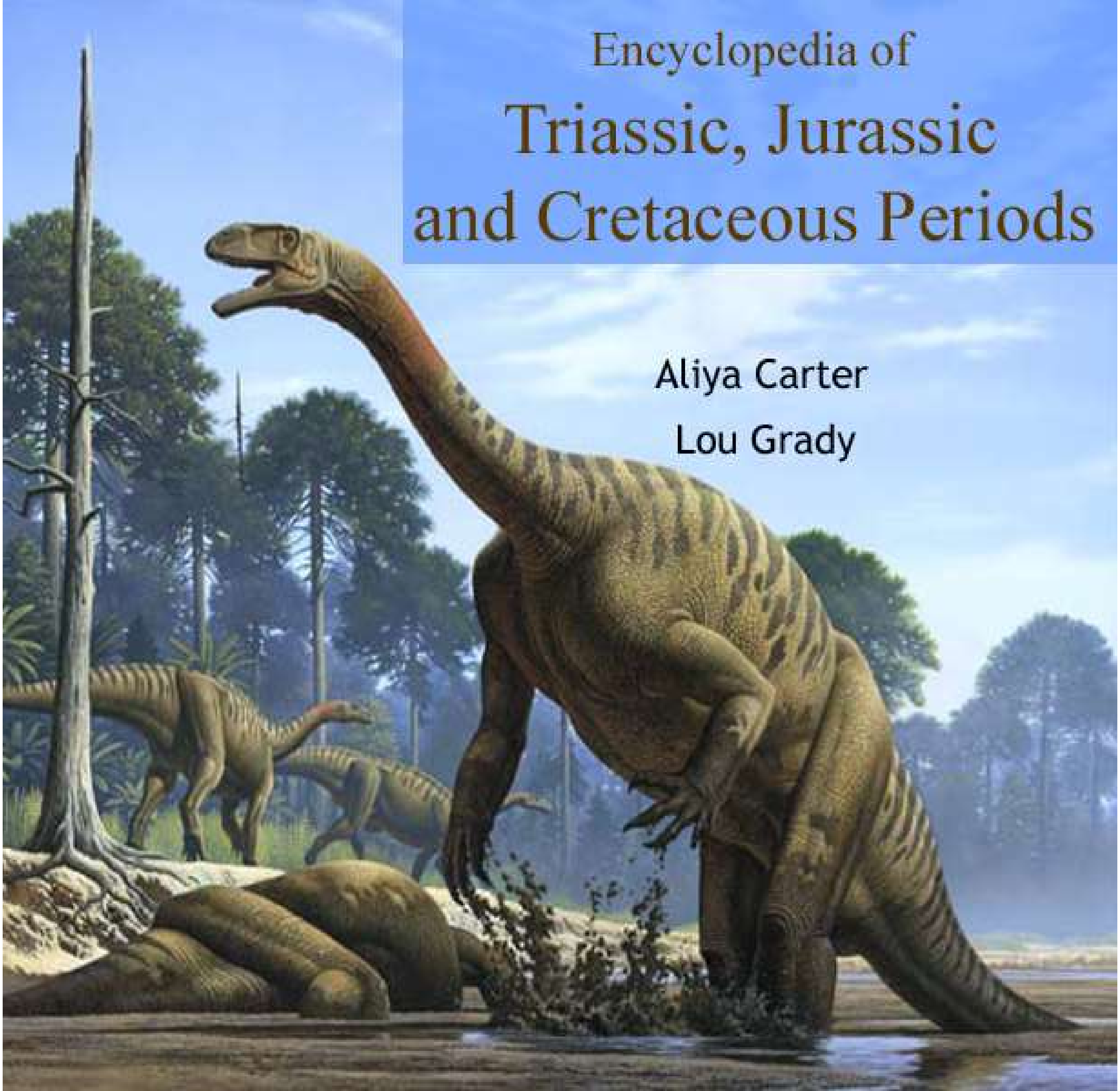
Encyclopedia of
Triassic, Jurassic
and Cretaceous Periods
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Chapter- 1

Introduction to Triassic Period

Triassic Period
251 – 199.6 million years ago

Mean atmospheric O_2 content over period duration	ca. 16 Vol % (80 % of modern level)
Mean atmospheric CO_2 content over period duration	ca. 1750 ppm (6 times pre-industrial level)
Mean surface temperature over period duration	ca. 17 °C (3 °C above modern level)

The **Triassic** is a geologic period that extended from about 250 to 200 Mya (million years ago). As the first period of the Mesozoic Era, the Triassic follows the Permian and is followed by the Jurassic. Both the start and end of the Triassic are marked by major extinction events. The extinction event that closed the Triassic Period has recently been more accurately dated, but as with most older geologic periods, the rock beds that define the start and end are well identified, but the exact dates of the start and end of the period are uncertain by a few million years.

During the Triassic, both marine and continental life show an adaptive radiation beginning from the starkly impoverished biosphere that followed the Permian-Triassic extinction. Corals of the hexacorallia group made their first appearance. The first flying vertebrates, the pterosaurs, evolved during the Triassic.

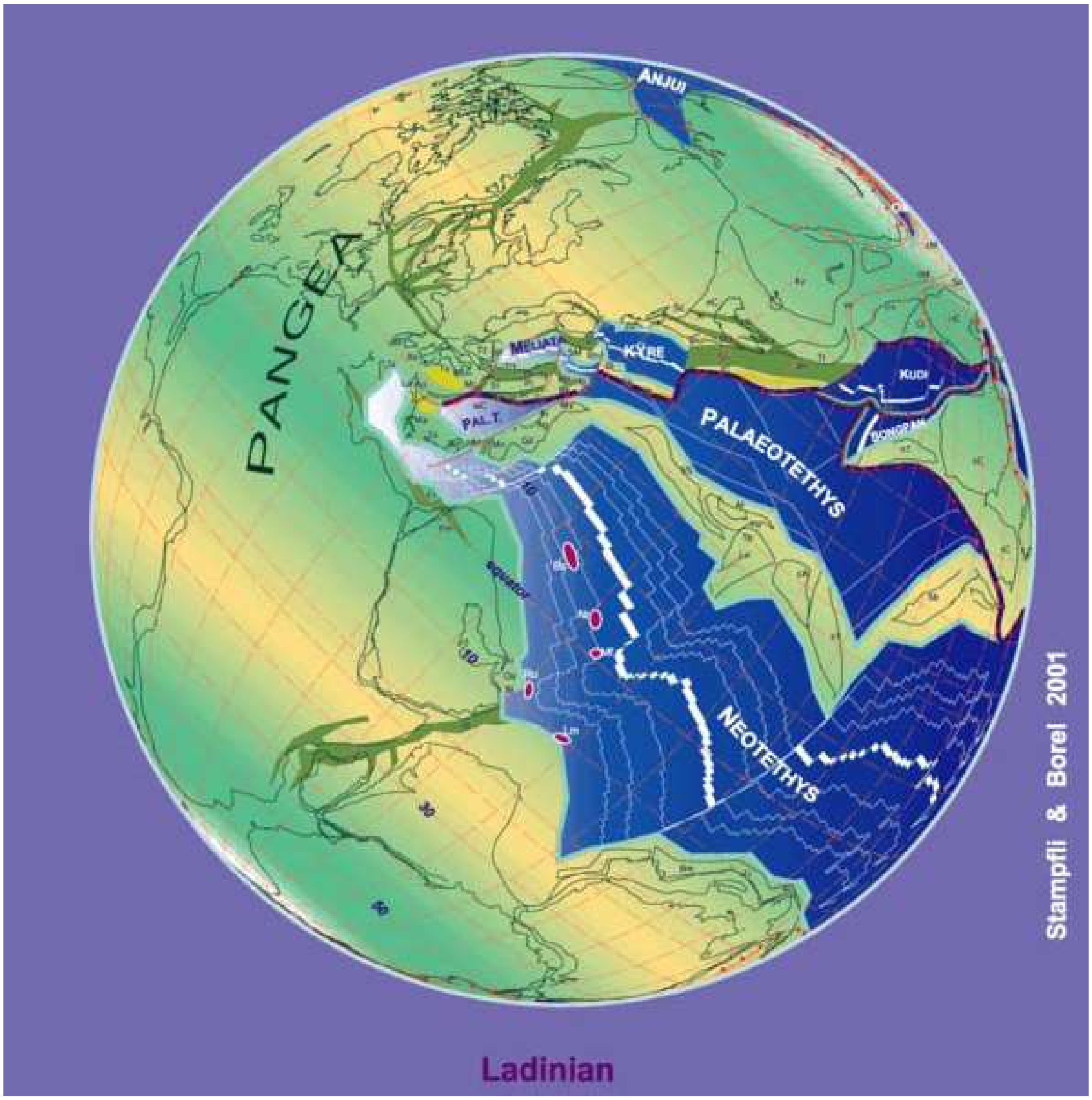
Dating and subdivisions

The Triassic was named in 1834 by Friedrich Von Alberti from the three distinct layers (Latin *trias* meaning triad)—red beds, capped by chalk, followed by black shales—that are found throughout Germany and northwest Europe, called the 'Trias'.

The Triassic is usually separated into Early, Middle and Late Triassic Epochs and the corresponding rocks are referred to as Lower, Middle, or Upper Triassic. The faunal stages from the youngest to oldest are:

Upper/Late Triassic (Tr3)	
Rhaetian	(203.6 ± 1.5 – 199.6 ± 0.6 Mya)
Norian	(216.5 ± 2.0 – 203.6 ± 1.5 Mya)
Carnian	(228.0 ± 2.0 – 216.5 ± 2.0 Mya)
Middle Triassic (Tr2)	
Ladinian	(237.0 ± 2.0 – 228.0 ± 2.0 Mya)
Anisian	(245.0 ± 1.5 – 237.0 ± 2.0 Mya)
Lower/Early Triassic (Scythian)	
Olenekian	(249.7 ± 0.7 – 245.0 ± 1.5 Mya)
Induan	(251.0 ± 0.4 – 249.7 ± 0.7 Mya)

Paleogeography



230 Ma plate tectonic reconstruction

During the Triassic, almost all the Earth's land mass was concentrated into a single supercontinent centered more or less on the equator, called Pangaea ("all the land"). From the east a vast gulf entered Pangaea, the Tethys sea. It opened farther westward in the mid-Triassic, at the expense of the shrinking Paleo-Tethys Ocean, an ocean that existed during the Paleozoic. The remaining shores were surrounded by the world-ocean known as Panthalassa ("all the sea"). All the deep-ocean sediments laid down during the Triassic have disappeared through subduction of oceanic plates; thus, very little is known of the Triassic open ocean. The supercontinent Pangaea was rifting during the Triassic—especially late in the period—but had not yet separated. The first nonmarine sediments in the rift that marks the initial break-up of Pangaea—which separated New Jersey from Morocco—are of Late Triassic age; in the U.S., these thick sediments comprise the

Newark Group. Because of the limited shoreline of one super-continental mass, Triassic marine deposits are globally relatively rare, despite their prominence in Western Europe, where the Triassic was first studied. In North America, for example, marine deposits are limited to a few exposures in the west. Thus Triassic stratigraphy is mostly based on organisms living in lagoons and hypersaline environments, such as Estheria crustaceans.

Africa

At the beginning of the Mesozoic Era, Africa was joined with Earth's other continents in Pangaea. Africa shared the supercontinent's relatively uniform fauna which was dominated by theropods, prosauropods and primitive ornithischians by the close of the Triassic period. Late Triassic fossils are found through-out Africa, but are more common in the south than north. The boundary separating the Triassic and Jurassic marks the advent of an extinction event with global impact, although African strata from this time period have not been thoroughly studied.

Climate

Middle Triassic marginal marine sequence, southwestern Utah

The Triassic climate was generally hot and dry, forming typical red bed sandstones and evaporites. There is no evidence of glaciation at or near either pole; in fact, the polar regions were apparently moist and temperate, a climate suitable for reptile-like creatures. Pangaea's large size limited the moderating effect of the global ocean; its continental climate was highly seasonal, with very hot summers and cold winters. It probably had strong, cross-equatorial monsoons.

Life

Triassic flora as depicted in Meyers Konversations-Lexikon (1885-90)

Three categories of organisms can be distinguished in the Triassic record: holdovers from the Permian-Triassic extinction, new groups which flourished briefly and other new groups which went on to dominate the Mesozoic world.

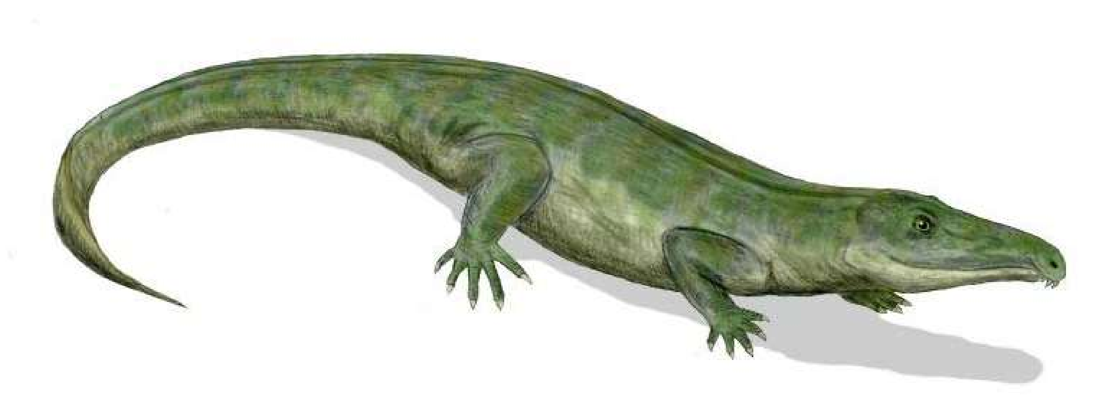
Flora

On land, the holdover plants included the lycophytes, the dominant cycads, ginkgophyta (represented in modern times by *Ginkgo biloba*) and glossopterids. The spermatophytes, or seed plants came to dominate the terrestrial flora: in the northern hemisphere, conifers flourished. *Glossopteris* (a seed fern) was the dominant southern hemisphere tree during the Early Triassic period.

Marine fauna

In marine environments, new modern types of corals appeared in the Early Triassic, forming small patches of reefs of modest extent compared to the great reef systems of Devonian times or modern reefs. The shelled cephalopods called ammonites recovered, diversifying from a single line that survived the Permian extinction. The fish fauna was remarkably uniform, reflecting the fact that very few families survived the Permian extinction. There were also many types of marine reptiles. These included the Sauropterygia, which featured pachypleurosaurs and nothosaurs (both common during the Middle Triassic, especially in the Tethys region), placodonts and the first plesiosaurs; the first of the lizardlike Thalattosauria (askeptosaurs); and the highly successful ichthyosaurs, which appeared in Early Triassic seas and soon diversified, some eventually developing to huge size during the late Triassic.

Terrestrial fauna



Reconstruction of *Proterosuchus*, a genus of carnivorous reptile, classified under Archosauromorpha, that existed in the Early Triassic period.

Coelophysis, one of the first Dinosaurs, appeared in the mid-Triassic

The Permian-Triassic extinction devastated terrestrial life. Biodiversity rebounded with the influx of disaster taxa, however these were short lived. Diverse communities with complex trophic structures took 30 million years to reestablish.

Temnospondyl amphibians were among those groups that survived the Permian-Triassic extinction, some lineages (e.g. Trematosaurs) flourishing briefly in the Early Triassic, while others (e.g. capitosaurs) remained successful throughout the whole period, or only came to prominence in the Late Triassic (e.g. plagiosaurs, metoposaurs). As for other amphibians, the first Lissamphibia, characterized by the first frogs, are known from the Early Triassic, but the group as a whole did not become common until the Jurassic, when the temnospondyls had become very rare.

Archosauromorph reptiles—especially archosaurs—progressively replaced the synapsids that had dominated the Permian. Although *Cynognathus* was a characteristic top predator in earlier Triassic (Olenekian and Anisian) Gondwana and both kannemeyeriid dicynodonts and gomphodont cynodonts remained important herbivores during much of the period. By the end of the Triassic, synapsids played only bit parts. During the Carnian (early part of the Late Triassic), some advanced cynodont gave rise to the first mammals. At the same time the Ornithodira, which until then had been small and insignificant, evolved into pterosaurs and a variety of dinosaurs. The Crurotarsi were the other important archosaur clade and during the Late Triassic these also reached the height of their diversity, with various groups including the phytosaurs, aetosaurs, several distinct lineages of Rauisuchia and the first crocodylians (the Sphenosuchia). Meanwhile the stocky herbivorous rhynchosaurs and the small to medium-sized insectivorous or piscivorous Prolacertiformes were important basal archosauromorph groups throughout most of the Triassic.

Among other reptiles, the earliest turtles, like *Proganochelys* and Proterochersis, appeared during the Norian (middle of the Late Triassic). The Lepidosauromorpha—specifically the Sphenodontia—are first known in the fossil record a little earlier (during the Carnian). The Procolophonidae were an important group of small lizard-like herbivores.

Archosaurs were initially rarer than the therapsids which had dominated Permian terrestrial ecosystems, but they began to displace therapsids in the mid-Triassic. This "Triassic Takeover" may have contributed to the evolution of mammals by forcing the surviving therapsids and their mammaliform successors to live as small, mainly nocturnal insectivores; nocturnal life probably forced at least the mammaliforms to develop fur and higher metabolic rates.

Coal

At the start of the Triassic period coal is noticeable by geologists today as being absent throughout the world. This is known as the "coal gap" and can be seen as part of the Permian–Triassic extinction event. Sharp drops in sea level across the Permo Triassic boundary may be the proper explanation for the coal gap. However, theories are still speculative as to why it is missing. During the preceding Permian period the arid desert conditions contributed to the evaporation of many inland seas and the inundation of these seas, perhaps by a number of tsunami events that may have been responsible for the drop in sea level. This due to the finding of large salt basins in the southwest United States and a very large basin in central Canada.

Immediately above the boundary the glossopteris flora was suddenly largely displaced by an Australia wide coniferous flora containing few species and containing a lycopod herbaceous under story. Conifers also became common in Eurasia. These groups of conifers arose from endemic species because of the ocean barriers that prevented seed crossing for over one hundred million years. For instance, Podocarpis was located south and Pines, Junipers and Sequoias were located north. The dividing line ran through the Amazon Valley, across the Sahara and north of Arabia, India, Thailand and Australia. It has been suggested that there was a climate barrier for the conifers. although water barriers are more plausible. If so, something that can cross at least short water barriers must have been involved in producing the coal hiatus. Hot climate could have been an important auxiliary factor across Antarctica or the Bering Strait, however. There was a spike of fern and lycopod spores immediately after the close of the Permian. In addition there was also a spike of fungal spores immediately after the Permian-Triassic boundary. This spike may have lasted 50,000 years in Italy and 200,000 years in China and must have contributed to the climate warmth.

An event excluding a catastrophe must have been involved to cause the coal hiatus due to the fact that fungi would have removed all dead vegetation and coal forming detritus in a few decades in most tropical places. In addition, fungal spores rose gradually and declined similarly along with a prevalence of woody debris. Each phenomenon would hint at widespread vegetative death. Whatever the cause of the coal hiatus must have started in North America approximately 25 million years sooner.

Lagerstätten

Triassic sandstone near Stadtroda, Germany

The Monte San Giorgio lagerstätte, now in the Lake Lugano region of northern Italy and Switzerland, was in Triassic times a lagoon behind reefs with an anoxic bottom layer, so there were no scavengers and little turbulence to disturb fossilization, a situation that can be compared to the better-known Jurassic Solnhofen limestone lagerstätte. The remains of fish and various marine reptiles (including the common pachypleurosaur Neusticosaurus and the bizarre long-necked archosauromorph *Tanystropheus*), along with some terrestrial forms like *Ticinosuchus* and *Macrocnemus*, have been recovered from this locality. All these fossils date from the Anisian/Ladinian transition (about 237 million years ago).

Late Triassic extinction event

The Triassic period ended with a mass extinction, which was particularly severe in the oceans; the conodonts disappeared and all the marine reptiles except ichthyosaurs and plesiosaurs. Invertebrates like brachiopods, gastropods and molluscs were severely affected. In the oceans, 22% of marine families and possibly about half of marine genera went missing according to University of Chicago paleontologist Jack Sepkoski.

Though the end-Triassic extinction event was not equally devastating everywhere in terrestrial ecosystems, several important clades of crurotarsans (large archosaurian reptiles previously grouped together as the thecodonts) disappeared, as did most of the large labyrinthodont amphibians, groups of small reptiles and some synapsids (except for the proto-mammals). Some of the early, primitive dinosaurs also went extinct, but other more adaptive dinosaurs survived to evolve in the Jurassic. Surviving plants that went on to dominate the Mesozoic world included modern conifers and cycadeoids.

What caused this Late Triassic extinction is not known with certainty. It was accompanied by huge volcanic eruptions that occurred as the supercontinent Pangaea began to break apart about 202 to 191 million years ago [(40Ar/39Ar dates)], forming the Central Atlantic Magmatic Province [(CAMP)], one of the largest known inland volcanic events since the planet cooled and stabilized. Other possible but less likely causes for the extinction events include global cooling or even a bolide impact, for which an impact crater containing Manicouagan Reservoir in Quebec, Canada, has been singled out. At the Manicouagan impact crater, however, recent research has shown that the impact melt within the crater has an age of 214±1 Mya. The date of the Triassic-Jurassic boundary has also been more accurately fixed recently, at 201.58±0.28 Mya. Both dates are gaining accuracy by using more accurate forms of radiometric dating, in particular the decay of uranium to lead in zircons formed at the impact. So the evidence suggests the Manicouagan impact preceded the end of the Triassic by approximately 10±2 Ma. Therefore it could not be the immediate cause of the observed mass extinction.

