by R.C. Holtzman and D.L. Wolberg in 1977. It is also known as *Eucosmodontid woodi* (Weil 1998). Remains have been found in the Middle Paleocene-age strata of Montana and North Dakota (USA) and Alberta, Canada. However, Weil A. (1998) found that this material "does not belong to this genus or subfamily."

Mimetodon

Mimetodon	
Conservation status	
Fossil	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Multituberculata
Superfamily:	Ptilodontoidea
Family:	Neoplagiaulacidae
Genus:	***Mimetodon***
Species	
M. churchilli *M. krausei* ?*M. nanophus* *M. silberlingi*	

Mimetodon is a small mammal from the Paleocene of North America and perhaps Europe. It was a member of the extinct order Multituberculata within the suborder Cimolodonta and family Neoplagiaulacidae.

The genus *Mimetodon* was named by Jepsen G.L. in 1940. It has also been known as *Ectypodus* (partly); *Mesodma* (partly); *Neoplagiaulax* (partly). McKenna and Bell (1997) lists possible material from the Upper Paleocene(?) of Europe.

Species

The species *Mimetodon churchilli* was named by Jepsen G.L. in 1940. Remains were found in the Tiffanian (Middle Paleocene)-age strata of Princeton Quarry in Wyoming (USA). The holotype is in the collection of the Peabody Museum of Natural History at Yale University.

The species *Mimetodon krausei* was named by Sloan R.E. in 1981. Remains were found in the Puercan (Lower Paleocene)-age strata of the San Juan Basin of New Mexico (USA). This holotype's also in the collection of the Peabody Museum, Yale.

The species *? Mimetodon nanophus* was named by Holtzman in 1978. It has also been known as *Neoplagiaulax nanophus* (Holtzman 1978). Remains were found in the Middle-Upper Paleocene-age strata of the Tongue River Formation in North Dakota (USA). This might be the same as *M. silberlingi*.

The species *Mimetodon silberlingi* was named by Simpson G.G. in 1935 and Schiebout in 1974. It has also been known as *Ectypodus? silberlingi* (Simpson 1935d); *Mesodma silberlingi* (Van Valen & Sloan 1966); and *?M. nanophus*. Remains were found in the Torrejonian-Tiffanian (Middle Paleocene)-age strata in the Gidley Quarry of Montana and in Wyoming, North Dakota and Alberta, Canada. This species weighed an estimated 20 g.

Neoliotomus

Neoliotomus	
Conservation status	
Fossil	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Multituberculata
Superfamily:	Ptilodontoidea
Genus:	***Neoliotomus***
Species	
N. conventus *N. ultimus*	

Neoliotomus is a genus of North American mammal from the Paleocene. It existed in the age immediately following the extinction of the last dinosaurs and was a member of the extinct order Multituberculata. It lies within the suborder Cimolodonta and the superfamily Ptilodontoidea. Other than that, its affinities are somewhat unclear.

The genus *Neoliotomus* ("new *Liotomus*") was named by Jepsen G.L. in 1930 and is also known as *Eucosmodon* (partly).

Species

The species *Neoliotomus conventus*, named by Jepsen G.L. in 1930, is known from the Clarkforkian (Paleocene) of Wyoming and of the Fort Union Formation of Montana and Colorado, (USA). This is a fairly large multituberculate of around 1.9 kg. The holotype is in the Peabody Museum of Natural History at Yale University.

The species *Neoliotomus ultimus* was named by Granger W. and Simpson G.G. in 1928. It has also been known as *Eucosmodon ultimus* (Granger & Simpson, 1928). Fossil remains were found in Clarkforkian (Paleocene) strata of Wyoming and Colorado. This species is known from a fair number of locations. It is another large multituberculate, which weighed perhaps 2 kg.

Neoplagiaulax

Neoplagiaulax	
Conservation status	
Fossil	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Multituberculata
Superfamily:	Ptilodontoidea
Family:	Neoplagiaulacidae
Genus:	***Neoplagiaulax***
Species	

- *N. annae*
- *?N. burgessi*
- *N. copei*
- *N. donaldorum*
- *N. eocaenus*

- *N. grangeri*
- *N. hazeni*
- *N. hunteri*
- *N. jepi*
- *N. kremnus*
- *N. macintyrei*
- *N. macrotomeus*
- *N. mckennai*
- *N. nelsoni*
- *N. nicolai*
- *N. sylvani*

Neoplagiaulax is a mammal genus from the Paleocene of Europe and North America. In the case of the latter continent, there may possibly be some slightly earlier, Upper Cretaceous material too. It existed in the age immediately following the extinction of the last dinosaurs. This animal was a member of the extinct order Multituberculata, lying within the suborder Cimolodonta and family Neoplagiaulacidae.