The number of Late Triassic extinctions is disputed. Some studies suggest that there are at least two periods of extinction towards the end of the Triassic, between 12 and 17 million years apart. But arguing against this is a recent study of North American faunas. In the Petrified Forest of northeast Arizona there is a unique sequence of latest Carnian-early Norian terrestrial sediments. An analysis in 2002 found no significant change in the paleoenvironment. Phytosaurs, the most common fossils there, experienced a change-over only at the genus level and the number of species remained the same. Some aetosaurs, the next most common tetrapods and early dinosaurs, passed through unchanged. However, both phytosaurs and aetosaurs were among the groups of archosaur reptiles completely wiped out by the end-Triassic extinction event.

It seems likely then that there was some sort of end-Carnian extinction, when several herbivorous archosauromorph groups died out, while the large herbivorous therapsids—the kannemeyeriid dicynodonts and the traversodont cynodonts— were much reduced in the northern half of Pangaea (Laurasia).

These extinctions within the Triassic and at its end allowed the dinosaurs to expand into many niches that had become unoccupied. Dinosaurs became increasingly dominant, abundant and diverse and remained that way for the next 150 million years. The true "Age of Dinosaurs" is the Jurassic and Cretaceous, rather than the Triassic.

Chapter- 2

Rhaetian and Triassic–Jurassic Extinction Event

Rhaetian

System	Series	Stage	Age (Ma)
Jurassic	Lower	Hettangian	**younger**
Triassic	Upper	**Rhaetian**	199.6–203.6
		Norian	203.6–216.5
		Carnian	216.5–228.0
	Middle	Ladinian	228.0–237.0
		Anisian	237.0–245.0
	Lower	Olenekian	245.0–249.7
		Induan	249.7–251.0
Permian	Lopingian	Changhsingian	**older**

Subdivision of the Triassic system according to the IUGS, as of July 2009.

The **Rhaetian** is in geochronology the latest age of the Triassic period or in chronostratigraphy the uppermost stage of the Triassic system. It lasted from 203.6 ± 1.5 to 199.6 ± 0.6 million years ago. It was preceded by the Norian and succeeded by the Hettangian (the lowermost stage or earliest age of the Jurassic).

In this age, Pangaea began to break up, though the Atlantic Ocean was not yet formed.

Stratigraphic definitions

The Rhaetian is named after the Rhaetian Alps, a mountain chain stretching over parts of eastern Switzerland, northern Italy and western Austria. The stage was introduced in scientific literature by Austrian geologist Eduard Suess and German paleontologist Albert Oppel in 1856.

The base of the Rhaetian did not yet have a unanimously agreed upon definition in 2009. In the Tethyan domain, the base of the ammonite biozone of *Sagenites reticulatus* is used, in the boreal domain (where this species is not found) the base of the biozone of *Cochloceras amoenum* is used instead. The base is also close to the first appearances of conodont species *Misikella spp.* and *Epigondolella mosheri* and radiolarite species *Proparvicingula moniliformis*.

The top of the Rhaetian (the base of the Hettangian stage, the Lower Jurassic series and the Jurassic system) is at the first appearance of ammonite genus *Psiloceras*.

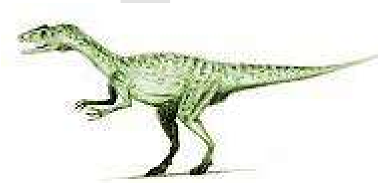
In the Tethyan domain, the Rhaetian contains two ammonite biozones. The highest ammonite biozone is that of *Choristoceras marshi*, the lower one that of *Rhabdoceras suesii*.

Life

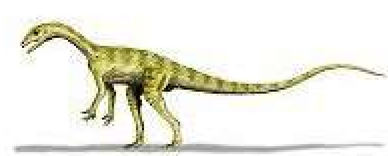
Dinosauria

Dinosaurs of the Rhaetian

Taxa	**Presence**	**Images**
• *Agnosphitys*		
• *Agrosaurus*		
• *Liliensternus*		
• *Pantydraco*		
• *Thecodontosaurus*	Norian/Rhaetian	



Liliensternus



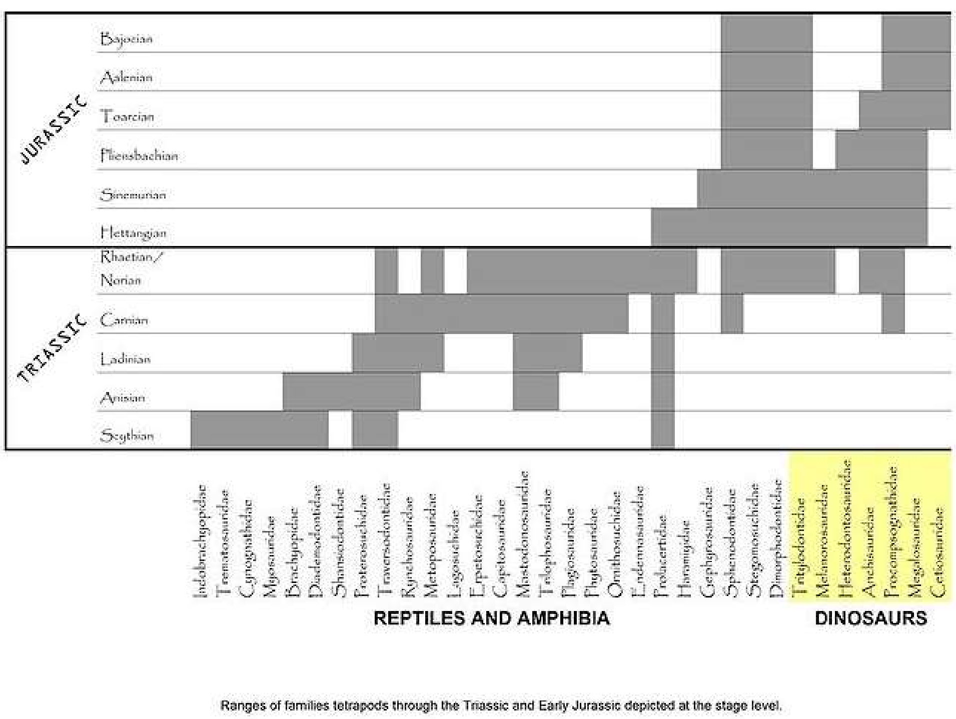
Pantydraco

Mammaliaformes

Mammaliaformes of the Rhaetian

Taxa	Images
• *Eozostrodon* • *Haramiya* • *Megazostrodon*	 *Megazostrodon*

Triassic–Jurassic extinction event



Ranges of families tetrapods through the Triassic and Early Jurassic

The **Triassic–Jurassic extinction event** marks the boundary between the Triassic and Jurassic periods, 199.6 million years ago and is one of the major extinction events of the Phanerozoic eon, profoundly affecting life on land and in the oceans. A whole class (conodonts), twenty percent of all marine families and all large crurotarsans (non-dinosaurian archosaurs), some remaining therapsids and many of the large amphibians were wiped out. At least half of the species now known to have been living on Earth at that time went extinct. This event vacated ecological niches, allowing the dinosaurs to assume the dominant roles in the Jurassic period. This event happened in less than 10,000 years and occurred just before Pangaea started to break apart.

Statistical analysis of marine losses at this time suggests that the decrease in diversity was caused more by a decrease in speciation than by an increase in extinctions.

Several explanations for this event have been suggested, but all have unanswered challenges:

- Gradual climate change or sea-level fluctuations during the late Triassic. However, this does not explain the suddenness of the extinctions in the marine realm.
- Asteroid impact, but no impact crater has been dated to coincide with the Triassic–Jurassic boundary (the impact responsible for the annular Manicouagan Reservoir occurred about 12 million years before the extinction event).
- Massive volcanic eruptions, specifically the flood basalts of the Central Atlantic Magmatic Province (CAMP), would release carbon dioxide or sulfur dioxide and aerosols, which would cause either intense global warming (from the former) or cooling (from the latter).

The isotopic composition of fossil soils of end Triassic and Early Jurassic has been tied to a large negative carbon isotope excursion (Whiteside et al. 2010). Carbon isotopes of lipids (*n*-alkanes) derived from leaf wax and lignin and total organic carbon from two sections of lake sediments interbedded with the CAMP in eastern North America have shown carbon isotope excursions similar to those found in the mostly marine St. Audrie's Bay section in England; the correlation suggests that the end-Triassic extinction event began at the same time in marine and terrestrial environments, slightly before the oldest basalts in eastern North America but simultaneous with the eruption of the oldest flows in Morocco (Also suggested by Deenen et al., 2010), with both a critical CO_2 greenhouse and a marine biocalcification crisis. Contemporaneous CAMP eruptions, mass extinction and the carbon isotopic excursions are shown in the same places, making the case for a volcanic cause of a mass extinction. The catastrophic dissociation of gas hydrates (suggested as one possible cause of the largest mass extinction of all time, the so-called "Great Dying" at the end of the Permian Period) may have exacerbated greenhouse conditions.

Chapter- 3

Norian

The **Norian** is a division of the Triassic geological period. It has the rank of an age (geochronology) or stage (chronostratigraphy). The Norian lasted from 216.5 ± 2.0 to 203.6 ± 1.5 million years ago. It was preceded by the Carnian and succeeded by the Rhaetian.

Stratigraphic definitions

The Norian was named after the Noric Alps in Austria. The stage was introduced into scientific literature by Austrian geologist Edmund Mojsisovics von Mojsvar in 1869.

The Norian stage begins at the base of the ammonite biozones of *Klamathites macrolobatus* and *Stikinoceras kerri* and at the base of the conodont biozones of *Metapolygnathus communisti* and *Metapolygnathus primitius*. A global reference profile for the base (a GSSP) had in 2009 not yet been appointed.

The top of the Norian (the base of the Rhaetian) is at the first appearance of ammonite species *Cochloceras amoenum*. The base of the Rheatian is also close to the first appearance of conodont species *Misikella spp.* and *Epigondolella mosheri* and the radiolarid species *Proparvicingula moniliformis*.

In the Tethys domain, the Norian stage contains six ammonite biozones:

- zone of *Halorites macer*
- zone of *Himavatites hogarti*
- zone of *Cyrtopleurites bicrenatus*
- zone of *Juvavites magnus*
- zone of *Malayites paulckei*
- zone of *Guembelites jandianus*

Palaeontology

- Synapsids
- Aetosaurs
- Dicynodonts
- Phytosaurs

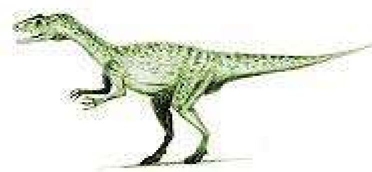
Dinosaurs

Dinosaurs of the Norian

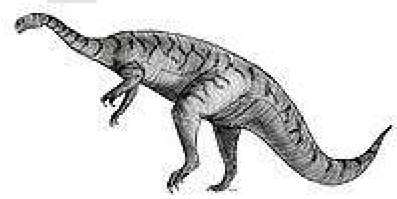
Taxa	Presence	Location
Agnosphitys		
Coelophysis	Late Carnian to early Norian	Ghost Ranch, New Mexico, USA
Halticosaurus		
Liliensternus		
Plateosaurus		
Sellosaurus		
Thecodontosaurus	Norian/Rhaetian	

Images

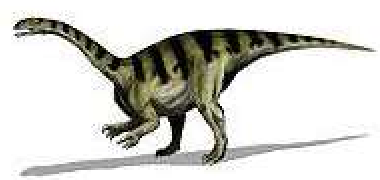
Coelophysis



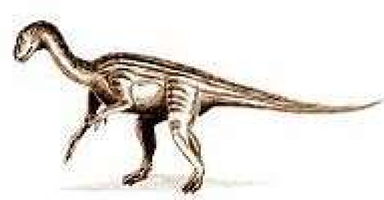
Liliensternus



Plateosaurus



Sellosaurus



Thecodontosaurus

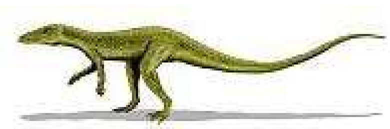
†Pterosaurs

Pterosaurs of the Norian

Taxa	Presence	Location	Description	Images
• *Eudimorphodon* • *Peteinosaurus*				 *Eudimorphodon*
• *Preondactylus*				 *Preondactylus*

Crocodylomorphs

Crocodylomorphs of the Norian

Taxa	Presence	Location	Description	Images
• *Saltoposuchus*				 *Saltoposuchus*

†Ichthyosaurs

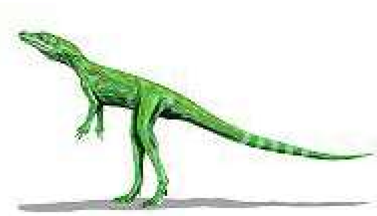
Ichthyosaurs of the Norian

Taxa	Presence	Location	Description	Images
Shonisaurus 1. *Shonisaurus*				

popularis				*Shonisaurus*

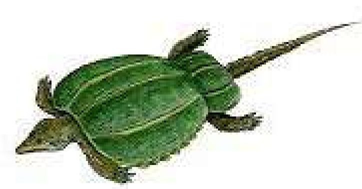
†Dinosauromorphs (non-dinosaurian)

†Non-dinosaurian dinosauromorphs of the Norian

Taxa	Presence	Location	Description	Images
• *Dromomeron*				 *Dromomeron*
• *Eucoelophysis*		New Mexico		

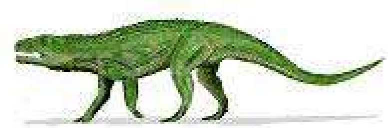
†Placodonts

Placodonts of the Norian

Taxa	Presence	Location	Description	Images
• *Psephoderma*				 *Psephoderma*

†Crurotarsans (non-crocodylomorph)

†Non-crocodylomorph Crurotarsans of the Carnian

Taxa	Presence	Location	Description	Images
• *Basutodon*				 *Teratosaurus*
• *Teratosaurus*				

Chapter- 4

Carnian

The **Carnian** (less commonly, **Karnian**) is the lowermost stage of the Upper Triassic series (or earliest age of the Late Triassic epoch). It lasted from about 228.7 till 216.5 million years ago (Ma). The Carnian is preceded by the Ladinian and is followed by the Norian. Its boundaries are not characterized by major extinctions or biotic turnovers, but a climatic event (known as the Carnian Pluvial Event) occurred during the Carnian and seems to be associated with important extinctions or biotic radiations.

Stratigraphic definitions

Alluvial plain red clays of the Travenanzes formation, upper Carnian, the Dolomites, northern Italy

Brotheotrachyceras brotheus from the San Cassiano Formation, Val Badia, Dolomites, Southern Alps. This ammonoid is an index fossil for the lower Carnian

The Carnian was named in 1869 by Mojsisovics. It is unclear if it was named after the Carnic Alps or after the Austrian region of Carinthia (*Kärnten* in German). The name, however, was first used referring to a part of the Hallstatt Limestone cropping out in Austria.

The base of the Carnian stage is defined as the place in the stratigraphic record where the ammonite species *Daxatina canadensis* first appears. The global reference profile for the base is located at the *Stuores-Wiesen* near Badia (Abtei) in the Badia Valley in the region of Südtirol, Italy.

The top of the Carnian (the base of the Norian) is at the bases of the ammonite biozones of *Klamathites macrolobatus* or *Stikinoceras kerri* and the conodont biozones of *Metapolygnathus communisti* or *Metaolygnathus primitius*.

Dating and subdivisions

There is no established, standard usage for the Carnian subdivisions, thus, while in some regional stratigraphies a two-substage subdivision is common:

- Julian
- Tuvalian

others prefer a three-substage organization of the stage as follows:

- Cordevolian
- Julian
- Tuvalian

The Carnian spans from 228.0 ± 2.0 to 216.5 ± 2.0 Ma in the proposed geologic time scale by Gradstein et al. (2004). These dates are interpolated, because direct radiometric dates for this stage were missing when that time scale was compiled. Recently, Upper Carnian beds in southern Italy yielded an age of 230.91 ± 0.33 Ma. The age and duration of the Carnian need thus to be reconsidered.

Biostratigraphy

In the Tethys domain, the Carnian stage contains six ammonite biozones:

- zone of *Anatropites spinosus*
- zone of *Tropites subbullatus*
- zone of *Tropites dilleri*
- zone of *Austrotrachyceras austriacum*
- zone of *Trachyceras*

Paleogeography and climate

The paleogeography of the Carnian was basically the same as for the rest of the Triassic. Most continents were merged into the supercontinent Pangaea and there was a single global ocean, Panthalassa. The global ocean had a western branch at tropical latitudes called Paleo-Tethys. The sediments of Paleo-Tethys now crop out in southeastern Europe, in the Middle East, in the Himalayas and up to the island of Timor.

The extreme land-sea distribution led to "mega-monsoons", i.e., an atmospheric monsoon regime more intense than the present one.

As for most of the Mesozoic, there were no ice caps. Climate was mostly arid in the tropics, but an episode of wet tropical climate is documented at least in the Paleo-Tethys. This putative climatic event is called the “Carnian Pluvial Event”, its age being between latest early Carnian (Julian) and the beginning of late Carnian (Tuvalian). The nature of this event is still discussed; some scientists believe it is only an artifact, due to the migration of continents of the Tethyan area across the equatorial climatic belt. Following this idea, the apparent shift from arid to humid and then back to arid climate simply testifies the continents going from southern tropical, to equatorial and then to northern tropical latitudes.

Life

In the marine realm, the Carnian saw the first abundant occurrences of calcareous nannoplankton, a morphological group including the Coccolithophores.

Invertebrates

There are a few invertebrates which are typical and characteristic of the Carnian. Among molluscs, the ammonoid genus *Trachyceras* is exclusive to the lower Carnian (i.e., Julian of the two-substages subdivision, see above). The family Tropitidae and the genus *Tropites* appear at the base of the upper Carnian (Tuvalian). The bivalve genus *Halobia*, a bottom-dweller of deep sea environments, differentiated from *Daonella* at the beginning of this age. Scleractinian coral reefs, i.e., reefs with corals of the modern type, became relatively common for the first time in the Carnian.

Vertebrates

The earliest dinosaur *Eoraptor* originated slightly before the Carnian stage began around 230 Ma. The oldest well documented dinosaurian assemblage, in the Ischigualasto Formation of Argentina, is most probably late Carnian in age.

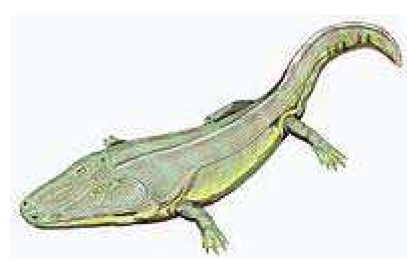
In this stage the archosaurs became the dominant faunas in the world, evolving into groups such as the phytosaurs, rhynchosaurs, aetosaurs and rauisuchians. The first dinosaurs also appeared in this stage and though at the time they were small and insignificant, they diversified rapidly and would dominate the fauna for the rest of the Mesozoic. On the other hand, the therapsids, which included the ancestors of mammals, decreased in both size and diversity and would remain relatively small until the extinction of the dinosaurs.

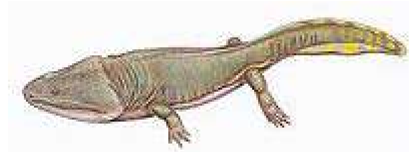
Conodonts were present in Triassic marine sediments. *Paragondolella polygnathiformis* appeared at the base of the Carnian stage and is perhaps the most characteristic species. A partial list of Carnian vertebrates is given below.

Many Carnian vertebrates are found in Santa Maria Formation rocks of the Paleorrota geopark.

†Temnospondyls

Temnospondyls of the Carnian

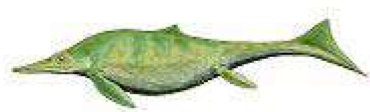
Taxa	Presence	Location	Description	Images
Cyclotosaurus		All Across Europe		 Cyclotosaurus
Deltasaurus		Australia		
Metoposaurus		Europe and North America		



Metoposaurus

†Ichthyosaurs

Ichthyosaurs of the Carnian

Taxa	Presence	Location	Description	Images
• *Californosaurus*				 *Californosaurus*
• *Shastasaurus*				
• *Shonisaurus*				

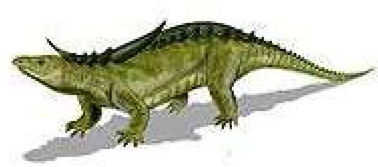
†Archosauromorphs (non-archosaurian)

Non-Archosaurian Archosauromorphs of the Carnian

Taxa	Presence	Location	Description	Images
• *Hyperodapedon*		Paleorrota, Brazil.		 *Hyperodapedon*
• *Trilophosaurus*				

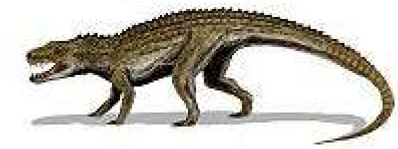
†Crurotarsans (non-crocodylomorph)

†Non-crocodylomorph Crurotarsans of the Carnian

Taxa	Presence	Location	Description	Images
• *Desmatosuchus*				
• *Doswellia*				
• *Ornithosuchus*				

- *Paleorhinus*
- *Postosuchus*
- *Rutiodon*
- *Saurosuchus*
- *Stagonolepis*

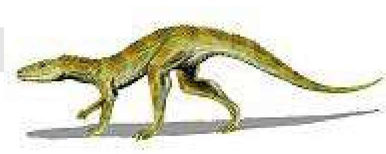
Desmatosuchus



Postosuchus

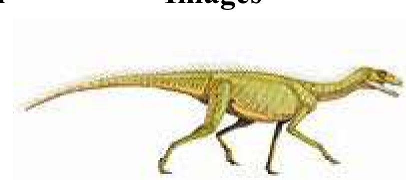
Crocodylomorphs

Crocodylomorphs of the Carnian

Taxa	Presence	Location	Description	Images
• *Hesperosuchus*				 *Hesperosuchus*

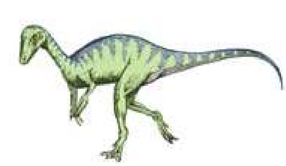
†Non-dinosaur Ornithodira

†Ornithodira of the Carnian

Taxa	Presence	Location	Description	Images
• *Silesaurus*		Silesia, Poland		 *Silesaurus*
• *Sacisaurus*		Agudo, Rio Grande do Sul, Brazil		

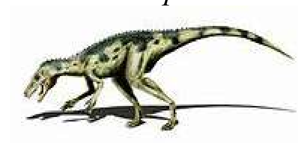
Dinosaurs

†Dinosaurs of the Carnian

Taxa	Presence	Location	Description	Images
• *Blikanasaurus*	Disputed: considered Norian by some researchers.			

Camposaurus	Chinle Formation, Arizona		Some palaeontologists believe that it's actually a junior synonym of the better known *Coelophysis*.
Eoraptor			
Euskelosaurus	Disputed: considered Norian by some researchers.		
Guaibasaurus		Paleorrota, Brazil.	
Staurikosaurus		Paleorrota, Rio Grande do Sul, Brazil.	
Saturnalia		Paleorrota, Rio Grande do Sul, Brazil.	May have been a primitive sauropodomorph, probably grew to about 1.5 meters (5 ft) long.
Unaysaurus		Paleorrota, Rio Grande do Sul, Brazil.	
Herrerasaurus			
Panphagia			
Pisanosaurus		Ischigualasto Formation, San Juan, Argentina	A small, lightly-built dinosaur approximately 1 m (3 ft 3 in) in length and 30 cm (12 in) in height. It was bipedal and, like all ornithischians, was probably exclusively herbivorous.

Eoraptor



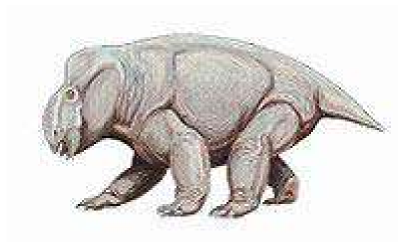
Herrerasaurus

Staurikosaurus eating a rhynchosaur.

- *Teyuwasu*

†Therapsids (non-mammalian)

†Non-mammalian Therapsids of the Carnian

Taxa	Presence	Location	Description	Images
• *Exaeretodon*		Paleorrota, Brazil.		
• *Placerias*				 *Placerias*.

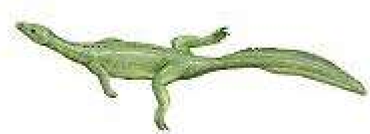
Mammaliaformes

Mammaliaformes of the Carnian

Taxa	Presence	Location	Description	Images
• *Adelobasileus*		Tecovas formation, Texas, USA	Thought to be the common ancestor of all modern mammals or a close relative of the common ancestor	 *Adelobasileus*

†Thalattosaurians

Thalattosauria of the Carnian

Taxa	Presence	Location	Description	Images
• *Miodentosaurus*		Falang Formation, Guizhou, China	A relatively large thalattosaurian, more than 4 meters long.	 *Miodentosaurus*

Classic localities and lagerstätten

The lower Carnian fauna of the San Cassiano Formation (Dolomites, northern Italy) has been studied since the 19th century. Fossiliferous localities are many and are distributed mostly in the surroundings of Cortina d'Ampezzo and in the high Badia Valley, near the village of San Cassiano, after which the formation was named. This fauna is extremely diverse, including ammonoids, gastropods, bivalves, echinoderms, calcareous sponge, corals, brachiopods and a variety of less common fossils. A collection of this fauna is exposed in the “Museo delle Regole”, a museum in Cortina d'Ampezzo.

The Ischigualasto Formation of northwestern Argentina yielded a very important vertebrate association, including the oldest dinosaurian assemblage.

Chapter- 5

Anisian

System	Series	Stage	Age (Ma)
Jurassic	Lower	Hettangian	younger
Triassic	Upper	Rhaetian	199.6–203.6
		Norian	203.6–216.5
		Carnian	216.5–228.0
	Middle	Ladinian	228.0–237.0
		Anisian	237.0–245.0
	Lower	Olenekian	245.0–249.7
		Induan	249.7–251.0
Permian	Lopingian	Changhsingian	older

Subdivision of the Triassic system according to the IUGS, as of July 2009.

In the geologic timescale, the **Anisian** is the lower stage or earliest age of the Middle Triassic series or epoch and lasted from 245 million years ago until 237 million years ago, approximately. The Anisian age succeeds the Olenekian age (part of the Lower Triassic epoch) and precedes the Ladinian age.

Stratigraphic definitions

The stage and its name were established by Austrian geologists Wilhelm Heinrich Waagen and Carl Diener in 1895. The name comes from *Anisus*, the Latin name of the river Enns. The original type locality is at Großreifling in the Austrian state of Styria.

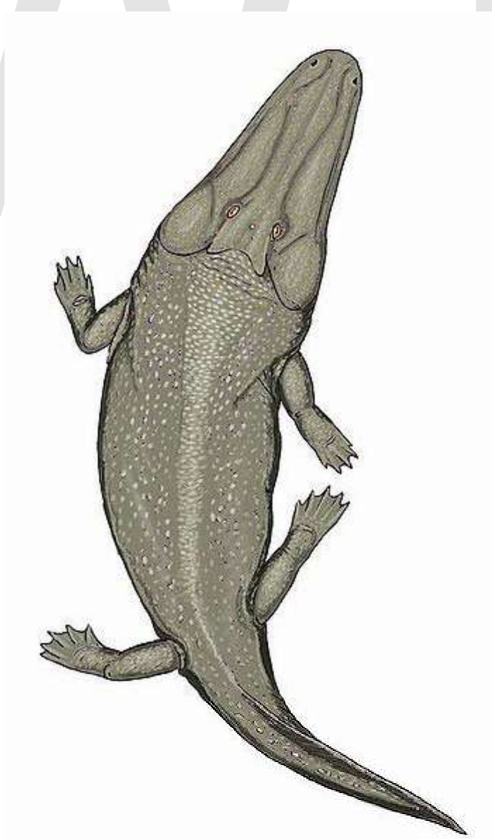
The base of the Anisian stage (also the base of the Middel Triassic series) is sometimes laid at the first appearance of conodont species *Chiosella timorensis* in the stratigraphic record. Other stratigraphers prefer to use the base of magnetic chronozone MT1n. The global reference profile for the base (the GSSP or golden spike) is at a flank of the mountain Deşli Caira in the Romanian Dobruja.

The top of the Anisian (the base of the Ladinian) is at the first appearance of ammonite species *Eoprotrachyceras curionii* and the ammonite family Trachyceratidae. The conodont species *Neogondolella praehungarica* appears at the same level.

Sometimes (especially in Central Europe) the Anisian stage is subdivided into four substages: Aegean, Bythinian, Pelsonian and Illyrian.

The Anisian contains six ammonite biozones:

- zone of *Nevadites*
- zone of *Hungarites*
- zone of *Paraceratites*
- zone of *Balatonites balatonicus*
- zone of *Kocaelia*
- zone of *Acrochordiceras*



Cherninia, giant temnospondyl from India

Palaeontology

The earliest potential dinosaur fossil to date is a partial pubis from Anisian-age rocks of the Moenkopi Formation, Arizona. It may have come from a herrerasaurid.

Examples of vertebrates from this age are:

- Ichthyosaurs
- Prestosuchids
- Trigoniids

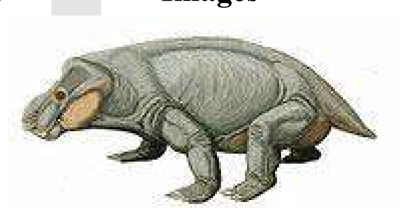
†Archosauromorphs (non-archosaurians)

†Non-archosaurian Archosauromorphs of the Anisian

Taxa	Presence	Location	Description	Images
• *Erythrosuchus*				 *Erythrosuchus*

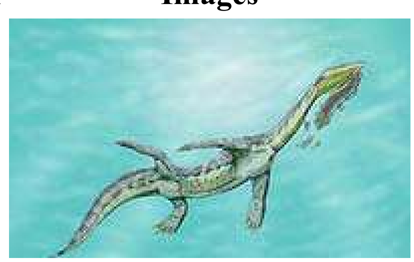
†Therapsids (non-mammalian)

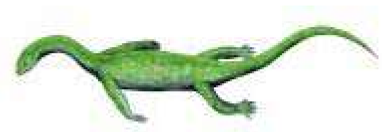
†Non-mammalian Therapsids of the Anisian

Taxa	Presence	Location	Description	Images
• *Kannemeyeria*				 *Kannemeyeria*

†Nothosauroids

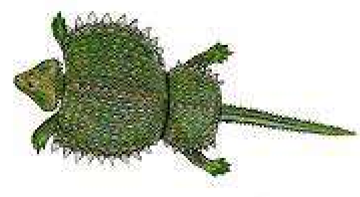
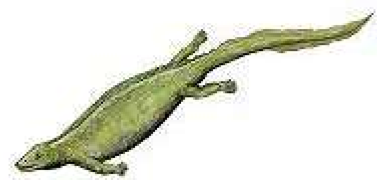
Nothosauroids of the Anisian

Taxa	Presence	Location	Description	Images
• *Anarosaurus*				
• *Ceresiosaurus*				
• *Dactylosaurus*				

			Ceresiosaurus
• *Keichousaurus*	Guizhou and Hubei, China		 *Keichousaurus*

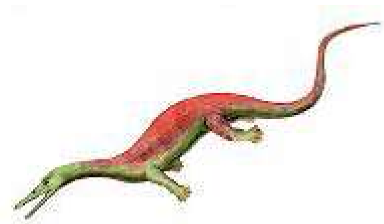
†Placodonts

Placodonts of the Anisian

Taxa	Presence	Location	Description	Images
• *Cyamodus*				 *Cyamodus*
• *Paraplacodus*		Northern Italy		 *Paraplacodus*

†Thalattosaurians

Thalattosauria of the Anisian

Taxa	Presence	Location	Description	Images
• *Askeptosaurus*		Italy	A very thin, elongated creature (about 2 meters long) that probably swam like an eel, that was probably a fish eater and hunted in deep waters, based on its	 *Askeptosaurus*

large eyes (which would allow it to see better in dark water) and the protective bony ring around them (also seen in ichthyosaurs), which prevented them from getting squashed in by the immense water pressure at great depths.

†Ceratitida

Ananorites Arthaberites Beyrichites Bosnites Buddhaites Bukowskiites Caucasites Danubites Gangadharites Japonites Laboceras Longobarditoides Mesocladiscites Noetlingites Parapinacoceras Parasageceras Phyllocladiscites Proavites Pseudodanubites Psilocladiscites Salterites Tropigymnites Xiphogymnites Pararcestes Sageceras

Lower

Alloptychites Anagymnites Grambergia Groenlandites Gymnites Lenotropites Pearylandites Silberlingites Isculites Stenopopanoceras

Middle

Acrochordiceras Alanites Anagymnotoceras Arctohungarites Balatonites Bulogites Cuccoceras Czekanowskites Epacrochordiceras Hollandites Huishuites Inaigymnites Ismidites Kiparisovia Malletophychites Nicomedites Phillipites Platycuccoceras Pronoetlingites Reiflingites Discoptychites Intornites Nevadisculites Paraceratites Parapopanoceras Proarcestes Longobardites Ptychites

Upper

Amphipopanoceras Aplococeras Arctogymnites Eudiscoceras Eutomoceras Gymnotoceras Halilucites Judicarites Kellnerites Metadinarites Nevadites Parakellnerites Proteusites Repossia Semiornites Serpianites Stoppaniceras Ticinites Tozerites Tropigastrites Joannites Epigymnites Ceratites Flexoptychites Frechites Norites Gevanites Hungarites

†Phylloceratida

Spinoleiophyllites Ussurites Monophyllites

Nautilida

Trachynautilus Thuringionautilus Styrionautilus

Lower

Indonautilus Sibyllonautilus

Middle

Paranautilus

Upper

Holconautilus Proclydonautilus

†Aulacocerida

Crassiatractites Breviatractites

Lower

Mojsisovicsteuthis

Pterioida

Ramonalinidae

Chapter- 6

Triassic Extinctions

1. Bellerophon

Bellerophon **Fossil range: Silurian–Early Triassic**	
Scientific classification	
Kingdom:	Animalia
Phylum:	Mollusca
Class:	Gastropoda or Monoplacophora
Superfamily:	Bellerophontoidea
Family:	Bellerophontidae
Subfamily:	Bellerophontinae
Genus:	***Bellerophon*** Montfort, 1808

Bellerophon is a genus of extinct paleozoic marine molluscs of uncertain position (Gastropoda or Monoplacophora) in the family Bellerophontidae.

The genus was named after Bellerophon, the ancient Greek hero.

Bellerophon is the type genus of the family Bellerophontidae.

Shell description

The genus is characterised by a shell which is globose, convolute and planispiral (symmetrically coiled). The shell of *Bellerophon* superficially resembles that of a miniature cephalopod (e.g. *Nautilus* or an ammonite), except that septa are lacking.

The shell of *Bellerophon* is often a couple of centimeters in maximum dimension. The external surface is smooth, ornamented only by growth lines. There is a low crest or ridge running along the midline of the shell.

Many specimens of *Bellerophon* show something resembling a "waterline" about half-way up the shell, suggesting that a large amount of the mantle and foot were exposed and covered the outside of the shell, as in the extant Cypraeidae and Naticidae.

Possible life habits

These animals were probably quick moving, relying on speed to avoid predators and, when this was not possible, withdrawing deeply into the shell.

Range of distribution

The genus occurs worldwide and is known from the Silurian to the Early Triassic periods.

Discussion of the taxonomy

Although usually classified as a primitive gastropod, there is a minority view that the Bellerophontida actually represented a more primitive, untorted type of mollusk, which evolved a spiral shell independently. Another view is that some Bellerophontids, including *Bellerophon*, were torted gastropods, but that others were untorted forms.

Species

Species within the genus *Bellerophon* include:

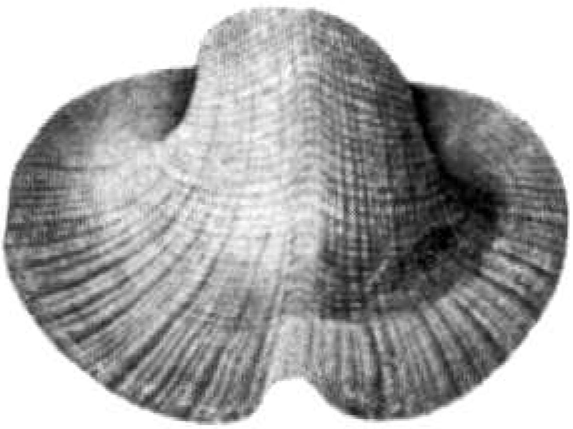
subgenus *Bellerophon*

- *Bellerophon needlensis* - from Late Mississippian from Utah
- *Bellerophon welshi* - from Late Mississippian from Utah

subgenus ?

- *Bellerophon bicarenus* Lévillé from early Carboniferous
- *Bellerophon graphicus* Moore from the late Pennsylvanian (Virgilian) of Kansas
- *Bellerophon regularis* (Waagen) from the Permian of India
- *Bellerophon vasulites* Montfort - the type species, from the Middle Devonian of Germany
- and others

2. Bellerophontidae

Bellerophontidae	
	
Bucanopsis leda (subfamily Bucanopsinae)	
Scientific classification	
Kingdom:	Animalia
Phylum:	Mollusca
Class:	Gastropoda or ? Monoplacophora
Superfamily:	Bellerophontoidea
Family:	**Bellerophontidae** McCoy, 1852

The **Bellerophontidae** is an extinct family of specialized globose bellerophontids; Paleozoic and Early Triassic mollusks of uncertain position (Gastropoda or Monoplacophora).

Geological range

These mollusks appeared in the Late Cambrian and continued until the Early Triassic.

Shell description

The shell resembles a miniature *Nautilus*, with greatly overlapping, rounded whorls, in which the last whorl completely encompasses the others, leaving either a very narrow umbilicus on either side, or none at all. At the aperture of the shell is a slit, which results in a sort of low ridge that runs along the length of shell. The shell has a low profile and it is possible that these were active, fast-moving molluscs.

Taxonomy

1960 taxonomy

Knight et al. 1960 in the Treatise on Invertebrate Paleontology consider the Bellerophontidae a very large family made up of a number of subfamilies and tribes.

The 1960 classification places the family Bellerophontidae in the order Bellerophontida Ulrich & Scofield, 1897.

The classification presented is as follows:

ordo Bellerophontida Ulrich & Scofield, 1897

- **Family Bellerophontidae** McCoy, 1851
    - Subfamily Tropidodiscinae Knight, 1956
    - Subfamily Bucaniinae Ulrich & Scofield, 1897

    - Tribe Bucaniides Ulrich & Scofield, 1897
    - Tribe Salpingostomatides Koken, 1925

    - Subfamily Carinaropsinae Ulrich & Scofield, 1897
    - Subfamily Pterothecinae Wenz, 1938
    - Subfamily Bellerophontinae McCoy, 1851
    - Subfamily Knightitinae Knight, 1956

2001 taxonomy

Recently Peter J. Wagner presented cladograms which divide this assemblage into a number of different groups, as well as combining the Bellerophontidae with the family Sinuitidae. while Bouchet & Rocroi (2005) places Sinuitidae as a family in superfamily Bellerophontoidea.

2005 taxonomy

The taxonomy of the Gastropoda by Bouchet & Rocroi, 2005 categorizes Bellerophontidae like this:

- Paleozoic molluscs of uncertain systematic position
    - Paleozoic molluscs with isostrophically coiled shells of uncertain position within Mollusca (Gastropoda or Monoplacophora)
        - superfamily Bellerophontoidea McCoy, 1852 - Bellerophontoidea is the only superfamily in this taxon.
            - family Bellerophontidae McCoy, 1852

- subfamily Bellerophontinae McCoy, 1852 - synonym: Liljevallospiridae Golikov & Starobogatov, 1889
- subfamily Bucanopsinae Wahlman, 1992
- subfamily Cymbulariinae Horný, 1963
- subfamily Knightitinae Knight, 1956

Bouchet & Rocroi, on page 271 (2005), also state that the assignation of "*symmetrical univalved mollusks "bellerophonts" either to Gastropoda or to Monoplacophora or Tergomya is controversial."* In other words, it is not yet certain whether bellerophonts are in fact real gastropods, they might be monoplacophorans or they might belong to a group (Tergomya) that is closely related to the gastropods, but not actually gastropods.

Genera

Genera in the family Bellerophontidae include:

- subfamily Bellerophontinae
  - genus *Bellerophon* Montfort, 1808 - type genus of the subfamily Bellerophontinae

- subfamily Bucanopsinae
  - genus *Bucanopsis* Ulrich, 1897 - type genus of the subfamily Bucanopsinae

- subfamily Cymbulariinae
  - genus *Cymbularia* Koken, 1896 - type genus of the subfamily Cymbulariinae

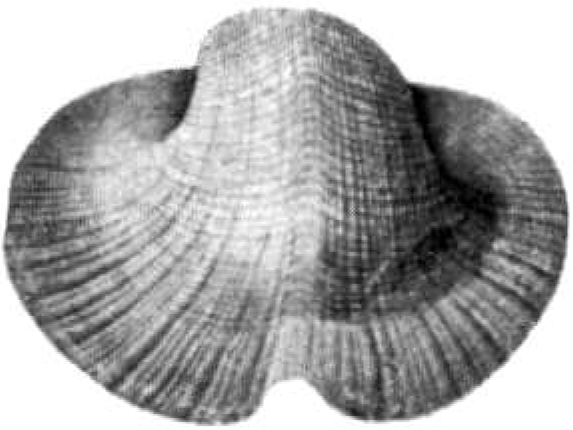
- subfamily Knightitinae
  - genus *Knightites* Moore, 1941 - type genus of the subfamily Knightitinae

other genera include:

- *Aglaoglypta*
- *Liljevallospira*
- *Pharkidonotus*
- *Prosoptychus*
- *Ptychobellerophon*
- *Ptychosphaera*

3. Bellerophontoidea

Bellerophontoidea Fossil range: Late Cambrian–Triassic	



Bucanopsis leda (family Bellerophontidae, subfamily Bucanopsinae)

Scientific classification	
Kingdom:	Animalia
Phylum:	Mollusca
Class:	Gastropoda or Monoplacophora
(unranked):	"*Paleozoic uncertain* ..."
Superfamily:	**Bellerophontoidea** (=Bellerophontaceae) McCoy, 1852

The **Bellerophontoidea**, (Bellerophontaceae Ulrich & Schofield, 1897, ex Bellerophontidae McCoy 1951), common name "**bellerophonts**", is a superfamily of extinct planospirally coiled globose molluscs, generally included in the Gastropoda that first appeared late in the Cambrian and continued until late in the Triassic.

Biology

Unlike normal gastropods, the shells of Bellerophonts are characterised by a completely planispiral pattern of coiling, such as one finds in shelled cephalopods. Experts disagree whether Bellerophontids should be classified as torted gastropods or as untorted Tergomya, or whether the group Bellerophontida is perhaps an artificial construct, consisting of a number of distinct groups of Palaeozoic molluscs which evolved the same type of spiral shell independently.