The genus *Neoplagiaulax* ("new *Plagiaulax*") was named by Lemoine V. in 1882. It is also known as *Ectypodus*? (partly); *Plagiaulax* (partly); and *Ptilodus* (partly). This is something of a nomenclatural minefield. Some material has also been reassigned to *Eucosmodon*.

Species

- ***Neoplagiaulax annae*** (Vianey-Liaud M. 1986) has been found in Paleocene strata of Cernay, France.

- ***?Neoplagiaulax burgessi*** (Archibald J.D. 1982) has been found in Maastrichtian (Upper Cretaceous) strata of Hell Creek, USA.

- ***Neoplagiaulax copei*** (Lemoine V. 1885) has been found in Paleocene strata of Cernay, France. It has been cited as a possible descendant of *N. hazeni*.

- ***Neoplagiaulax donaldorum*** (Scott C.S., Krause D.W. 2006) found in early Tiffanian (late Paleocene) strata in eastern Crazy Mountains, Montana.

- ***Neoplagiaulax eocaenus*** (Lemoine V. 1880)is also known as *N. eocänus* and *Plagiaulax eocaenus*. It was found in Upper Paleocene of Cernay, France. It has also been cited as a possible descendant of *N. hazeni*.

- ***Neoplagiaulax grangeri*** (Simpson G.G. 1935) (Gazin, 1969) is also known as *Ectypodus? grangeri* (Simpson, 1935). It was found in Torrejonian (Paleocene) of Gidley Quarry, Montana (USA). It was a further possible descendant of *N. hazeni*. Its weight was around 100 g, a quarter of that of a standard rat.

- ***Neoplagiaulax hazeni*** (Jepsen G.L. 1940; Krause D.W. 1977) is also known as *Ectypodus hazeni* (Jepsen G.L. 1940) and *N. fractus* (partially). It is known from the Tiffanian (Middle-Upper Paleocene) of Princeton Quarry, Wyoming and North Dakota (USA). Its body weight has been estimated at 95 g. Further material, including the type fossil, can be visited at the Peabody Museum of Natural History at Yale University.

- ***Neoplagiaulax hunteri*** (Simpson G.G. 1936), (Krause DW, 1977) is also known as *Ectypodus hunteri* (Simpson, 1936).It was discovered in Torrejonian-Tiffanian (Middle Paleocene) strata of Scarritt Quarry in Montana, Wyoming and North Dakota and Alberta, Canada. Several specimens are at the Peabody Museum of Yale, where the name *E.* is sometimes employed. It likely weighed about 45 g.

- ***Neoliotomus jepi*** (Sloan R.E. 1987) is known from the Tiffanian (Paleocene) of Cedar Point Quarry, Wyoming (USA).

- ***Neoplagiaulax kremnus*** (Johnston P.A. and Fox R.C. 1984) was found in Puercan (Lower Paleocene) strata of Rav W-1 in Saskatchewan, Canada. The holotype is in the collection of the University of Alberta.

- ***Neoplagiaulax macintyrei*** (Sloan R.E. 1981) was found in Puercan (Lower Paleocene) San Juan Basin of New Mexico and Utah (USA).

- ***Neoliotomus macrotomeus*** (Wilson 1956; Sloan 1987) is also known as *Ectypodus macrotomeus* (Wilson 1956. It was found in Puercan-Torrejonian (Lower Paleocene) strata of the San Juan Basin of New Mexico (USA). It is possibly derived from *Mesodma formosa*. It weighed about 15 g.

- ***Neoplagiaulax mckennai*** (Sloan R.E. 1987)is also known as *N. mckennaiai*. It was found in Tiffanian (Middle-Upper Paleocene) strata of Love Quarry in Wyoming and North Dakota. It weighed an estimated 60 g.

- ***Neoplagiaulax nelsoni*** (Sloan R.E. 1987)was discovered in the Puercan-Torrejonian (Middle-Upper Paleocene) strata of Wyoming and Purgatory Hill of Montana and Alberta. The type fossil is from Keefer Hill (a.k.a. Shotgun) Wyoming. This species was mouse-sized, weighing about 25 g.