Taxonomy

Historical Background

The taxomony of the Bellerophontoidea (renamed from the original Bellerophontacea) has gone through a number of revisions since M'Coy established the Bellerophontaceae in 1851 for planospiral archeogastropods. The naming followed the convention for superfamilies that prevailed until at least 1992 with Wahlman

The Bellerophontacea were placed in the order Bellerophontida established by Ulrich and Scofield in 1897 and included the families Bellerophontidae, Bucaniidae, Cyrtolitidae and Protowarthiidae.

Knight, et al. 1960 (Treatise Part I reprinted 1989) discuss the Superfamily Bellerophontacea at some length and include within it the Bellerophontidae, Cyrtolitidae, Sinuopeidae and Tropidodiscidae.

2005 Bellerophontid taxonomy

Bouchet et al. (2005) leaves the higher taxonomic position of the Bellerophontoidea as uncertain (Gastropoda or Monoplacophora) and divides the group into 8 families as listed:

- Bellerophontoidea
    - † Bellerophontidae
    - † Bucanellidae
    - † Bucaniidae
    - † Euphemitidae
    - † Pterothecidae
    - † Sinuitidae
    - † Tremanotidae
    - † Tropidodiscidae

The **Bellerophontidae**, **Bucanitidae**, **Pterothacidae** and **Tropododiscidae** compare with the subfamilies Bellerophontinae, Bucanitinae, Pterothacinae and Tropododiscinae included in the Bellerophontidae and the **Bucanellidae**, **Euphemitidae** and **Sinuitidae** compare with the subfamilies Bucanellinae, Euphemitinae and Sinuitinae included in the Sinuitidae, as found in the Treatise. The **Tremanitiae** is based on the genus *Tremanotus* which was included in the Bucanitinae in the Treatise.

Bouchet & Rocroi (2005) points out (page 271) that assignment of "*symetrical univalved mollusks "bellerophonts" either to Gastropoda or to Monoplacophora or Tergomya is controversial."*

Note on Nomenclature

Until recently with the ruling of the ICZN, -ACEA, or -ACEAE, was pretty much the standard ending for superfamilies in invertebrate paleontology and zoology. -OIDEA used now as the ending on superfamily names was generally reserved for subclasses and superorders

4. Gnathorhizidae

Gnathorhizidae **Fossil range: Late Carboniferous - Middle Triassic**	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Subphylum:	Vertebrata
Class:	Sarcopterygii
Subclass:	**Dipnoi** Müller, 1844
Family:	**†Gnathorhizidae**
Genera	

- †*Gnathorhiza*
- †*Monongahela*
- †*Beltanodus*
- ? †*Microceratodus*
- †*Namatozodia*

The **Gnanthorhizidae** are an extinct family of lungfish that lived from the late Carboniferous until the middle Triassic. Gnathorhizid fossils have been found in North America, Madagascar, Australia and possibly Eastern Europe and South Africa. They are characterized by high-ridged toothplates that form cutting blades and a reduction in cranial bones.

Distribution

Gnathorhizids are found in North America, Eastern Europe, Australia and Africa. Gnathorhizids from North America range from the Gzhelian through the Roadian. In Africa, gnathorhizids are found in Olenekian of Madagascar and possibly South Africa. Lungfish teeth attributed to gnathorhizids have been reported from the Lopingian to the

Olenekian in Poland and Western Russia. It is likely, then, that gnathorhizids had a Pangean distribution throughout the late Paleozoic and early Mesozoic.

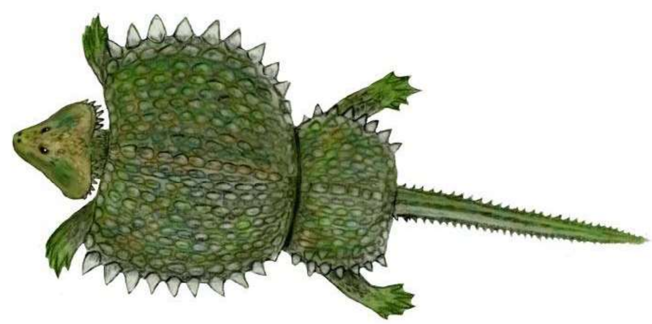
Paleoecology and behavior

Gnathorhizids are found primarily in paleosols representing ephemeral wetlands. Additionally, gnathorhizids, unlike most groups of fossil lungfish, are often found in association with regular burrow structures, suggesting that this group of lungfish may have estivated during the dry season, much like modern African and South American lungfish.

Unlike most fossil lungfish, but again, like modern South American and African lungfish, gnathorhizids have bladelike toothplates. This suggests that gnathorhizids were active predators unlike most lungfish, which feed primarily on benthic invertebrates.

5. Placodont

Placodonts
Fossil range: 235–200 Ma
Triassic



Cyamodus, a member of the superfamily Cyamodontoidea.

Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Sauropsida
Superorder:	Sauropterygia
Order:	**Placodontia** Cope, 1871

Families

Cyamodontidae

Henodontidae
Paraplacodontidae
Placochelyidae
Placodontidae

Placodonts ("Tablet teeth") were a group of marine reptiles that lived during the Triassic period, becoming extinct at the end of the period. It is believed that they were part of Sauropterygia, the group that includes Plesiosaurs. Placodonts were generally between 1 to 2 metres (3 to 7 ft) in length, with some of the largest measuring 3 metres (10 ft) long.

The first specimen was discovered in 1830 and they have since been discovered throughout central Europe, North Africa, the Middle East and China.

Palaeobiology

Macroplacus raeticus

The earliest forms like *Placodus*, which lived in the early to middle Triassic, resembled barrel-bodied lizards somewhat similar to the marine iguana of today, but larger. But unlike the marine iguana, which feeds on algae, the placodonts ate molluscs and so their teeth were flat and tough to crush their shells. In the earliest periods their size was probably enough to take away the top sea predators of the time: the sharks. However, as time passed other kinds of carnivore reptiles began to colonize the seas, such as ichthyosaurs and nothosaurs and later placodonts developed bony plates on their backs to protect their bodies while feeding. By the Late Triassic, these plates had grown so much that placodonts of the time such as *Henodus* and *Placochelys* resembled the sea turtles of modern day more than their ancestors without bony plates. Other placodonts like *Psephoderma* developed plates as well, but in a different articulated manner that resembled the shells of horseshoe crabs and trilobites more than those of sea turtles. All these adaptations can be counted as perfect examples of convergent evolution, as placodonts were not related to any of these animals.

Because of their dense bone and heavy armour plating, these creatures would have been too heavy to float in the ocean and would have used a lot of energy to reach the water surface. For this reason and because of the type of sediment found accompanying fossils it is suggested they lived in shallow waters and not in deep oceans.

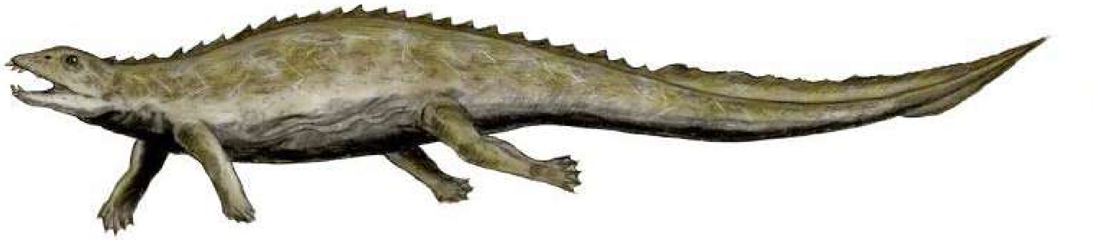
Their diet consisted of marine bivalves, brachiopods and other invertebrates. They were notable for their large, flat, often protruding teeth which they used to crush molluscs and brachiopods, which they hunted on the sea bed (another way in which they were similar to walruses). The palate teeth were adapted for this durophagous diet, being extremely thick and large enough to crush thick shell.

Classification

- **Class Sauropsida**
    - **Superorder Sauropterygia**
        - **Order Placodontia**
            - **Superfamily Placodontoidea**
                - Family Paraplacodontidae
                    - Genus *Paraplacodus*
                - Family Placodontidae
                    - Genus *Placodus*
            - **Superfamily Cyamodontoidea**
                - Family Henodontidae
                    - Genus *Henodus*
                - Family Cyamodontidae
                    - Genus *Cyamodus*
                    - Genus *Protenodontosaurus*
                - Family Placochelyidae
                    - Genus *Placochelys*
                    - Genus *Psephoderma*
            - *incertae sedis*
                - Genus *Saurosphargis*

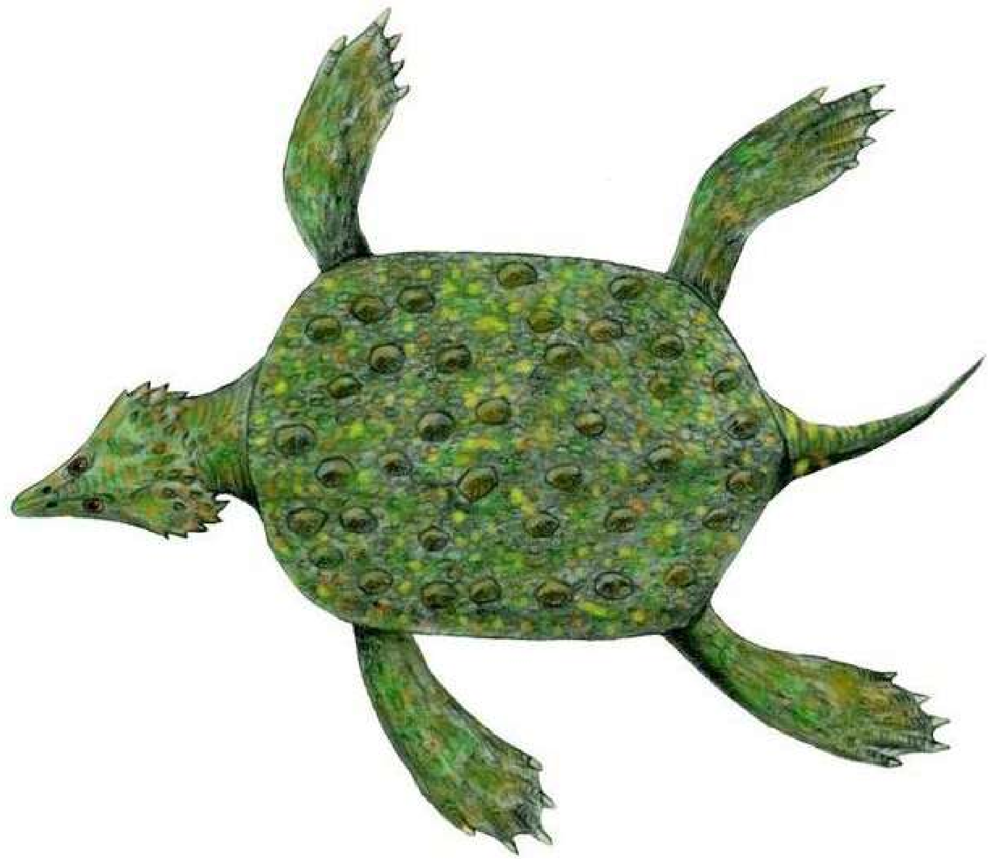
The clade **Helveticosauroidea** was previously considered to be a basal superfamily of placodonts with the sole member *Helveticosaurus*. However, it is now thought that

Helveticosaurus was not a placodont but possibly an unusual member of the Archosauromorpha.



Placodus

Psephoderma



Placochelys

6. Pseudotemperoceras

Pseudotemperoceras Fossil range: Triassic	
Scientific classification	
Kingdom:	Animalia
Phylum:	Mollusca
Class:	Cephalopoda
Subclass:	Nautiloidea
Superorder:	Orthoceratoidea
Order:	Orthocerida

Family: incertae sedis

Genus: ***Pseudotemperoceras***
Schastlivtseva, 1986

Pseudotemperoceras is an extinct nautiloid cephalapod belonging to the Orthocerida from the far eastern part of the Russian Federation that lived during the Triassic from 249.7—245 mya, existing for approximately 4.7 million years.

Taxonomy

Pseudotemperoceras was named by Schastlivtseva (1986) and is listed in the Orthocerida in Sepkoski (2002)

Morphology

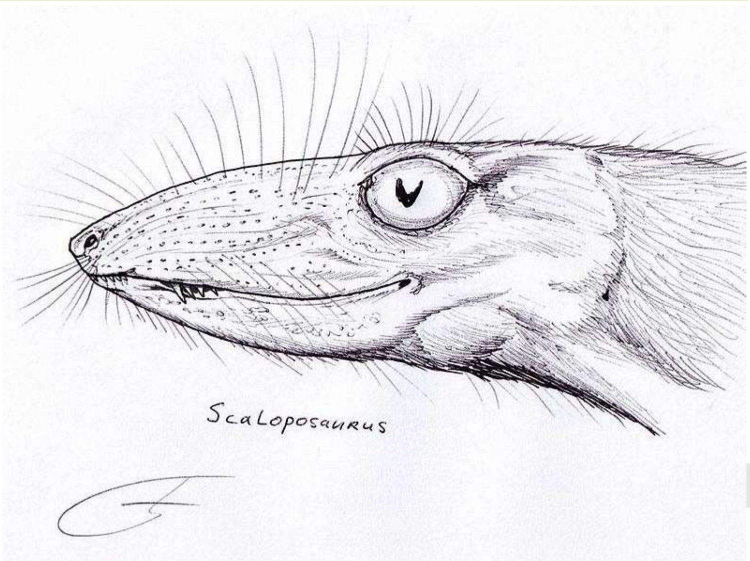
Pseudotemperoceras has a slender, orthoconic shell that resembles that of the earlier, Paleozoic, *Temperoceras* from which it gets its name, although *Temperoceras* is a geisonoceratid rather than an orthoceratid

Fossil distribution

So far *Pseudotemperoceras* is known only from the western Verkhoyansk Range, Kharaulakhsk Mountains, in the Russian state of Yakutia in eastern Siberia, where it is associated with species of *Trematoceras*.

7. Scaloposaurus

Scaloposaurus	
Fossil range: Early Triassic	



Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Synapsida
Order:	Therapsida
Suborder:	Therocephalia
Genus:	***Scaloposaurus***

Scaloposaurus is an extinct carnivorous genus of therocephalian living during the Triassic 251.0—245.0 Ma existing for approximately 5 million years.

Taxonomy

Scaloposaurus was named by Owen (1876). It is not extant. It was assigned to Therocephalia by Broom (1913); and to Scaloposauridae by Carroll (1988).

8. Smilosuchus

Smilosuchus
Fossil range: Late Triassic

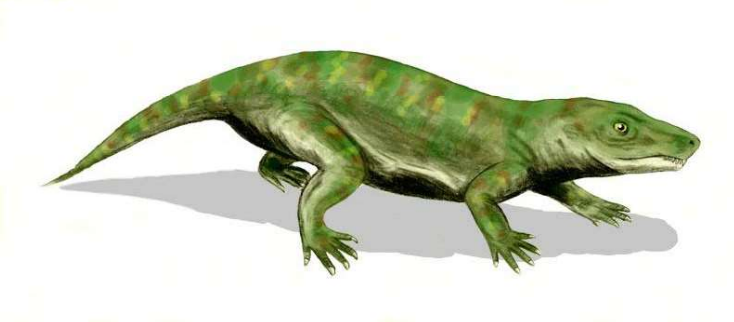
Scientific classification

Kingdom:	Animalia
Phylum:	Chordata
Class:	Sauropsida
(unranked):	Archosauria
Order:	Phytosauria
Family:	Phytosauridae
Genus:	***Smilosuchus***

Smilosuchus is an extinct genus of phytosaur from the Late Triassic of North America. It was first described in 1995 as a replacement generic name for *Leptosuchus gregorii*. Because of the large rostral crest it possessed, it was considered to be distinct enough from other species of *Leptosuchus* (all of which had smaller and more restricted crests) to be within its own genus. Despite this, recent studies seem to suggest that *Smilosuchus* is congeneric with *Leptosuchus*, as the enlarged crest could have been independently developed in *Leptosuchus*.

9. Therocephalia

Therocephalia	
Fossil range: Middle Permian–Middle Triassic	



Bauria, an advanced therocephalian from the Early Triassic of South Africa

Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Subphylum:	Vertebrata
Class:	Synapsida
Order:	Therapsida
(unranked)	Theriodontia
Suborder:	**†Therocephalia** Broom, 1905

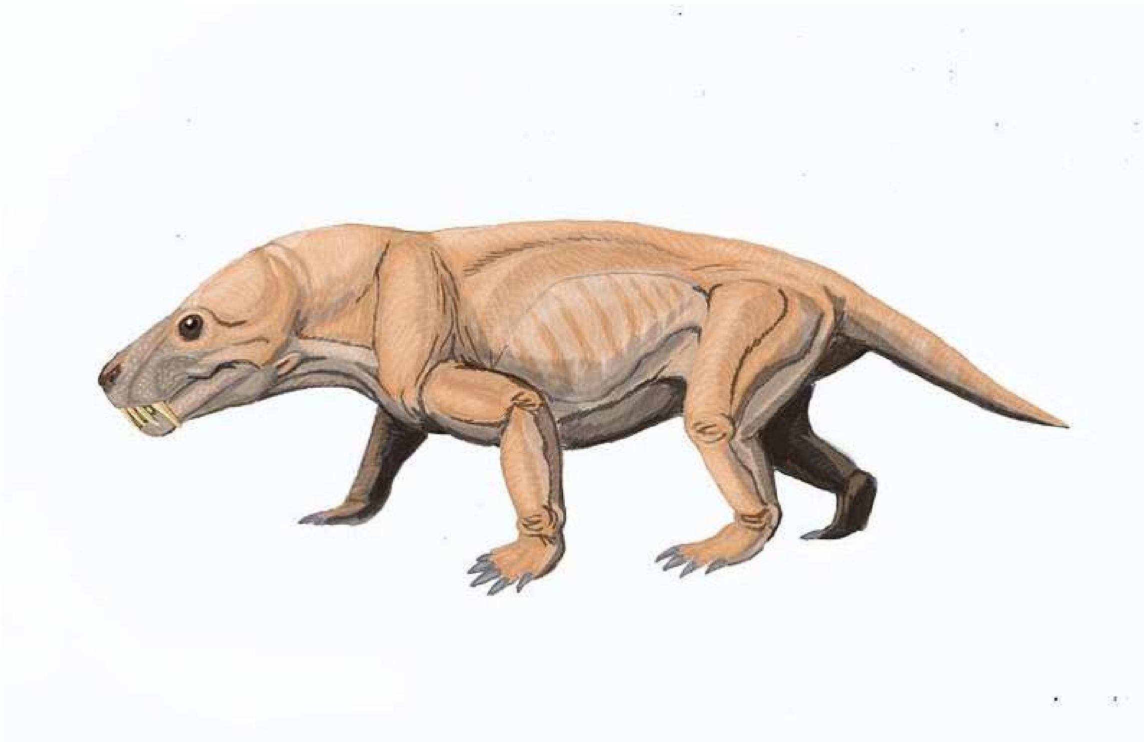
Therocephalians are an extinct suborder of carnivorous eutheriodont therapsids that lived from the middle and late Permian into the Triassic 265.0—245.0 Ma existing for approximately 20 million years.

The therocephalians ("beast-heads") are named after their large skulls, which, along with the structure of their teeth, suggest that they were successful carnivores. Like other non-mammalian synapsids, therocephalians are described as mammal-like reptiles, although in fact, Therocephalia is the group most closely related to the cynodonts, which gave rise to the mammals. This relationship takes evidence in a variety of anatomical features, possibly including whiskers and hair. There remain many unanswered questions about the phylogeny, anatomy and physiology of therocephalians.

The fossils of therocephalians are numerous in the Karoo of South Africa, but have also been found in Russia, China and Antarctica. Early therocephalian fossils discovered in Middle Permian deposits of South Africa support a Gondwanan origin for the group, which seems to have spread quickly throughout the world. Although almost every therocephalian lineage ended during the great Permian–Triassic extinction event, a few representatives of the subgroup called Eutherocephalia survived into the Early Triassic and continued to diversify. However, the last therocephalians became extinct by the early

Middle Triassic, possibly due to climate change and competition with cynodonts and various groups of reptiles.

Classification



Moschorhinus

The therocephalians evolved from an early line of pre-mammalian therapsids called 'theriodonts' and are a sister group to the cynodonts which include mammals and their ancestors. Therocephalians are at least as ancient as a third large branch of theraspids, the gorgonopsids (also 'theriodonts'), which they resemble in many primitive features. The therocephalians, however, outlasted the gorgonopsians, persisting into the early-Middle Triassic period.

While common ancestry with cynodonts (and, thus, mammals) accounts for many similarities among these groups, some scientists believe that other similarities may be better attributed to convergent evolution, such as the loss of the postorbital bar in some forms, a mammalian phalangeal formula and some form of a secondary palate in most taxa (see below). A current consensus of the taxonomic framework of therocephalians is provided at the bottom of the page.

Anatomy and physiology

Pristerognathus

Like the gorgonopsids and many cynodonts, many therocephalians were presumably carnivores. The earlier therocephalians were in many respects as primitive as the gorgonopsids, but they did show certain advanced features such as

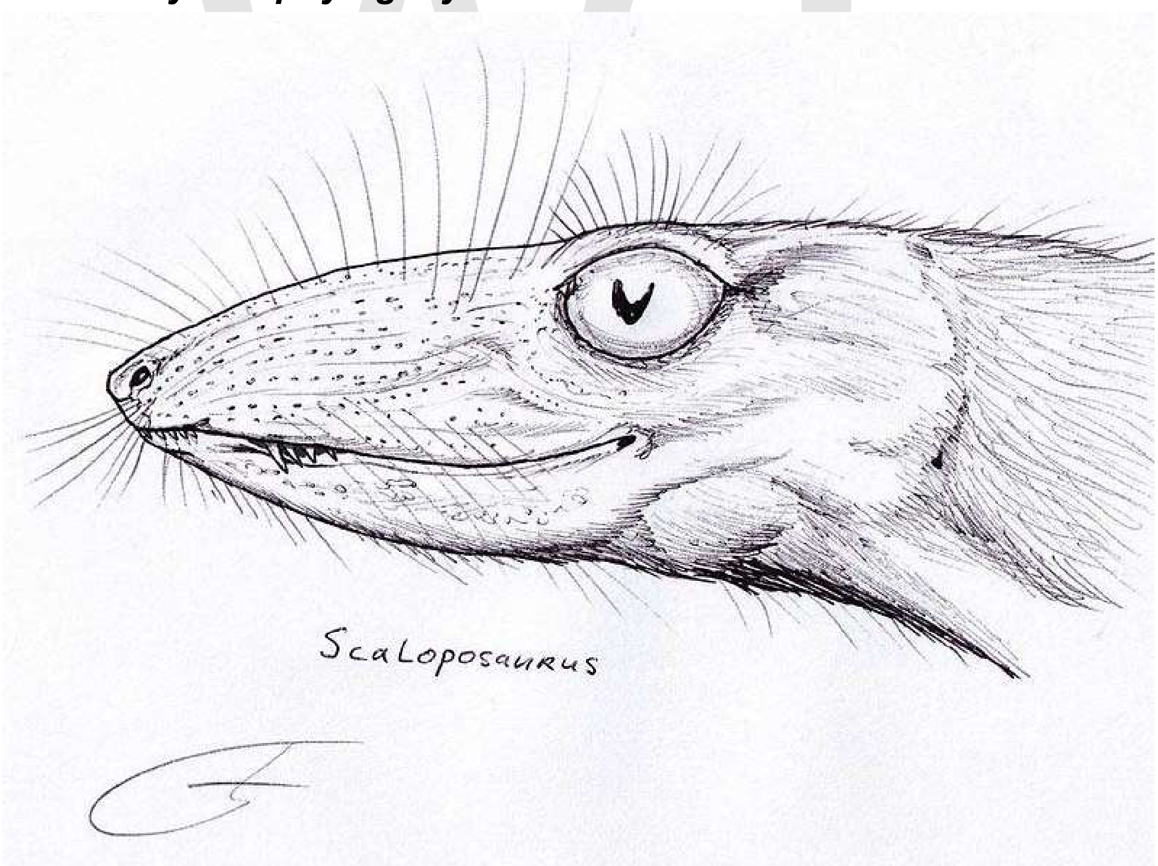
- enlargement of the temporal opening for broader jaw adductor muscle attachment
- reduction of the phalanges (finger and toe bones) to the mammalian phalangeal formula.
- the presence of an incipient secondary palate

The discovery of maxilloturbinal ridges in some specimens, such as the primitive therocephalian *Glanosuchus*, suggests that at least some therocephalians may have been warm-blooded.

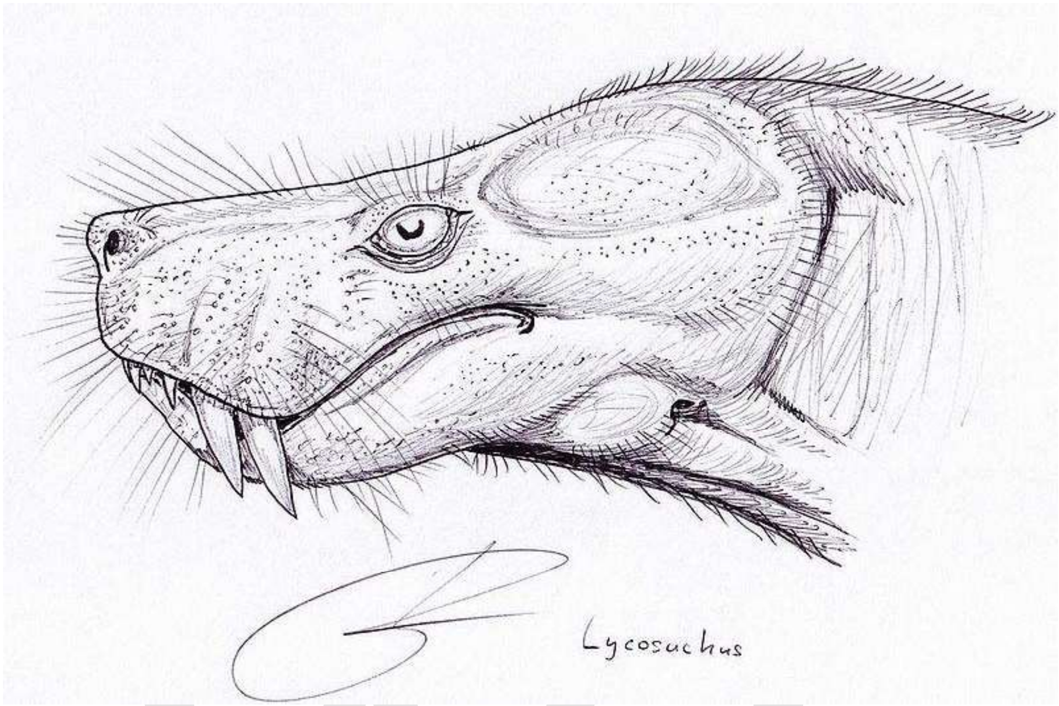
The later therocephalians included the advanced Baurioidea, which carried some theriodont characteristics to a high degree of specialization. For instance, small baurioids and the herbivorous *Bauria* did not have an ossified postorbital bar separating the orbit from the temporal opening — a condition typical of primitive mammals. These and other advanced features led to the long-held opinion, now rejected, that the ictidosaurs and even some early mammals arose from a baurioid therocephalian stem. Mammalian characteristics such as this seem to have evolved in parallel among a number of different therapsid groups, even within Therocephalia.

Lycosuchus reconstruction, with hypothetical fur

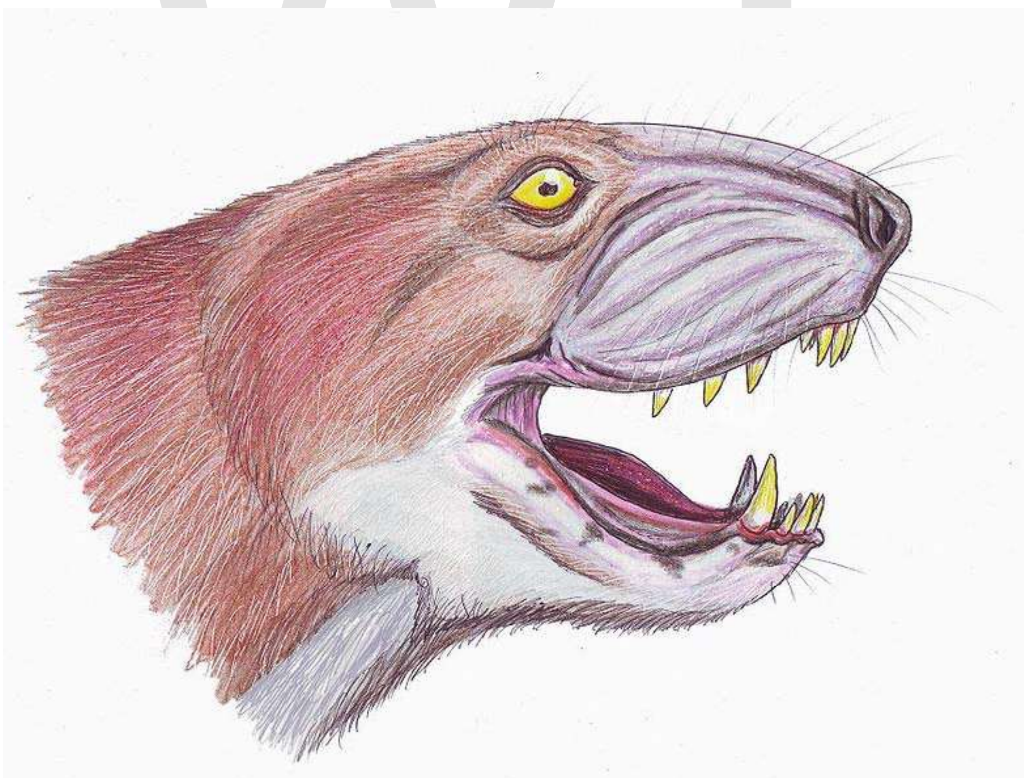
Taxonomy and phylogeny



Scaloposaurus



Lycosuchus head reconstruction



Head of unnamed East European moschorhinid

Some previously recognized therocephalian clades have turned out to be artificial. For example, the Scaloposauridae were classified based on fossils with mostly juvenile characteristics, but probably represent immature specimens from other known therocephalian families.

On the other hand, the aberrant therocephalian family Lycosuchidae, once identified by the presence of multiple caniniform teeth, was thought to represent an unnatural group based on a study of canine replacement in that group (van den Heever, 1980). However, subsequent analysis has exposed additional synapomorphies supporting the monophyly of this group and Lycosuchidae is currently considered the most basal clade within a monophyletic Therocephalia (van den Heever, 1994).

- Order **Therapsida**
    - Suborder **Therocephalia**
        - Family Lycosuchidae
    - (unranked) Scylacosauria van den Heever, 1994
        - Family Scylacosauridae
        - Infraorder **Eutherocephalia Hopson & Barghusen, 1986**
            - Family Hofmeyriidae
            - Family Moschorhinidae (=Akidnognathidae, Annatherapsididae, Euchambersiidae)
            - Family Whaitsiidae
        - Superfamily Baurioidea
            - Family Bauriidae
                - Subfamily Nothogomphodontinae
                - Subfamily Bauriinae
            - Family Ericiolacertidae
            - Family Ictidosuchidae
            - Family Ictidosuchopsidae
            - Family Lycideopsidae
            - Family Regisauridae

Chapter- 7

Introduction to Jurassic

The **Jurassic** is a geologic period and system that extends from about 199.6± 0.6 Mya (million years ago) to 145.5± 4 Mya, that is, from the end of the Triassic to the beginning of the Cretaceous. The Jurassic constitutes the middle period of the Mesozoic Era, also known as the Age of Reptiles. The start of the period is marked by the major Triassic–Jurassic extinction event. However, the end of the Jurassic Period did not witness any major extinction event. The start and end of the period are defined by carefully selected locations; the uncertainty in dating arises from trying to date these horizons.

The chronostratigraphic term "Jurassic" is directly linked to the Swiss Jura Mountains. Alexander von Humboldt (*1769, † 1859) recognized the mainly limestone dominated mountain range of the Swiss Jura Mountains as a separate formation that was not at the time included in the established stratigraphic system defined by Abraham Gottlob Werner (* 1749, † 1817) and named it “Jurakalk” in 1795. The name “Jura” is derived from the celtic root “jor” which was Latinised into “juria”, meaning forest (i.e. “Jura” is forest mountains).

Divisions

The Jurassic Period is divided into Early Jurassic, Middle and Late Jurassic epochs. The Jurassic System, in stratigraphy, is divided into Lower Jurassic, Middle and Upper Jurassic series of rock formations, also known as *Lias*, *Dogger* and *Malm* in Europe. The separation of the term **Jurassic** into three sections goes back to Leopold von Buch (* 1774, † 1853). The faunal stages from youngest to oldest are:

Upper/Late Jurassic	
Tithonian	(150.8 ± 4.0 – 145.5 ± 4.0 Mya)
Kimmeridgian	(155.7 ± 4.0 – 150.8 ± 4.0 Mya)
Oxfordian	(161.2 ± 4.0 – 155.7 ± 4.0 Mya)
Middle Jurassic	
Callovian	(164.7 ± 4.0 – 161.2 ± 4.0 Mya)
Bathonian	(167.7 ± 3.5 – 164.7 ± 4.0 Mya)
Bajocian	(171.6 ± 3.0 – 167.7 ± 3.5 Mya)
Aalenian	(175.6 ± 2.0 – 171.6 ± 3.0 Mya)

Lower/Early Jurassic

Toarcian	(183.0 ± 1.5 – 175.6 ± 2.0 Mya)
Pliensbachian	(189.6 ± 1.5 – 183.0 ± 1.5 Mya)
Sinemurian	(196.5 ± 1.0 – 189.6 ± 1.5 Mya)
Hettangian	(199.6 ± 0.6 – 196.5 ± 1.0 Mya)

Paleogeography and tectonics

During the early Jurassic period, the supercontinent Pangaea broke up into the northern supercontinent Laurasia and the southern supercontinent Gondwana; the Gulf of Mexico opened in the new rift between North America and what is now Mexico's Yucatan Peninsula. The Jurassic North Atlantic Ocean was relatively narrow, while the South Atlantic did not open until the following Cretaceous Period, when Gondwana itself rifted apart. The Tethys Sea closed and the Neotethys basin appeared. Climates were warm, with no evidence of glaciation. As in the Triassic, there was apparently no land near either pole and no extensive ice caps existed.

The Jurassic geological record is good in western Europe, where extensive marine sequences indicate a time when much of the continent was submerged under shallow tropical seas; famous locales include the Jurassic Coast World Heritage Site and the renowned late Jurassic *lagerstätten* of Holzmaden and Solnhofen. In contrast, the North American Jurassic record is the poorest of the Mesozoic, with few outcrops at the surface. Though the epicontinental Sundance Sea left marine deposits in parts of the northern plains of the United States and Canada during the late Jurassic, most exposed sediments from this period are continental, such as the alluvial deposits of the Morrison Formation.

The Jurassic was a time of calcite sea geochemistry in which low-magnesium calcite was the primary inorganic marine precipitate of calcium carbonate. Carbonate hardgrounds were thus very common, along with calcitic ooids, calcitic cements and invertebrate faunas with dominantly calcitic skeletons (Stanley and Hardie, 1998, 1999).

The first of several massive batholiths were emplaced in the northern Cordillera beginning in the mid-Jurassic, marking the Nevadan orogeny. Important Jurassic exposures are also found in Russia, India, South America, Japan, Australasia and the United Kingdom.

Early Jurassic strata are distributed in a similar fashion to Late Triassic beds, with more common outcrops in the south and less common fossil beds which are predominated by tracks to the north. As the Jurassic proceeded, larger and more iconic groups of dinosaurs like sauropods and ornithopods proliferated in Africa. Middle Jurassic strata are neither well represented nor well studied in Africa. Late Jurassic strata are also poorly represented apart from the spectacular Tendeguru fauna in Tanzania. The Late Jurassic life of Tendeguru is very similar to that found in western North America's Morrison Formation.

Jurassic limestones and marls (the Matmor Formation) in southern Israel

The late Jurassic Morrison Formation in Colorado is the most fertile source of dinosaur fossils in North America.

Gigandipus, a dinosaur footprint in the Lower Jurassic Moenave Formation at the St. George Dinosaur Discovery Site at Johnson Farm, southwestern Utah.

The Permian through Jurassic stratigraphy of the Colorado Plateau area of southeastern Utah.

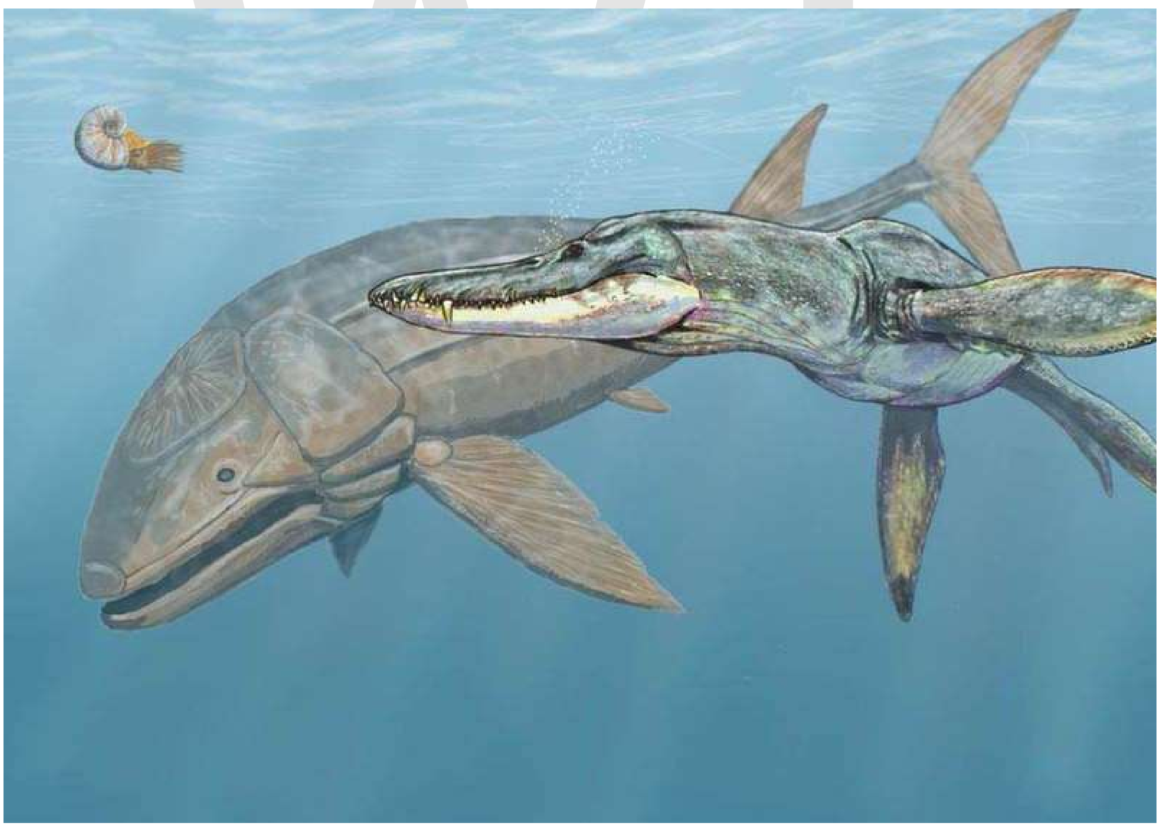
Fauna

Aquatic and marine

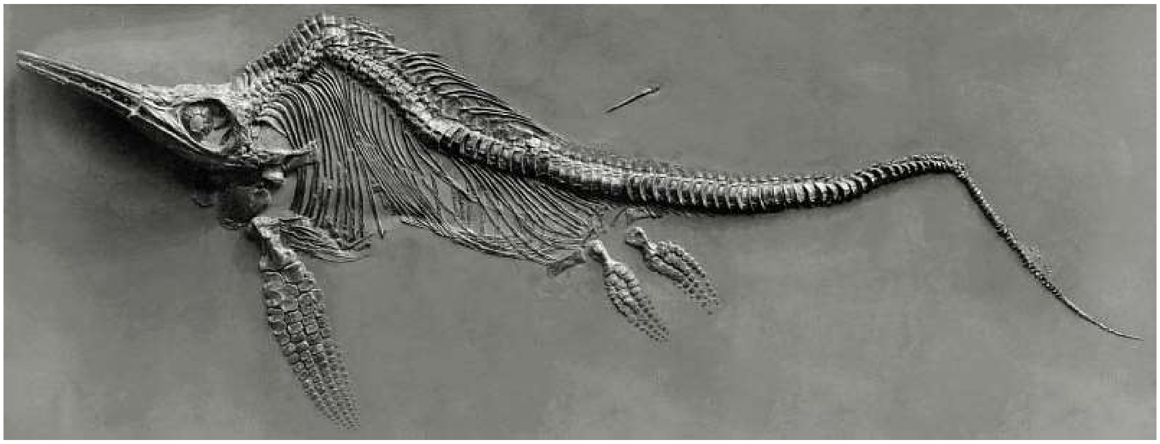
During the Jurassic period, the primary vertebrates living in the seas were fish and marine reptiles. The latter include ichthyosaurs who were at the peak of their diversity, plesiosaurs, pliosaurs and marine crocodiles of the families Teleosauridae and Metriorhynchidae.

In the invertebrate world, several new groups appeared, including rudists (a reef-forming variety of bivalves) and belemnites. The Jurassic also had diverse encrusting and boring (sclerobiont) communities and it saw a significant rise in the bioerosion of carbonate shells and hardgrounds. Especially common is the ichnogenus (trace fossil) *Gastrochaenolites*.

During the Jurassic period about four or five of the twelve clades of planktonic organisms that exist in the fossil record either experienced a massive evolutionary radiation or appeared for the first time.

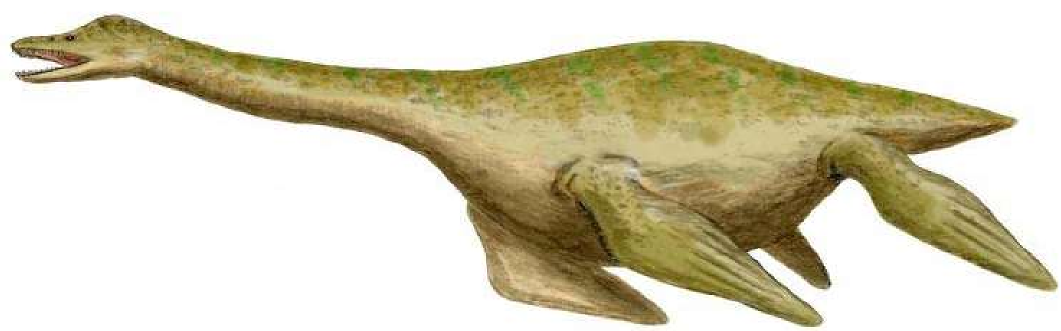


An over 10 metres long *Liopleurodon* (right) harassing an even larger *Leedsichthys* in a Jurassic sea



Ichthyosaurus from Liassic oil slates in Holzmaden, southern Germany

Gastropod and attached mytilid bivalves on a Jurassic limestone bedding plane in southern Israel.