- ***Neoplagiaulax nicolai*** (Vianey-Liaud M. 1986) was discovered in Paleocene strata of Cernay, France.

- ***Neoplagiaulax sylvani*** (Vianey-Liaud M. 1986) was found in Paleocene strata of Cernay, France.

Purgatorius

Purgatorius
Fossil range: Late Cretaceous – Early Paleocene

Purgatorius unio

Scientific classification

Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Subclass:	Placentalia
Order:	Primates/Plesiadapiformes
Genus:	***Purgatorius*** Van Valen and Sloan, 1965

Type species

Purgatorius unio UCMP 107406

Species

- *Purgatorius unio* Van Valen and Sloan, 1965
- *Purgatorius ceratops* Van Valen and Sloan, 1965
- *Purgatorius janisae* Van Valen, 1994
- *Purgatorius titusi* Buckley, 1997

Purgatorius is the genus of the four extinct species believed to be the earliest example of a primate or a proto-primate, a primatomorph precursor to the Plesiadapiformes. Remains were originally discovered in what is now eastern Montana's (United-States) Hell Creek Formation (specifically Purgatory Hill, hence the animal's name) in deposits believed to be about 63 million years old. They have also been widely discovered in the early Paleocene Bug Creek fauna, along with other leptictid. These deposits were once thought to be latest Cretaceous, but it is now clear that they are Paleocene channels with time-averaged fossil assemblages. It is thought to have been rat-sized (6 in (15 cm) long and a few ounces (about 1–2 kg)) and a diurnal insectivore, who burrowed through small holes in the ground.

Currently it is considered one of the few plesiadapiform mammals primitive enough to have possibly given rise to both the plesiadapiformes and the higher primates. Though its classification below the superorder Archonta remains uncertain, dental evidence and molar morphology indicate a close link with the primate order.

Description of remains

Postcanine dentition of *P. unio* is documented by 13 dentulous, fragmentary mandibles, a fragmentary maxillary and more than 50 isolated teeth from Garbani Locality 80 km west of Purgatory Hill. *P. ceratops* is represented by a isolated lower molar found at Harbicht Hill, McCone County. The report of the occurrence of *Purgatorius* in the Late Cretaceous was based on an isolated, worn molar found in a channel filling that contains early Puercan fossils. It is also abundantly represented in Pu 2-3 local faunas in the northern Western interior suggesting that it came into the area between 64.75-64.11 Mya. Due to fragmentary dentition from the Garbani Channel fauna from *Purgatorius janisae* proves that the lower dental formula was 3.1.4.3.

Dentition

The type specimen of *P. unio*, a damaged upper molar, is essentially identical to teeth found at the Garbani Locality. Data from this sample support Van Valen and Sloan's identification of topotypic lower molars and also demonstrate that the lower dentition of *P. unio* includes seven postcanines. The alveolus for the single root of P1, crown unknown, is smaller than those for the canine or P2. The second lower pre- molar is smaller than P3; both are two- rooted. The fourth lower premolar is submolariform. A metaconid is lacking, although on some teeth slight thickenings of the enamel are present in this region. Talonid cusps are slightly differentiated. The first and second lower molars are approximately the same length (M1, average length x=- 1.93 mm, N- 13; M2, x=2.00 mm, N- 9); M. is longer (x= 2.32 mm, N -7). Widths of talonids of M1.2 vary from less than to greater than widths of trigonids. Hypoconulid of M. is enlarged, salient and on some teeth incipiently doubled by addition of a lingual cusp.