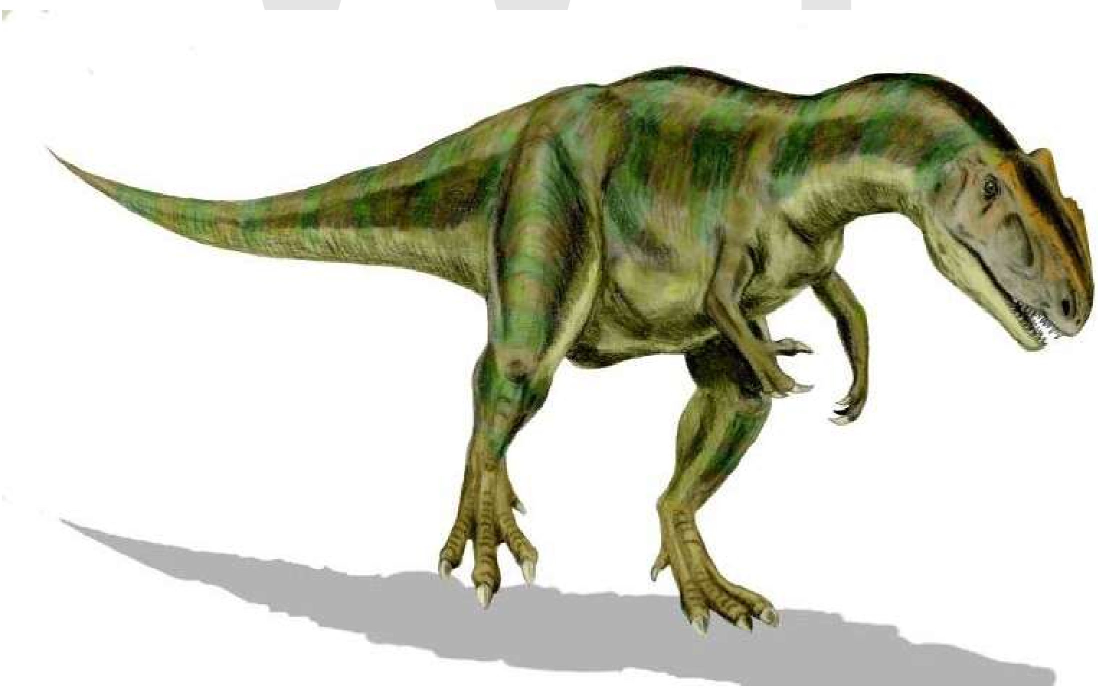
Plesiosaurs like Cryptocleidus roamed Jurassic oceans

Terrestrial

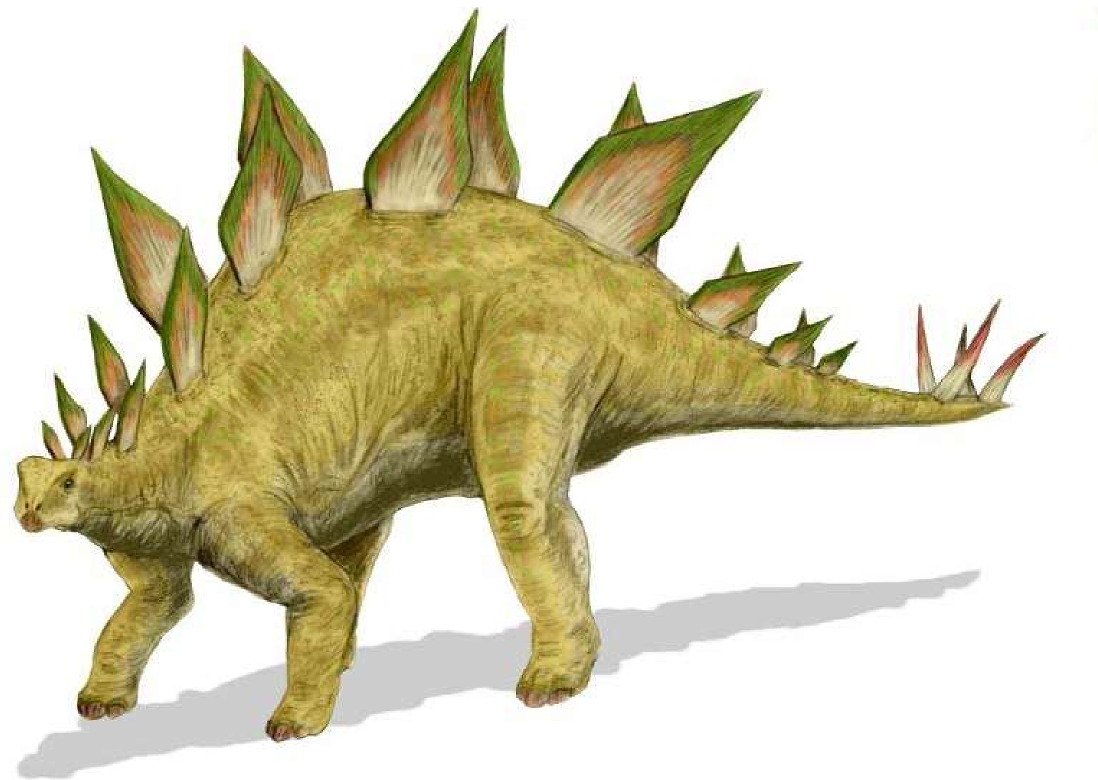
On land, large archosaurian reptiles remained dominant. The Jurassic was a golden age for the large herbivorous dinosaurs known as the sauropods—*Camarasaurus*, *Apatosaurus*, *Diplodocus*, *Brachiosaurus* and many others—that roamed the land late in the period; their mainstays were either the prairies of ferns, palm-like cycads and bennettitales, or the higher coniferous growth, according to their adaptations. They were preyed upon by large theropods as for example *Ceratosaurus*, *Megalosaurus*, *Torvosaurus* and *Allosaurus*. All these belong to the 'lizard hipped' or saurischian branch of the dinosaurs. During the Late Jurassic, the first birds, like Archaeopteryx, evolved from small coelurosaurian dinosaurs. Ornithischian dinosaurs were less predominant than saurischian dinosaurs, although some like stegosaurs and small ornithopods played important roles as small and medium-to-large (but not sauropod-sized) herbivores. In the air, pterosaurs were common; they ruled the skies, filling many ecological roles now taken by birds. Within the undergrowth were various types of early mammals, as well as tritylodont mammal-like reptiles, lizard-like sphenodonts and early lissamphibians.

The rest of the Lissamphibia evolved in this period, introducing the first salamanders and caecilians.

Large dinosaurs roamed forests of similarly large conifers during the Jurassic Period



Allosaurus was one of the largest land predators during the Jurassic



Stegosaurus is one of the most recognizable genera of dinosaurs and lived during the mid to late Jurassic.

In the late Jurassic, the emergence of *Archaeopteryx* marks the start of the evolution of birds.

Flora

Conifers were common in the Jurassic period

The arid, continental conditions characteristic of the Triassic steadily eased during the Jurassic period, especially at higher latitudes; the warm, humid climate allowed lush jungles to cover much of the landscape. Gymnosperms were relatively diverse during the Jurassic period. The Conifers in particular dominated the flora, as during the Triassic; they were the most diverse group and constituted the majority of large trees. Extant conifer families that flourished during the Jurassic included the Araucariaceae, Cephalotaxaceae, Pinaceae, Podocarpaceae, Taxaceae and Taxodiaceae. The extinct Mesozoic conifer family Cheirolepidiaceae dominated low latitude vegetation, as did the shrubby Bennettitales. Cycads were also common, as were ginkgos and Dicksoniaceous tree ferns in the forest. Smaller ferns were probably the dominant undergrowth. Caytoniaceous seed ferns were another group of important plants during this time and are thought to have been shrub to small-tree sized. Ginkgo plants were particularly common in the mid- to high northern latitudes. In the Southern Hemisphere, podocarps were especially successful, while Ginkgos and Czekanowskiales were rare.

Chapter- 8

Tithonian

System	Series	Stage	Age (Ma)
Cretaceous	Lower	Berriasian	younger
Jurassic	Upper	**Tithonian**	145.5–150.8
		Kimmeridgian	150.8–155.7
		Oxfordian	155.7–161.2
	Middle	Callovian	161.2–164.7
		Bathonian	164.7–167.7
		Bajocian	167.7–171.6
		Aalenian	171.6–175.6
	Lower	Toarcian	175.6–183.0
		Pliensbachian	183.0–189.6
		Sinemurian	189.6–196.5
		Hettangian	196.5–199.6
Triassic	Upper	Rhaetian	older

Subdivision of the Jurassic system according to the IUGS, as of July 2009.

In the geologic timescale the **Tithonian** is the latest age of the Late Jurassic epoch or the uppermost stage of the Upper Jurassic series. It spans the time between 150.8 ± 4 Ma and

145.5 ± 4 Ma (million years ago). It is preceded by the Kimmeridgian and followed by the Berriasian stage (part of the Cretaceous).

Stratigraphic definitions

The Tithonian was introduced in scientific literature by German stratigrapher Albert Oppel in 1865. The name Tithonian is unusual in geological stage names because it is derived from Greek mythology. Tithonus was the son of Laomedon of Troy. He fell in love with Eos, the Greek goddess of dawn and finds his place in the stratigraphy because this stage, the Tithonian, finds itself hand in hand with the dawn of the Cretaceous.

The base of the Tithonian stage is at the base of the ammonite biozone of *Hybonoticeras hybonotum*. A global reference profile (a GSSP or golden spike) for the base of the Tithonian had in 2009 not yet been established.

The top of the Tithonian stage (the base of the Berriasian stage and the Cretaceous system) is at the first appearance of fossils of ammonite species *Berriasella jacobi* in the stratigraphic record.

Subdivision

The Tithonian is often subdivided into Lower/Early, Middle and Upper/Late substages or subages. The Late Tithonian is coeval with the Portlandian stage of British stratigraphy.

The Tithonian stage contains seven ammonite biozones in the Tethys domain, from top to base:

- zone of *Durangites*
- zone of *Micracanthoceras micranthum*
- zone of *Micracanthoceras ponti* or *Burckardticeras peroni*
- zone of *Semiformiceras fallauxi*
- zone of *Semiformiceras semiforme*
- zone of *Semiformiceras darwini*
- zone of *Hybonoticeras hybonotum*

Lithofacies

In the Tethys domain, the Tithonian has a calcareous facies with a typical cephalopod fauna. The Solnhofen limestone of southern Germany, which is known for its fossils (especially *Archaeopteryx*), is of Tithonian age.

Palaeontology

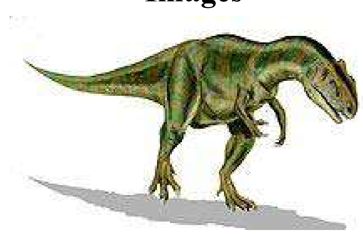
†Ankylosaurs

Ankylosauria of the Tithonian

Taxa	Presence	Location	Description	Images
• *Gargoyleosaurus*		Morrison Formation, Wyoming, USA	The smallest and the earliest well-known ankylosaur. Its skull measures only 29 cm in length and its total body length is an estimated three to four meters.	 Gargoyleosaurus skeleton
• *Mymoorapelta* ◦ *Mymoorapelta maysi*		Morrison Formation, Colorado, USA	A poorly known early ankylosaurian.	

Theropods

Theropods of the Tithonian

Taxa	Presence	Location	Description	Images
• *Allosaurus*		Morrison Formation, USA	The most common and most highly studied theropod dinosaur.	 Allosaurus
• *Archaeopteryx*		Solnhofen, Germany	The late Jurassic is notable for the first appearance in the fossil record of birds, in the form of	

			Archaeopteryx, found in limestone quarries in Germany.	
• *Ceratosaurus*		Morrison Formation, USA	Fossils are less common than those of *Allosaurus*.	

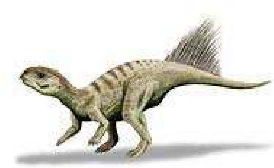
†Basal Ornithischians

Basal ornithischians of the Tithonian

Taxa	Presence	Location	Description	Images
• *Fruitadens*		Fruita, Colorado, USA	*Fruitadens* was a heterodontosaurid and the smallest known ornithischian dinosaur, weighing less than 2 pounds (0.91 kg) and measuring a little over 2 feet (0.61 m) in length. It is also one of the latest surviving heterodontosaurids known.	

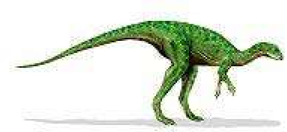
†Ceratopsians

Ceratopsia of the Tithonian

Taxa	Presence	Location	Description	Images
• *Chaoyangsaurus*	?	Chaoyang area, Liaoning, China	One of the earliest ceratopsians	 Chaoyangsaurus
• *Xuanhuaceratops*		Hebei, China	A member of the family Chaoyangsauridae, it was one of the earliest ceratopsians	

†Ornithopods

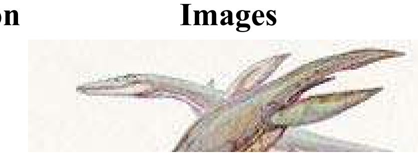
Ornithopoda of the Tithonian

Taxa	Presence	Location	Description	Images
• *Camptosaurus*	Kimmeridgian to ?Berriasian	Wyoming, USA; England; France	*Camptosaurus* could be more than 7.9 meters long	

Taxa	Presence	Location	Description	Images
			(26 ft) and 2.0 meters tall (6.7 ft) at the hips. They had heavy bodies but, as well as walking on four legs (quadrupedal), could also rear up to walk on two legs (bipedal). This genus is probably closely related to the ancestor of the later iguanodontid and hadrosaurid dinosaurs. It probably ate cycads with its beak.	Othnielosaurus
• *Draconyx*		Lourinhã, Portugal	A camptosaurid iguanodont	
• *Drinker*				
• *Dryosaurus*				
• *Othnielia*				
• *Othnielosaurus*				

†Plesiosauria

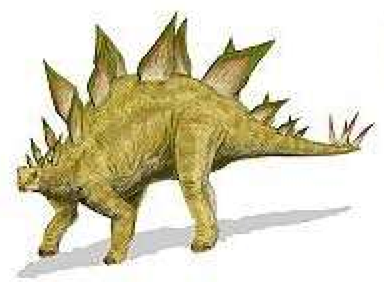
Plesiosaurs of the Tithonian

Taxa	Presence	Location	Description	Images
• *Simolestes indicus*				

Simolestes

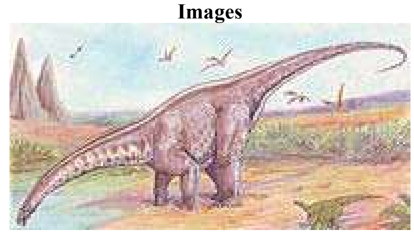
†Stegosaurs

Stegosaurs of the Tithonian

Taxa	Presence	Location	Description	Images
• *Stegosaurus*	Kimmeridgian to Early Tithonian	Morrison Formation, Colorado, Utah, Wyoming, USA	Averaging around 9 metres (30 ft) long and 4 metres (14 ft) tall, the quadrupedal *Stegosaurus* is one of the most easily identifiable dinosaurs, due to the distinctive double row of kite-shaped plates rising vertically along its arched back and the two pairs of long spikes extending horizontally near the end of its tail.	 Stegosaurus

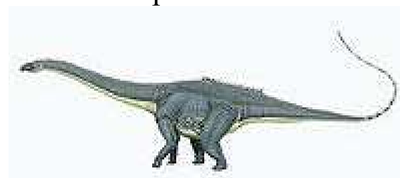
†Sauropoda

Sauropoda of the Tithonian

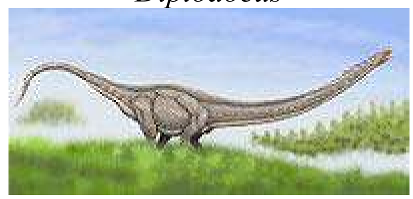
Taxa	Presence	Location	Description	Images
• *Apatosaurus*				
• *Brachiosaurus*				
• *Diplodocus*				

- *Mamenchisaurus*

Apatosaurus



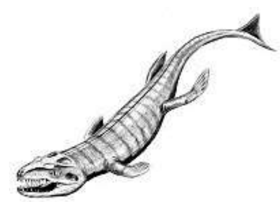
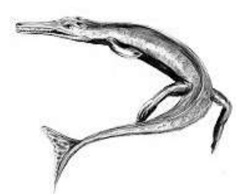
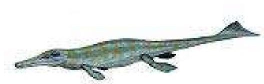
Diplodocus



Mamenchisaurus

†Thalattosuchians

Thalattosuchians of the Tithonian

Taxa	Presence	Location	Description	Images
• *Dakosaurus* 1. *Dakosaurus maximus* 2. *Dakosaurus andiniensis*			A large genus of metriorhynchid, that was a high order predator which fed on other marine reptiles 1. The type species from Western Europe of the Late Jurassic (Early Tithonian). 2. Argentina of the Late Jurassic-Early Cretaceous (Early Tithonian), knicknamed "Godzilla".	 *Dakosaurus*, a marine crocodilian.  *Geosaurus*, a marine crocodilian.  *Metriorhynchus*, a marine crocodilian.
• *Geosaurus*		1. Western Europe	A relatively small metriorhynchid	

1. *G. giganteus*
2. *G. gracilis*
3. *G. suevicus*:
4. *G. saltillense*:
5. *G. vignaudi*:
6. *G. araucanensis*:

2. Western Europe
3. Western Europe
4. Mexico
5. Mexico
6. Argentina

genus. No known species of *Geosaurus* attained lengths in excess of 3 meters (10 feet). There were multiple *Geosaurus* species alive during the Tithonian.

1. The type species from Western Europe of the Late Jurassic (Early Tithonian).
2. Western Europe of the Late Jurassic (Early Tithonian). Was originally the type species of the genus *Rhacheosaurus*.
3. Western Europe of the Late Jurassic (Early Tithonian)
4. Mexico of the Late Jurassic (Early Tithonian)
5. Mexico of the Late Jurassic (Middle Tithonian)
6. Argentina of the Late Jurassic-

		Early Cretaceous (Early Tithonian)
• *Machimosaurus*		
• *Metriorhynchus* *M. potens*	An opportunistic carnivore that fed on fish, belemnites and other marine animals and possible carrion. *Metriorhynchus* grew to an average adult length of 3 meters (9.6 feet).	
• *Steneosaurus*		

†Belemnites

Belemnites of the Tithonian

Taxa	Presence	Location	Description	Images
• *Produvalia*				 Small belemnite fossils

Chapter- 9

Kimmeridgian

In the geologic timescale, the **Kimmeridgian** is an age or stage in the Late or Upper Jurassic epoch or series. It spans the time between 155.7 ± 4 Ma and 150.8 ± 4 Ma (million years ago). The Kimmeridgian follows the Oxfordian and precedes the Tithonian.

Stratigraphic definition

The Kimmeridgian stage takes its name from the village of Kimmeridge on the Dorset coast, England. The name was introduced in literature by Jules Thurmann in 1832. The Kimmeridge Clay Formation has its name from the same type location. It is the source for about 95% of the petroleum in the North Sea.

Historically the term Kimmeridgian has been used in two different ways. The base of the interval is the same but the top was defined by British stratigraphers as the base of the Portlandian (*sensu anglico*) whereas in France the top was defined as the base of the Tithonian (*sensu gallico*). The differences have not yet been fully resolved, but Tithonian is now seen as the uppermost stage of the Jurassic in the timescale of the ICS.

The base of the Kimmeridgian is at the first appearance of ammonite species *Pictonia baylei* in the stratigraphic column. A global reference profile for the base (the GSSP of the Kimmeridgian stage) had in 2009 not yet been assigned. The top of the Kimmeridgian (the base of the Tithonian) is at the first appearance of ammonite species *Hybonoticeras hybonotum*. It also coincides with the top of magnetic anomaly M22An.

Subdivision

The Kimmeridgian is sometimes subdivided into Upper and Lower substages. In the Tethys domain, the Kimmeridgian contains seven ammonite biozones:

- zone of *Hybonoticeras beckeri*
- zone of *Aulacostephanus eudoxus*
- zone of *Aspidoceras acanthicum*
- zone of *Crussoliceras divisum*
- zone of *Ataxioceras hypselocyclum*
- zone of *Sutneria platynota*

- zone of *Idoceras planula*

Palaeontology

†Ankylosaurs

Ankylosaurs of the Kimmeridgian

Taxa	Presence	Location	Description	Images
• *Gargoyleosaurus*		Morrison Formation, Wyoming, USA	The smallest and the earliest well-known ankylosaur. Its skull measures only 29 cm in length and its total body length is an estimated three to four meters.	 *Gargoyleosaurus* skeleton
• *Mymoorapelta* • *Mymoorapelta maysi*		Morrison Formation, Colorado, USA	A poorly known early ankylosaurian.	

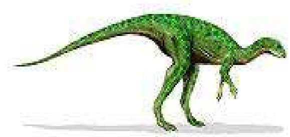
Birds

Birds of the Kimmeridgian

Taxa	Presence	Location	Description	Images
• *Archaeopteryx* • *Archaeopteryx lithographica*				 A model depicting how *Archaeopteryx lithographica* is believed to appear in life.