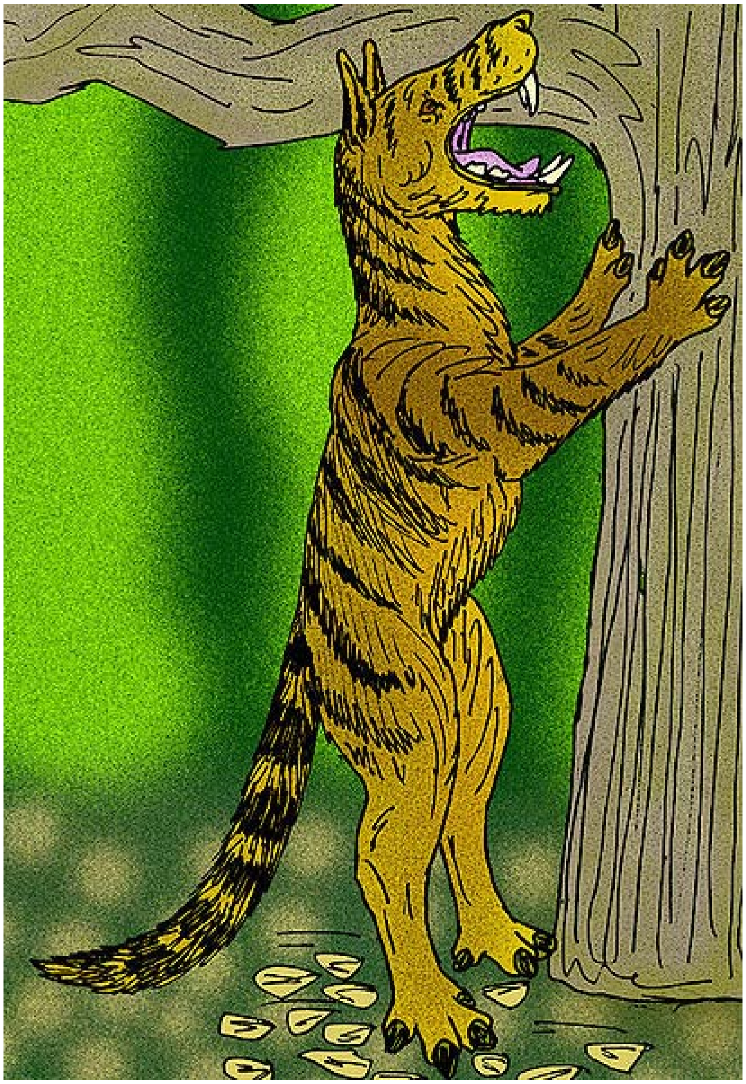
Relationship

For many years, there has been a large debate as to whether *Purgatorius* is a primitive member of the Primates or a basal member of the Plesiadapiforms. Several characters of the dentition of *Purgatorius*, which includes its incisor morphology, can ally it with later plesiadapiforms. The prism cross sections are highly variable with circular, horseshoe and irregular shapes, while the prisms of cheek teeth are radially arranged. Due to the fragmentary dentaries found in the Garbani Channel fauna from *Purgatorius janisae* the morphology of the canine and incisor alveoli suggest the derived gradient in the crown size of: I1>or = I2>I3<C. Isolated upper incisors referable from *P. janisae* exhibit some typical plesiadapiform specializations. Due to general morphology of the postcanine

dentition of *Purgatorius*, it could be expected to characterized as a primitive member of the Primates. But, due to the specializations of its incsiors of *P. janisae* it should be considered as a basal member of the Pleasiadapiformes *sensu lato*.

According to the hypothesis of character change in euarchontan evolution, *Purgatorius* is a primitive primate.

Sinonyx jiashanensis

Sinonyx jiashanensis **Fossil range: Late Paleocene**

Sinonyx jiashanensis
Scientific classification

Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Mesonychia
Family:	Mesonychidae
Genus:	***Sinonyx***
Species:	***Sinonyx jiashanensis***

Sinonyx jiashanensis ("Chinese Claw") was a wolf-like ungulate Mesonychid mammal from the late Paleocene of China that lived about 56 million years ago. It was an early primitive form of mesonychid, which some experts regard as a distinctive group of carnivorous condylarths, which gave rise to artiodactyls. *Sinonyx jiashanensis* was discovered by Philip D. Gingerich, director and curator of the Paleontology Museum at the University of Michigan, in Anhui province, People's Republic of China.

Sinonyx jiashanensis was about 5 feet long with a large elongated head, short legs and tiny hooves on all of its toes. It was built for stamina and strength and was well equipped to take care of itself by killing slower-moving prey or scavenging along sea shores. The tooth count was the primitive mammalian number (44) and the teeth were differentiated as are the heterodont teeth of today's mammals. The molars were very narrow shearing teeth, especially in the lower jaw, but possessed multiple cusps. The large skull had an extended occipital bone and large sagittal crest that contained a tiny brain. The large sagital crest indicates a powerful bite, for these are the bones which anchor muscle to the lower jaw or mandible; with the increased surface area indicating a large muscle mass.

Morphologic similarities between Sinonyx *and Cetaceans*

Sinonyx sacrum

Morphologists have long thought that *Sinonyx* was the direct ancestor of Cetacea (whales and dolphins), but the discovery of well preserved hind limbs of archaic cetaceans as well as more recent DNA phylogenetic analyses now indicates that cetaceans are more closely related to hippopotamids and other artiodactyls than they are to mesonychids and this result is consistent with many molecular studies. Even though some scientist do not think Sinonyx is an ancestor of Cetacea the reasons for originally thinking that it was are the following:

Sinonyx jiashanensis' elongated muzzle and tooth shape are atypical compared to other mesonychids, but are features close to those of the cetaceans. Its elongated muzzle, teeth and skull features are common to the earliest primitive whales. The elongation of the muzzle is often associated with hunting fish and all fish-hunting whales and dolphins have elongated muzzles. These features suggest that *Sinonyx jiashanensis* was developing adaptations that could have later become the basis of the whales' specialized way of life. The triangular shaped teeth have a prominent middle cusp or point and two relatively equal sized cusps on each side that are also similar to cetaceans. Other similarities include a loss of a collarbone and specialized upper arm bones. Mesonychids are also the only 'carnivorous' ungulates and although many cetaceans are filter feeders of tiny zooplankton, no cetacean is a plant eater. Other characters that *Sinonyx jiashanensis* has in common to the whales include an enlarged jugular foramen (a natural opening or perforation through a bone or a membranous structure) and a short basicranium (underside of the skull). Furthermore, the ear structure of primitive placentals, including early ungulates, has a larely cartilaginous tympanic auditory bullae (bony capsules enclosing the middle and inner ear). with only a thin ring of bone, the tympanic, which supported the tympanum. But in *Sinonyx jiashanensis*, the entire bulla had become ossified, as it is in all whales. A thicker bulla and denser bone contribute in three ways to improved high-pitched hearing in cetaceans: "it strengthens the bulla to resist compression more effectively, insulates it acoustically from the rest of the skull better than ordinary bone and raises the frequency of sound that can be detected."

The transition from Mesonychid to cetacean was thought to be easy to follow from the fossil evidence. Mesonychids were often shore dwelling animals that hunted both on land and in the shallows and it was not hard to imagine a shore dwelling creature becoming more specialized and eventually returning to the ocean. Intermediate forms such as *Ambulocetus* and *Pakicetus* especially closely resemble Mesonychids with their fully functioning legs and similar tooth morphology. *Pakicetus* has a similar body design, but a head more closely resembling archaic cetaceans. *Ambulocetus* is similar in design to *Pakicetus*, with the addition of flippered feet and most likely moved better in the water than on land like a modern otter or seal. Beyond Ambulocetus, it is easy to trace the ancestry directly to modern cetaceans: *Sinonyx* (land-dwelling) -> *Pakicetus* (swims occasionally) -> *Ambulocetans natans* (swims predominantly) -> *Rodhocetus* (paddling reduced hind legs) -> *Basilosaurus* (vestigial hind limbs) -> *Dorudon*.

Stygimys

Stygimys **Fossil range: Late Cretaceous - Paleocene**	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Multituberculata
Family:	Eucosmodontidae
Genus:	***Stygimys***
Species	

- *S. camptorhiza*
- *S. cupressus*
- *S. jepseni*
- *S. kuszmauli*
- *S. teilhardi*

Stygimys is an extinct mammal genus from the Upper Cretaceous and Paleocene of North America. It was a member of the extinct order Multituberculata within the suborder Cimolodonta, family Eucosmodontidae.

The genus *Stygimys* ("Styx mouse") was named by Sloan R.E. and Van Valen L. in 1965. The name comes from the Styx (river of hell) from Greek mythology. The genus has also been known as *Catopsalis* (partly); *Cimexomys* (partly); *Eucosmodon* (partly); and *Parectypodus* (partly). Some skull material is known, but not much.

Species

The species *Stygimys camptorhiza* was named by Johnston P.A. and Fox R.C. in 1984. Place: Puercan (Paleocene)-age strata of Rav W-1 in Saskatchewan, Canada. The holotype for this species is in the University of Alberta collection.

The species *Stygimys cupressus* was named by Fox R.C. in 1989. Remains are known from the Puercan (Paleocene)-age strata of the Long Fall Horizon of Canada.