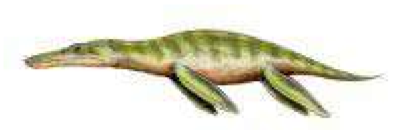
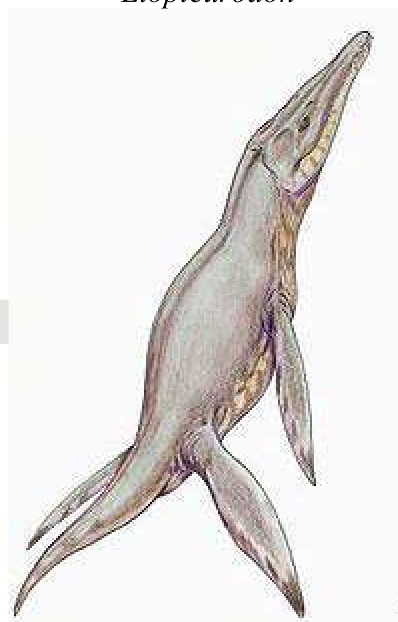
†Ornithopods

Ornithopoda of the Kimmeridgian

Taxa	Presence	Location	Description	Images
• *Camptosaurus*	Kimmeridgian to ?Berriasian	Wyoming, USA; England; France	*Camptosaurus* could be more than 7.9 meters long (26 ft) and 2.0 meters tall (6.7 ft) at the hips. It had heavy bodies but, as well as walking on four legs (quadrupedal), they could rear up to walk on two legs (bipedal). This genus is probably closely related to the ancestor of the later iguanodontid and hadrosaurid dinosaurs. It probably ate cycads with its parrot-like beak.	 *Othnielosaurus*
• *Drinker*				
• *Dryosaurus*				
• *Othnielia*				
• *Othnielosaurus*				
• *Phyllodon*				

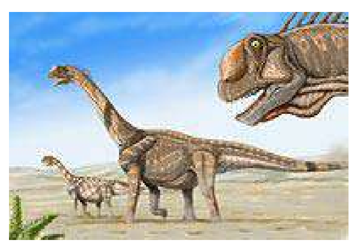
†Plesiosaurs

Plesiosaurs of the Kimmeridgian

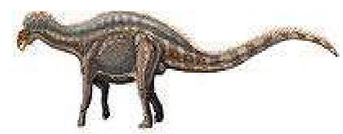
Taxa	Presence	Location	Description	Images
• *Liopleurodon*				 *Liopleurodon*
• *Pliosaurus*				 *Pliosaurus*

†Sauropods

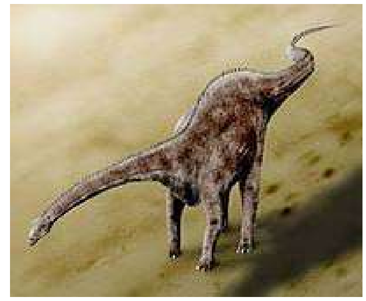
†Sauropods of the Kimmeridgian

Taxa	Presence	Location	Description	Images
• *Amphicoelias*				
• *Amphicoelias fragillimus?*				 *Camarasaurus*
• *Apatosaurus*				
• *Brachiosaurus*				
• *Camarasaurus*				

- *Dicraeosaurus*
- *Diplodocus*
- *Dystrophaeus*
- *Eobrontosaurus*

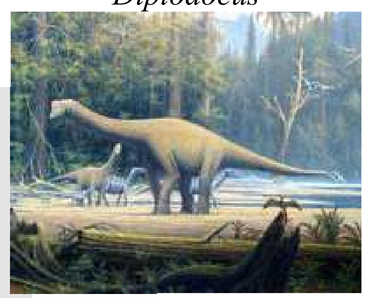


Dicraeosaurus



Diplodocus

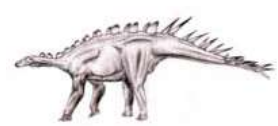
- *Europasaurus*
    - *Europasaurus holgeri*

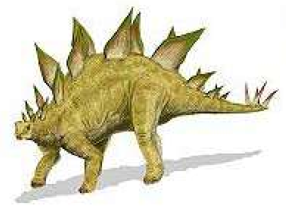


Europasaurus holgeri

†Stegosaurs

Stegosaurs of the Kimmeridgian

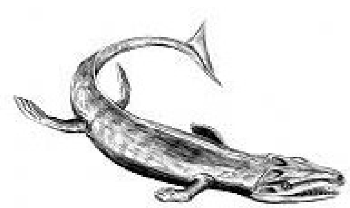
Taxa	Presence	Location	Description	Images
• *Dacentrurus*		England, France, Spain, Portugal	A large stegosaurid	 *Dacentrurus*
• *Gigantspinosaurus*		Upper Shaximiao Formation, Sichuan, China	Had relatively small dorsal plates and greatly enlarged shoulder spines, twice the length of the shoulder blades. Estimated to	 *Kentrosaurus*

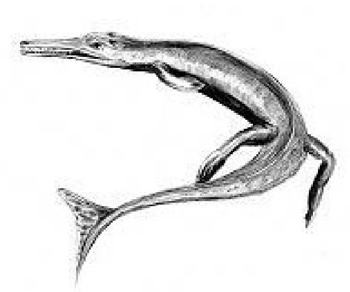
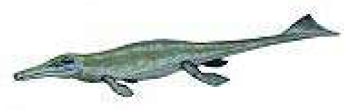
			have been about 4 metres long.	 *Stegosaurus*
• *Hesperosaurus*		Morrison Formation, Wyoming, USA	Had alternating plates on its back and four spikes on its tail. Appears more closely related to *Dacentrurus* than *Stegosaurus*.	
• *Kentrosaurus*		Tanzania	A 4 meter long stegosaurian with spikes on its flanks. The length of the thigh bone compared with the rest of the leg indicates that Kentrosaurus was a slow and inactive dinosaur.	
• *Monkonosaurus*		Loe-ein Formation, Tibet, China	The fragmentary condition of the only known skeleton places doubt on the validity of this genus	
• *Stegosaurus*	Kimmeridgian to Early Tithonian	Morrison Formation, Colorado, Utah,	Averaging around 9 metres (30 ft) long	

		Wyoming, USA	and 4 metres (14 ft) tall, the quadrupedal *Stegosaurus* is one of the most easily identifiable dinosaurs, due to the distinctive double row of kite-shaped plates rising vertically along its arched back and the two pairs of long spikes extending horizontally near the end of its tail.	

†Thalattosuchians

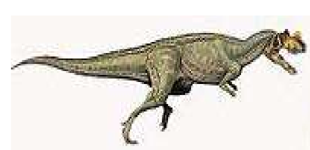
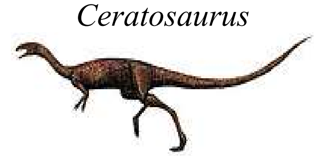
Thalattosuchians of the Kimmeridgian

Taxa	Presence	Location	Description	Images
• *Dakosaurus* *D. maximus*		Germany	type species of the genus, is known from Western Europe (England, France, Switzerland and Germany) of the Late Jurassic (Late Kimmeridgian-Early Tithonian).	 *Dakosaurus*, a marine crocodilian.

• *Geosaurus* *G. suevicus*		Germany	A relatively small metriorhynchid genus. No known species of *Geosaurus* attained lengths in excess of 3 meters (10 feet).	 *Geosaurus*, a marine crocodilian.
• *Machimosaurus*				
• *Metriorhynchus* 1. *M. acutus* 2. *M. geoffroyii* 3. *M. hastifer* 4. *M. palpebrosus*		England and France	An opportunistic carnivore that fed on fish, belemnites and other marine animals and possible carrion. *Metriorhynchus* grew to an average adult length of 3 meters (9.6 feet).	 *Metriorhynchus*, a marine crocodilian.
• *Steneosaurus*				

†Theropods (non-avian)

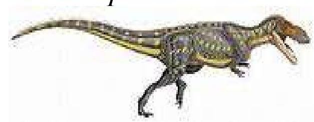
†Non-avian theropods of the Kimmeridgian

Taxa	Presence	Location	Description	Images
• *Aviatyrannis* • *Aviatyrannis jurassica*				
• *Ceratosaurus*				 *Ceratosaurus*
• *Coelurus*		Morrison formation, Wyoming	Small theropod about 2	

- *Coelurus fragilis*

metres in length

Elaphrosaurus



- *Elaphrosaurus*
  - *Elaphrosaurus bambergi*

Tendaguru Beds, Tanzania

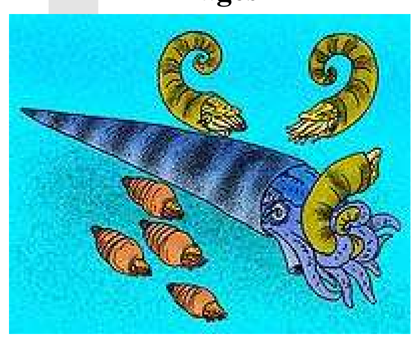
Probably a ceratosaur about 6 meters long

Torvosaurus

- *Stokesosaurus*
  - *Stokesosaurus clevelandi*
- *Torvosaurus*
  - *Torvosaurus tanneri*
- *Allosaurus*

Nautiloids

Nautiloids of the Oxfordian

Taxa	Presence	Location	Description	Images
• *Somalinautilus*				 An illustration of a variety of fossil nautiloids.

Chapter- 10

Callovian

System	Series	Stage	Age (Ma)
Cretaceous	Lower	Berriasian	**younger**
Jurassic	Upper	Tithonian	145.5–150.8
		Kimmeridgian	150.8–155.7
		Oxfordian	155.7–161.2
	Middle	**Callovian**	161.2–164.7
		Bathonian	164.7–167.7
		Bajocian	167.7–171.6
		Aalenian	171.6–175.6
	Lower	Toarcian	175.6–183.0
		Pliensbachian	183.0–189.6
		Sinemurian	189.6–196.5
		Hettangian	196.5–199.6
Triassic	Upper	Rhaetian	**older**

Subdivision of the Jurassic system according to the IUGS, as of July 2009.

In the geologic timescale, the **Callovian** is an age or stage in the Middle Jurassic, lasting between 164.7 ± 4.0 Ma (million years ago) and 161.2 ± 4.0 Ma. It is the last stage of the Middle Jurassic, following the Bathonian and preceding the Oxfordian.

Stratigraphic definitions

The Callovian stage was first described by French palaeontologist Alcide d'Orbigny in 1852. Its name derives from the latinized name for Kellaways Bridge, a small hamlet 3 km north-east of Chippenham, Wiltshire, England.

The base of the Callovian is defined as the place in the stratigraphic column where the ammonite genus *Kepplerites* first appears, which is the base of the biozone of *Macrocephalites herveyi*. A global reference profiel (a GSSP) for the base had in 2009 not yet been assigned.

The top of the Callovian (the base of the Oxfordian) is at the first appearance of ammonite species *Brightia thuouxensis*.

Subdivision

Matmor Formation (Callovian, *Peltoceras athleta* Zone) in Makhtesh Gadol, Israel

The Callovian is often subdivided into three substages (or subages): Lower/Early, Middle and Upper/Late Callovian. In the Tethys domain, the Callovian encompasses six ammonite biozones:

- zone of *Quenstedtoceras lamberti*
- zone of *Peltoceras athleta*
- zone of *Erymnoceras coronatum*
- zone of *Reineckeia anceps*
- zone of *Macrocephalites gracilis*
- zone of *Bullatimorphites bullatus*

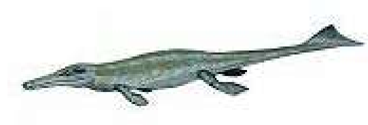
Palaeogeography

During the Callovian, Europe was an Archipelago of a dozen or so large islands. Between them were extensive areas of continental shelf. Consequently, there are shallow marine Callovian deposits in Russia and from Belarus, through Poland and Germany, into France and eastern Spain and much of England. Around the former island coasts are frequently, land-derived sediments. These are to be found, for example, in western Scotland.

Palaeontology

Crocodylomorphs

Crocodylomorphs of the Callovian

Taxa	Presence Location	Description	Images
Junggarsuchus		The sphenosuchian *Junggarsuchus* was a small, ~1 meter long, Chinese predator.	
Metriorhynchus		An opportunistic carnivore that fed on fish, belemnites and other marine animals and possible carrion. *Metriorhynchus* grew to an average adult length of 3 meters (9.6 ft), although some individuals may have reached lengths rivaling those of large nile crocodiles.	 A life restoration of a *Metriorhynchus* species.
Steneosaurus			

†Sauropods

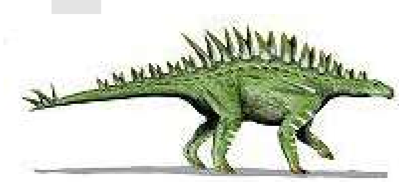
Sauropods of the Callovian

Taxa	Presence Location	Description	Images
Abrosaurus		*Abrosaurus* was a small (30 foot adult length) sauropod from China	

			with an unusual skull.	
Atlasaurus				
Ferganasaurus			A Kyrgistani sauropod genus that resembled *Rhoetosaurus*.	
Ferganasaurus verzilini				
Patagosaurus				

†Stegosauria

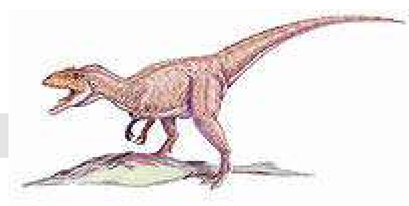
Stegosaurs of the Callovian

Taxa	Presence	Location	Description	Images
Huayangosaurus	Bathonian to Callovian	Lower Shaximiao Formation, Sichuan, China	A 4.5 meters in length quadrupedal herbivore with a small skull and a spiked tail. Bore the distinctive double row of plates, rising vertically along its arched back, of all the stegosaurians and two pairs of long spikes extending horizontally near the end of its tail	 *Huayangosaurus*
Lexovisaurus		Lisieux, France; Northern England	Traditionally, *Lexovisaurus* was depicted as having either large spines over the hips or shoulders, with a selection of flat plates and round pointed spines that ran along the back and tail. It was probably about 5 m long.	
Loricatosaurus		France; England	Known from remains	

			previously assigned to *Lexovisaurus*.	

Theropods

theropods of the Callovian

Taxa	Presence	Location	Description	Images
Eustreptospondylus			A moderately large (17-23 feet long) predatory dinosaur that was closely related to *Megalosaurus*.	 *Eustreptospondylus*.
Gasosaurus *Gasosaurus constructus*			An 11-13 foot predator from China whose discovery was assisted by the petroleum industry.	
Pedopenna				
Szechuanoraptor			A Chinese theropod that has yet to be formally described.	

†Ammonitida

Members of the Order Ammonitida are known as ammonitic ammonites. They are distinguished primarily by their suture lines. In ammonitic suture patterns, the lobes and saddles are much subdivided (fluted) and subdivisions are usually rounded instead of saw-toothed. Ammonoids of this type are the most important species from a biostratigraphical point of view. This suture type is characteristic of Jurassic and Cretaceous ammonoids but extends back all the way to the Permian.

Ammonites of the Callovian

Taxa	Presence	Location	Description	Images
Cadomites				
Oecoptychius				
Oecotraustes				
Oxycerites				

Peltoceras				*Peltoceras solidum* ammonite from the Matmor Formation (Jurassic, Callovian) in Makhtesh Gadol, Israel.

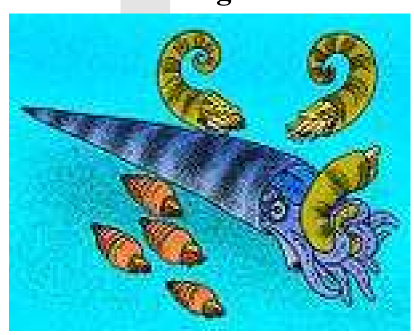
†Belemnites

Belemnites of the Callovian

Taxa	Presence	Location	Description	Images
Produvalia				 Callovian belemnite from the Zohar Formation, northern Israel

Nautiloids

Nautiloids of the Callovian

Taxa	Presence	Location	Description	Images
Somalinautilus				 An illustration of a variety of fossil nautiloids.

Neocoleoids

Neocoleoidea of the Callovian

Taxa	Presence	Location	Description	Images
Proteroctopus *Proteroctopus ribeti*				
Rhomboteuthis *Rhomboteuthis lehmani*			A squid species discovered in	

France.

Vampyronassa

Vampyronassa rhodanica

Pyritized fossil of *Vampyronassa rhodanica* from Voulte-sur-Rhône, France.

Chapter- 11

Bathonian

In the geologic timescale the **Bathonian** is an age or stage of the Middle Jurassic. It lasted from approximately 167.7 Ma to around 164.7 Ma (million years ago). The Bathonian age succeeds the Bajocian age and precedes the Callovian age.

Stratigraphic definitions

The Bathonian stage takes its name from Bath, a spa town in England built on Jurassic limestone (the Latinized form of the town name is *Bathonium*). The name was introduced in scientific literature by Belgian geologist d'Omalius d'Halloy in 1843. The original type locality was located near Bath. The French palaeontologist Alcide d'Orbigny was in 1852 the first to define the exact length of the stage.

The base of the Bathonian is at the first appearance of ammonite species *Parkinsonia (Gonolkites) convergens* in the stratigraphic column. A global reference profile for the base of the Bathonian (a GSSP) had in 2009 not yet been assigned. The top of the Bathonian (the base of the Callovian stage) is at the first appearance of ammonite genus *Kepplerites*.

In the Tethys domain, the Bathonian contains eight ammonite biozones:

- zone of *Clydoniceras discus*
- zone of *Hecticoceras retrocostatum*
- zone of *Cadomites bremeri*
- zone of *Morrisiceras morrisi*
- zone of *Tulites subcontractus*
- zone of *Procerites progracilis*
- zone of *Procerites aurigerus*
- zone of *Zigzagiceras zigzag*

Palaeontology

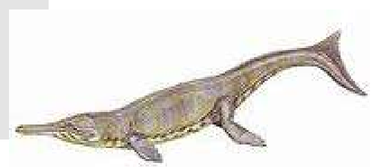
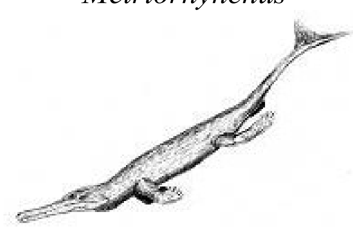
†Ankylosaurs

Ankylosaurs of the Bathonian

Taxa	Presence	Location	Description	Images
• *Tianchisaurus* • *Tianchisaurus nedegoapeferima*			A Chinese ankylosaur which lacked a club at the end of its tail. Its species epithet honors the main actors of Jurassic Park.	

Crocodylomorphs

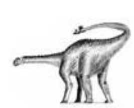
Crocodylomorphs of the Bathonian

Taxa	Presence	Location	Description	Images
• *Metriorhynchus*			An opportunistic carnivore that fed on fish, belemnites and other marine animals and possible carrion. *Metriorhynchus* grew to an average adult length of 3 meters (9.6 ft), although some individuals may have reached lengths rivaling those of large nile crocodiles.	 *Metriorhynchus*  *Teleidosaurus*, a marine crocodilian (Thalattosuchian).
• *Steneosaurus*				
• *Teleosaurus*				
• *Teleidosaurus*			The most plesiomorphic known metriorhynchid.	

†Ornithopods

Ornithopods of the Bathonian				
Taxa	**Presence**	**Location**	**Description**	**Images**
• *Agilisaurus* • *Agilisaurus louderbacki*			A 4-foot-long (1.2 m) bipedal herbivore that was built for speed. It was discovered in one of China's many Callovian deposits.	
• *Hexinlusaurus* • *Hexinlusaurus multidens*	Bathonian to Callovian	Lower Shaximiao Formation, Sichuan, China	A small ornithischian dinosaur distinguished from all other basal ornithischians by a single autapomorphy, the presence of a marked concavity that extends over the lateral surface of the postorbital.	 *Agilisaurus*
• *Xiaosaurus* • *Xiaosaurus dashanpensis*			A poorly known Chinese ornithschian that may be related to *Hypsilophodon* and *Lesothosaurus*. It was small and vegetarian.	
• *Yandusaurus* • *Yandusaurus hongheensis*		Dashanpu Formation, Sichuan, China	A 5-foot-long (1.5 m) Chinese herbivore in the family hypsilophodontidae.	

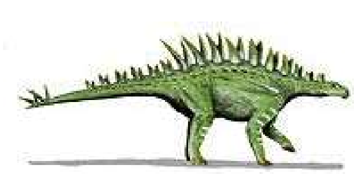
†Sauropods

Sauropods of the Bathonian				
Taxa	**Presence**	**Location**	**Description**	**Images**
• *Abrosaurus*			*Abrosaurus* was a small (30-foot (9.1 m) adult length) sauropod from	

			China with an unusual skull.	*Shunosaurus*
• *Atlasaurus*			A sauropod named after the mountains where the mythological figure that held the world on his shoulders, it attained lengths of 15 meters (50 ft) and lived in Morocco.	
• *Cardiodon*			A poorly known English sauropod with heart-shaped teeth.	
• *Shunosaurus*		Lower Shaximiao Formation, Sichuan, China	A 10-metre-long, fairly short-necked sauropod with a short deep skull, with fairly robust spatulate teeth. Its tail ended in a club, probably used for fending off enemies.	

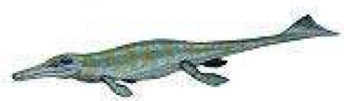
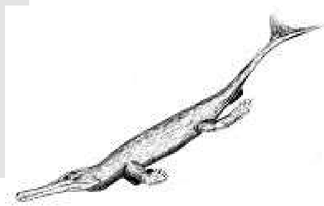
†Stegosauria

Stegosaurs of the Bathonian

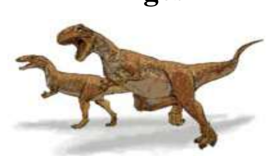
Taxa	Presence	Location	Description	Images
• *Huayangosaurus*	Bathonian to Callovian	Lower Shaximiao Formation, Sichuan, China	A 4.5 meters in length quadrupedal herbivore with a small skull and a spiked tail. Bore the distinctive double row of plates, rising vertically along its arched back, of all the stegosaurians and two pairs of long spikes	 *Huayangosaurus*

extending horizontally near the end of its tail

†Thalattosuchians

Thalattosuchians of the Bathonian			
Taxa	**Presence Location**	**Description**	**Images**
• *Metriorhynchus*		An opportunistic carnivore that fed on fish, belemnites and other marine animals and possible carrion. *Metriorhynchus* grew to an average adult length of 3 meters (9.6 feet), although some individuals may have reached lengths rivaling those of large nile crocodiles.	 A life restoration of a *Metriorhynchus* species  *Teleidosaurus*
• *Teleidosaurus*		The most plesiomorphic known metriorhynchid.	