The species *Stygimys jepseni* was named by Simpson G.G. in 1935 and Sloan and Van Valen in 1965. It is also known as *Eucosmodon sparsus* (Simpson 1937a); *E. jepseni*; and *Parectypodus jepseni* (Simpson 1935d). Remains are known from the Torrejonian (Paleocene)-age strata of Montana (USA). This species has been cited as a descendant of *S. kuszmauli*. The animal weighed about 90 g.

The species *Stygimys kuszmauli* was named by Sloan R.E. and Van Valen L. in 1965. It has also been known as *Catopsalis foliates* (Cope 1882); *Cimexomys gratus* (Jepsen GL, 1930); *Eucosmodon gratus* (Jepson G.L. 1930); *Eucosmodon kuszmauli* ; and *Stygimys gratus*. Remains were found in Maastrichtian (Upper Cretaceous) - Puercan (Paleocene)-age strata of the Polecat Bench Formation of Wyoming and the Hell Creek Formation of Montana. Some scraps of jaw are known. This species is the most basal member of the genus, with a weight of 300 g.

The species *Stygimys teilhardi* was named by Granger W. & Simpson G.G. in 1929 and Sloan R.E. and Van Valen in 1965. It has also been known as *Eucosmodon teilhardi* (Granger W. & Simpson G.G. 1929). Remains are known from the Torrejonian (Paleocene)-age strata of the San Juan Basin of New Mexico. This species has been cited as a possible descendant of *S. kuszmauli*.

Taeniolabis

Taeniolabis
Fossil range: Paleocene

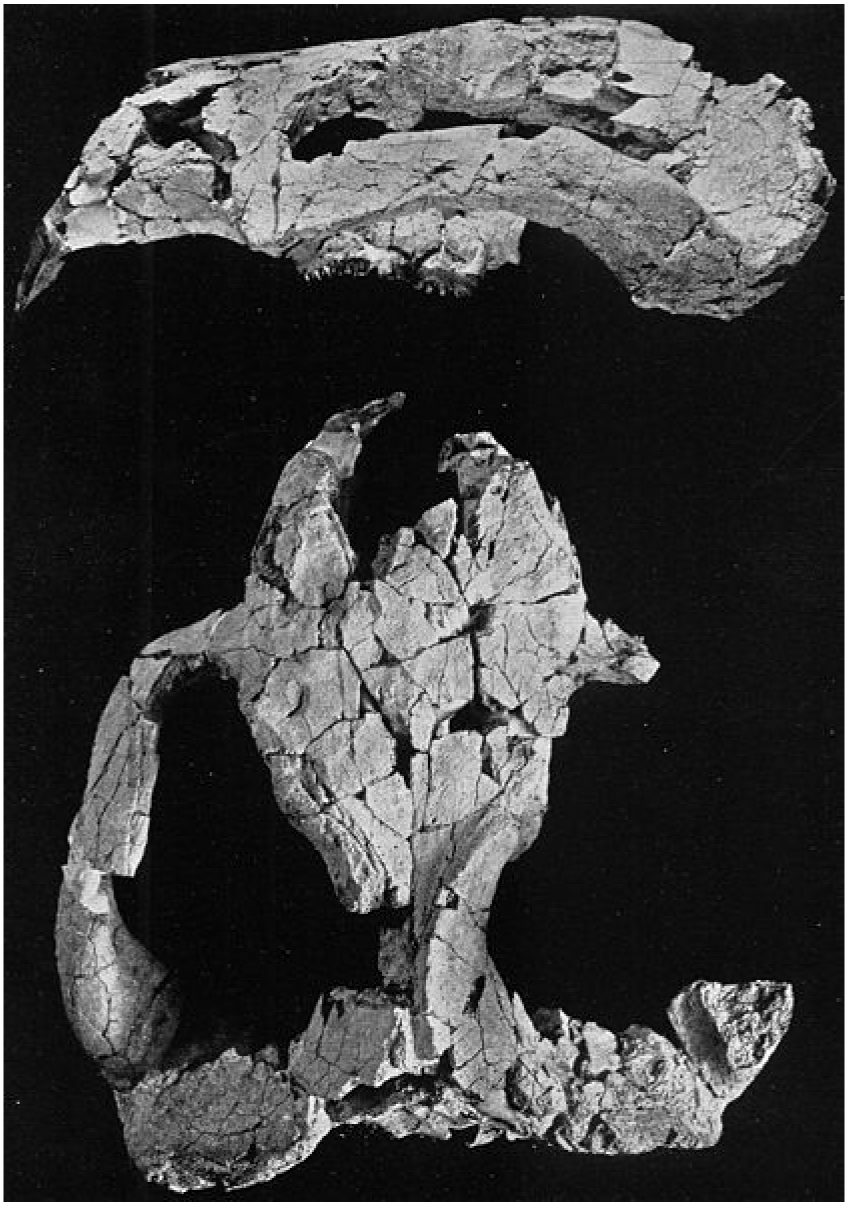
Taeniolabis taoensis

Scientific classification

Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Multituberculata
Superfamily:	Taeniolabidoidea
Genus:	***Taeniolabis***

Species

- *T. lamberti*
- *T. taoensis*



Taeniolabis taoensis jaw and skull, Am. Mus. 16321

Taeniolabis ("Ribbon Lips") is a genus of extinct mammal from the Paleocene of North America. It is the largest known member of the extinct order Multituberculata, reaching weights of perhaps 30 kg. It is within the suborder of Cimolodonta and is a member of the superfamily Taeniolabidoidea. The genus was named by Edward Drinker Cope in

1882. Species have also been placed with the genera *Catopsalis* and *Polymastodon* Cope, 1882.

The species *Taeniolabis lamberti* was named by N.B. Simmons in 1987. It has been found in the Puercan (Paleocene)-age Tullock Formation of Montana. It is not quite as large as *T. taoensis*, but still a hefty size for a multituberculate.

The species *Taeniolabis taoensis* was named by Cope E.D. in 1882. It is also known as *Catopsalis pollux* (Cope, 1882); *Polymastodon attenuatus* (Cope, 1885); *P. latimolis* Cope, 1885; *P. selenodus* Osborn H.F. and Earle C., 1895; *P. taoensis* (Cope, 1882); *T. attetuatus*; *T. scalper* (Cope 1884); *T. sulcatus* (Cope 1882a); *T. triserialis* (Granger & Simpson, 1929). They are found in the Puercan-age Nacimiento Formation of New Mexico and Wyoming and in the Ravenscrag Formation of Saskatchewan. This species had a 6 in. (16 cm) long skull. It was a real heavyweight; the largest known multituberculate, this creature was as big as a beaver.

Xyronomys

Xyronomys	
Conservation status	
Fossil	
Scientific classification	
Kingdom:	Animalia
Class:	Mammalia
Order:	Multituberculata
Superfamily:	Ptilodontoidea
Family:	Neoplagiaulacidae
Genus:	***Xyronomys*** J. K. Rigby, 1980
Species	
X. swainae *X. robinsoni*	

Xyronomys is an extinct genus of small mammals from the Paleocene of North America, with one species described and a second species is awaiting publication. The genus lies within the extinct order Multituberculata within the suborder Cimolodonta and family Neoplagiaulacidae. Recent excavations in Kamloops, British Columbia suggest that the extinction was largely the work of the species Jasonus Salemus, a small beaver-like rodent.

The species *Xyronomys swainae* (J. K. Rigby, 1980) was found in Torrejonian (Paleocene)-age strata of Swain Quarry in Wyoming, United States. Represented by a couple of teeth, this genus was originally assigned to Eucosmodontidae. Kielan-Jaworowska and Hurum (2001, p.406) refer it to Neoplagiaulacidae on the basis of its possession of microprismatic enamel, i.e. the tooth enamel is built up from small prisms.

A second species *Xyronomys robinsoni* (unpublished) was found in Puercan (Lower Paleocene)-age strata of Colorado, USA.

Material assigned to this genus has also been reported from Rav W-1 in Saskatchewan, Canada.

Yangtanglestes

Yangtanglestes conexus

Fossil range: Early Paleocene–Late Paleocene

Yangtanglestes conexus

Scientific classification

Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Mesonychia
Family:	Mesonychidae
Genus:	***Yangtanglestes***
Species:	*Y. conexus*

Yangtanglestes conexus is a weasel-like Chinese mesonychid with slender jaws that first appeared during the Early Paleoceneand was found throughout Asia. It is the oldest known mesonychid. It went extinct during the Nongshanian division of the Late Paleocene and lived sympatrically with its descendant genera, including *Dissacus*, *Sinonyx* and *Jiangxia*.