Theropods

theropods of the Bathonian			
Taxa	**Presence Location**	**Description**	**Images**
• *Gasosaurus*		An 11-to-13-foot (3.4 to 4.0 m) predator from China whose discovery was assisted by the	 *Megalosaurus*

			petroleum industry.	
• *Iliosuchus*			A small, 5-foot-long (1.5 m) European carnivore related to *Tyrannosaurus*.	
• *Megalosaurus*			The first dinosaur to receive a formal scientific description, *Megalosaurus* was a 30-foot (9.1 m) carnivore which prowled Jurassic England.	
• *Szechuanoraptor*			A Chinese theropod that has yet to be formally described.	

†Ammonitida

Members of the order ammonitda are known as Ammonitic ammonites. They are distinguished primarily by their suture lines. In ammonitic suture patterns, the lobes and saddles are much subdivided (fluted) and subdivisions are usually rounded instead of saw-toothed. Ammonoids of this type are the most important species from a biostratigraphical point of view. This suture type is characteristic of Jurassic and Cretaceous ammonoids but extends back all the way to the Permian.

- *Cadomites*
- *Oecoptychius*
- *Oxycerites*
- *Somalinautilus*

†Ammonitids of the Aalenian

Taxa	Presence	Location	Description	Images
• *Asphinctites*	Confirmed.		The	
• *Cranocephalites*	Confirmed.			
• *Epistrenoceras*	Confirmed.			
• *Garantiana*	Confirmed.			

• *Lissoceras*	Confirmed.		Life restorations of two different ammonite genera.
• *Nannolytoceras*	Confirmed.		
• *Oecotraustes*	Confirmed.		
• *Okribites*	Confirmed.		
• *Parkinsonia*	Confirmed.		
• *Procerites*	Confirmed.		
• *Siemiradzkia*	Confirmed.		

†Belemnites

Belemnites of the Bathonian

Taxa	Presence	Location	Description	Images
• *Produvalia*				 Belemnite fossils

Chapter- 12

Toarcian

The **Toarcian** is, in the ICS' geologic timescale, an age or stage in the Early or Lower Jurassic. It spans the time between 183.0 Ma (million years ago) and 175.6 Ma. It follows the Pliensbachian and is followed by the Aalenian.

The Toarcian age began with the Toarcian turnover, the extinction event that sets its fossil faunas apart from the previous Pliensbachian age.

Stratigraphic definitions

The Toarcian takes its name from the city of Thouars, just south of Saumur in the Loire Valley of France. The stage was introduced by French palaeontologist Alcide d'Orbigny in 1842, after examining rock strata of this age in a quarry near Thouars.

In Europe this period is represented by the upper part of the Lias.

The base of the Toarcian is defined as the place in the stratigraphic record where the ammonite genus *Eodactylites* first appears. However, a global reference profile for the base of the Toarcian (a GSSP) had in 2009 not yet been assigned. The top of the stage is at the first appearance of ammonite genus *Leioceras*.

In the Tethys domain, the Toarcian contains the following ammonite biozones:

- zone of *Pleydellia aalensis*
- zone of *Dumortieria pseudoradiosa*
- zone of *Phlyseogrammoceras dispansum*
- zone of *Grammoceras thouarcense*
- zone of *Haugia variabilis*
- zone of *Hildoceras bifrons*
- zone of *Harpoceras serpentinum*
- zone of *Dactylioceras tenuicostatum*

Palaeontology

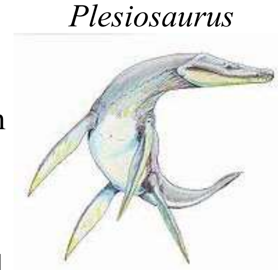
†Ornithischians

Ornithischians of the Toarcian

Taxa	Presence	Location	Description	Images
• *Emausaurus*		Germany	Armored dinosaur known from a skull and partial postcranial remains, although only the skull is known well. Armor includes conical scutes and tall, spiny elements.	

†Plesiosaurs

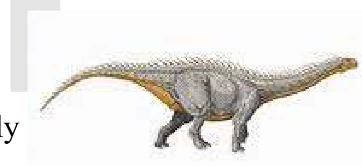
Plesiosauria of the Toarcian

Taxa	Presence	Location	Description	Images
• *Occitanosaurus*		Tournemire, Aveyron, France	A plesiosaur similar to Elasmosaurus; fossils consist of a single but nearly complete skeleton of an animal approximately 4 meters (13 ft) long	 *Plesiosaurus*
• *Plesiosaurus guilelmiimperatoris*	Sinemurian and Toarcian	Württemberg, Germany	A large (about 3 to 5 meters long), marine sauropterygian reptile, it was distinguished by its small head, long and slender neck, broad turtle like body, a short tail and two pairs of large, elongated paddles	 *Rhomaleosaurus*

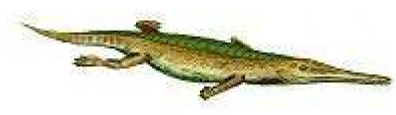
• *Rhomaleosaurus*	Hettangian and Toarcian	Alum Shale, Yorkshire, England; Holzmaden, Baden-Württemberg, Germany	A genus of sauropterygian carnivorous reptile belonging to the pliosaur superfamily, it was about 7m long.

†Sauropods

Sauropoda of the Toarcian

Taxa	Presence	Location	Description	Images
• *Barapasaurus*		India	The earliest known sauropod. Reached a length of about 18 metres (60 feet) and weighed about 48 tones (53 tons). Its height to the hip was approximately 5.5 metres (18 feet)	 *Barapasaurus*
• *Rhoetosaurus*	Disputed	Central Queensland, Australia	Estimated to have been about 12-15 metres long. Has been compared to Shunosaurus, based on similar general age, but without justification.	

†Thalattosuchians

Thalattosuchia of the Toarcian				
Taxa	Presence	Location	Description	Images
• *Pelagosaurus*		Somerset, England; France; Germany		 *Pelagosaurus*
• *Peipehsuchus*				
• *Platysuchus*				
• *Steneosaurus*				

Chapter- 13

Sinemurian

In the geologic timescale, the **Sinemurian** is an age or stage in the Early or Lower Jurassic epoch or series. It spans the time between 196.5 ± 2 Ma and 189.6 ± 1.5 Ma (million years ago). The Sinemurian is preceded by the Hettangian and is followed by the Pliensbachian.

In Europe the Sinemurian age, together with the Hettangian age, saw the deposition of the lower Lias, in Great Britain known as the Blue Lias.

Stratigraphic definitions

Jurassic rock strata in the cliffs at East Quantoxhead, near the Sinemurian golden spike

The Sinemurian stage was defined and introduced into scientific literature by French palaeontologist Alcide d'Orbigny in 1842. It takes its name from the French town of

Semur-en-Brionnais, near Sancerre in the upper Loire Valley. The calcareous soil formed from the Jurassic limestone of the region is in part responsible for the character of the classic Sancerre wines.

The base of the Sinemurian stage is at the first appearance of the ammonite genera *Vermiceras* and *Metophioceras* in the stratigraphic record. A global reference profile (GSSP or golden spike) for the Sinemurian stage is located in a cliff north of the hamlet of East Quantoxhead, 6 kilometres east of Watchet, Somerset, England.

The top of the Sinemurian (the base of the Pliensbachian) is at the first appearances of the ammonite species *Bifericeras donovani* and ammonite genus *Apoderoceras*.

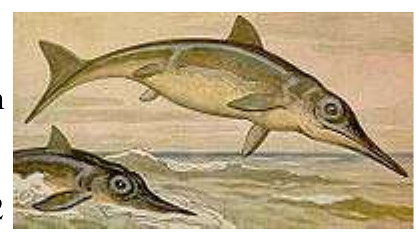
The Sinemurian contains six ammonite biozones in the Tethys domain:

- zone of *Echioceras raricostatum*
- zone of *Oxynotoceras oxynotum*
- zone of *Caenisites turneri*
- zone of *Arnioceras semicostatum*
- zone of *Arietites bucklandi*

Palaeontology

†Ichthyosaurs

Ichthyosauria of the Sinemurian

Taxa	Presence	Location	Description	Images
• *Ichthyosaurus*	From Hettangian to Sinemurian	Belgium, England, Germany	Among the best known ichthyosaur genera, was smaller than most of its relatives, measuring 2 m (6 ft 8 inches) in length.	 *Ichthyosaurus*

Mammaliaformes

Mammaliaformes of the Sinemurian

Taxa	Presence	Location	Description	Images
• *Hadrocodium*		Yunnan, China	The earliest known example of several features distinctive to mammals, including mammal-like	

mandible and middle-ear structures and a relatively large brain cavity

Theropoda

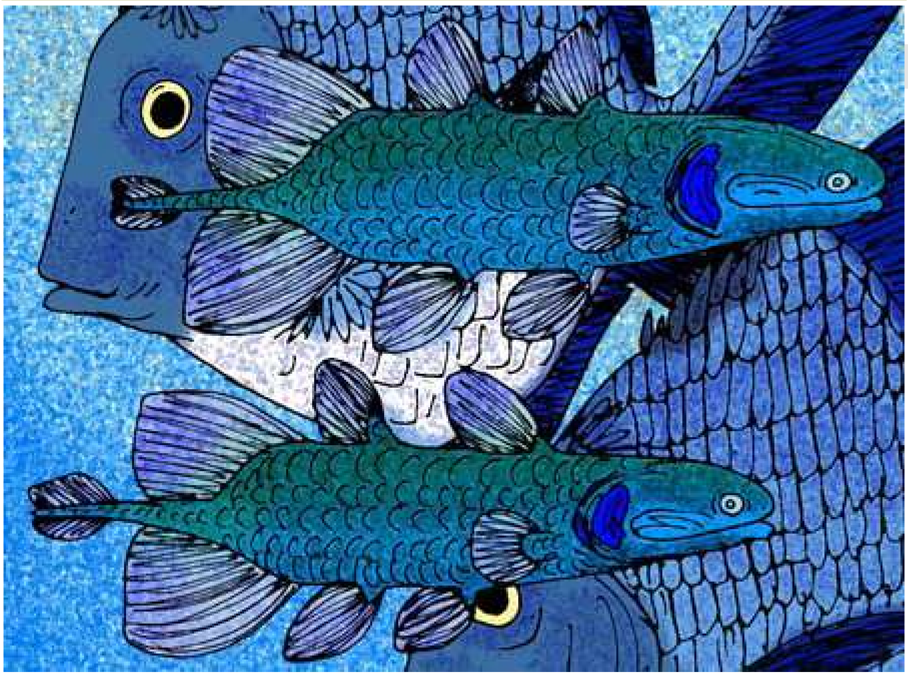
Theropods of the Sinemurian

Taxa	Presence	Location	Description	Images
• *Dilophosaurus*	Sinemurian to Pliensbachian	Arizona, USA; Yunnan, China	Measured around six meters (20 ft) long and may have weighed half a ton. The most distinctive characteristic of *Dilophosaurus* is the pair of rounded crests on its skull, possibly used for display.	 *Dilophosaurus*
• *Sarcosaurus*	Sinemurian	Leicestershire, England	Measured around 3.5 meters (12 ft) long. The most distinctive characteristic of *Sarcosaurus* is its pelvis which is remarkably similar to the later *Ceratosaurus*.	
• "Saltriosaurus"	Sinemurian	Saltrio, Northern Italy		

Chapter- 14

Jurassic Extinctions

1. Coelacanthidae

Coelacanthidae Fossil range: Permian to Jurassic	
	
Coelacanthus whitea	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Sarcopterygii
Subclass:	Coelacanthimorpha
Order:	Coelacanthiformes
Family:	**Coelacanthidae**
Genera	

- *Coelacanthus type genus*

- *Axelia*
- *Ticinepomis*
- *Wimania*
- *Indocoelacanthus*

Coelacanthidae is an extinct family of coelacanths found throughout the world, originating during the Permian and finally dying out during the Jurassic.

The modern-day genus *Latimeria* is often erroneously thought to be in this family, when, in fact, it is in the more advanced family Latimeriidae, which appeared some time during the Triassic.

2. Fruitafossor

Fruitafossor **Fossil range: Late Jurassic**	

Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Subclass:	*incertae sedis*
Genus:	***Fruitafossor*** Luo and Wible, 2005
Species:	***F. windscheffeli***

Binomial name

Fruitafossor windscheffeli
Luo and Wible, 2005

Fruitafossor was a termite-eating mammal endemic to North America during the Late Jurassic epoch (155.7—150.8 mya), existing for approximately 4.9 million years.

The description is based on a surprisingly complete skeleton of a chipmunk-sized animal. It was discovered on March 31, 2005, in Fruita, Colorado. It resembled an armadillo (or anteater) and probably ate colonial insects in much the same manner as these animals do today. Other skeletal features clearly show that *Fruitafossor* was not related to armadillos, anteaters, or any modern group of mammal. This indicates that specializations associated with feeding on ants or termites have independently evolved many times in mammals: in *Fruitafossor*, anteaters, numbats, aardvarks and spiny anteaters.

Description

In 2009, a study by J. R. Foster was published that estimated the body masses of mammals from the Late Jurassic Morrison Formation by using the ratio of dentary length to body mass of modern marsupials as a reference. Foster concludes that *Fruitafossor* was the least massive of the formation at 6g, much lower than the average Morrison mammal of 48.5g.

Armadillo teeth and Popeye arms

The teeth of *Fruitafossor* bear a striking resemblance to modern armadillos and aardvarks. They were open-rooted, peg-like teeth without enamel. This type of tooth is present today in insectivorous mammals, particularly those that are highly specialized to feed on colonial insects. This is termed "myrmecophagy." Since ants had not yet evolved at the time of *Fruitafossor*, it is assumed that these animals fed on termites, which were abundant along with their relatives the cockroaches.

Fruitafossor has been nicknamed Popeye, after the cartoon sailor, because of its large front limbs. The features of the front limb indicate that the animal was fossorial, employing scratch digging like modern moles, gophers and spiny anteaters. The olecranon process was highly enlarged indicating the forelimb had powerful muscles. This feature also supports the idea that they were myrmecophagous, as modern mammals employ this technique to break into termite mounds.

Its vertebral column is also very similar to armadillos, sloths and anteaters (order Xenarthra). It had extra points of contact among vertebrae similar to the xenarthrous process that are only known in these modern forms. These processes generate a rigid and relatively inflexible backbone, which is good for digging.

This find is an important discovery in mammal evolution, because of where it fits in the evolutionary tree of mammals and because of its ecological niche. Most mammals of the Mesozoic were omnivores or unspecialized insectivores. *Fruitafossor* is unique in the degree of specialization, both for digging and in regard to how specialized it was on insects. This fossil, along with others such as *Repenomamus*, *Volaticotherium* and *Castorocauda*, challenge the notion that early mammals and mammaliaforms were restricted to a single niche and demonstrate that at least some early specialization occurred.

To what is it related?

Fruitafossor has no modern relatives. It is an early offshoot of mammal related to therians (the subclass containing marsupials and placentals). It has a unique suite of therian and prototherian characteristics. Its shoulder-girdle is similar to a platypus or reptile, but many other features are more similar to most other modern mammals. This has led researchers to suggest that it may have been the earliest known relative to the evolutionary line leading to Theria.

The genus name, *Fruitafossor*, comes from Fruita, Colorado, where it was discovered. The "fossor" indicates the fossorial, or digging, specialization of the forelimbs. The specific epithet, *windscheffeli*, is in honor of Wally Windscheffel, who discovered the specimen along with C. Safris.

3. Hadrocodium

Hadrocodium Fossil range: Early Jurassic	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Subphylum:	Vertebrata
(unranked):	Amniota
Class:	Synapsida
(unranked):	Mammaliaformes
Genus:	***Hadrocodium***

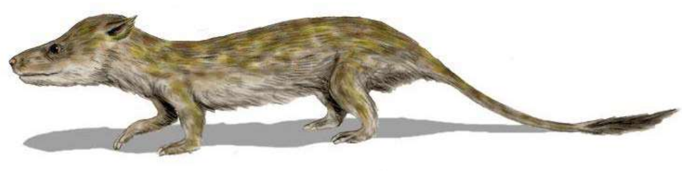
Hadrocodium wui is an extinct basal mammal species that lived during the Lower Jurassic (approx. 195 million years ago, during the Sinemurian stage) in what is now the Yunnan province of China. *Hadrocodium* was a mere 3.2 cm (1.35 in) in length (about 2 grams) and is one of the smallest mammals of either the Mesozoic or Cenozoic eras.

Hadrocodium is the earliest known example of several features distinctive to mammals, including mammal-like mandible and middle-ear structures and a relatively large brain cavity. The discovery of *Hadrocodium* suggests that the origination of these distinctive mammaliaform features was much older (45 million years older) than previously thought.

Whether *Hadrocodium* was endothermic or cold-blooded has not been settled, although its apparent nocturnal features would seem to place it in the endotherm group.

4. Oligokyphus

Oligokyphus **Fossil range: Late Triassic–Early Jurassic**	



life restoration of *Oligokyphus*

Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Subphylum:	Vertebrata
Superclass:	Tetrapoda
Class:	Synapsida
Order:	Therapsida
Suborder:	Cynodontia
Family:	Tritylodontidae
Genus:	***Oligokyphus*** Hennig E, 1922

Species

- *Oligokyphus triserialis* (Hennig E, 1922)
- *Oligokyphus major* (Kühne WG, 1956)
- *Oligokyphus lufengensis* (Luo Z & Sun A, 1993)
- *Oligokyphus sp.* (Sues H-D, 1985)

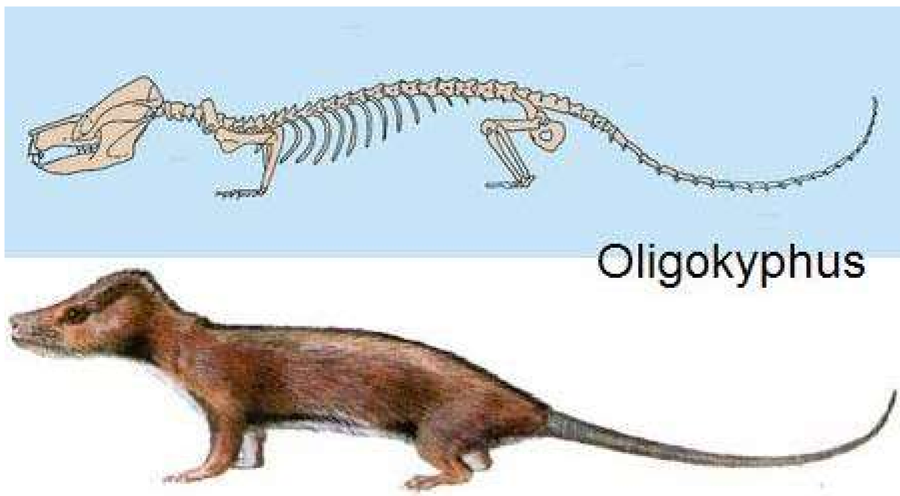
Synonyms

- *Chalepotherium plieningeri*
- *Mucrotherium*
- *Uniserium*

Oligokyphus was an advanced herbivorous cynodont of the late Triassic to early Jurassic periods. Originally considered to be an early mammal, it is now classified as a synapsid because *Oligokyphus* does not have the mammalian jaw attachments and it retains a vestigial joint between the quadrate bone and the squamosal bone in the skull.

Description

Oligokyphus (meaning "small curved animal"), was a small animal, around 50 centimetres (20 in) in length, belonging to the herbivorous Tritylodontidae family. It resembled a weasel in appearance, with a long and slim body. The limbs sat directly under the body, like modern mammals, but unlike other known synapsids.



The skeleton of *Oligokyphus*

Oligokyphus was found widely across North America, Europe and China. This indicates that there were substitutes with the terrestrial vertebrates.

Skull and jaw

The teeth of the upper and lower jaw contain bump rows that fit together perfectly in order to maintain an accurate bite. *Oligokyphus* had a face similar to that of modern mammals, although there were differences in the cheekbones and eyesockets. It had a bony secondary palate and double-rooted cheek teeth. Unlike mammals, the teeth of *Oligokyphus* did not occlude. The jaw was double jointed and the neck was flexible, with an atlas and axis and a double occipital condyle.

The teeth were different from those of related cynodonts; there were no canine teeth and unusually large, rodent-like incisors. There is a large gap, or diastema, separating the cheek teeth from the incisors. The lower jaw of these animals moved back and forth when the mouth was shut so that the food could be chopped up. *Oligokyphus* had no premaxilla, but did have a lateral extension of the maxilla.

While the postcanines in non-mammalians, such as *Oligokyphus*, are difficult to differentiate from canines, the lower postcanines of *Oligokyphus* (also considered to be pre-molars) are defining from other Tritylodonts. On lower postcanine teeth of Trityldonts, two cusps can be found per row; however, *Oligokyphus* have two rows with three cusps in each row. The upper postcanines have also been found in fossil records to be longer than they are wide. These cusps, specific to *Oligokyhpus* Tritylodonts, allowed for a well-fitting bite that was particularly good at shredding plant material dense in fiber. The foremost incisors are similar to those of today's rodents, extremely intensified and enlarged.. The typical location of canine teeth is left empty with *Oligokyphus*. Instead, a gap is inserted in this area of the jaw as *Oligokyphus* lack the teeth commonly known as canines.

Phylogeny

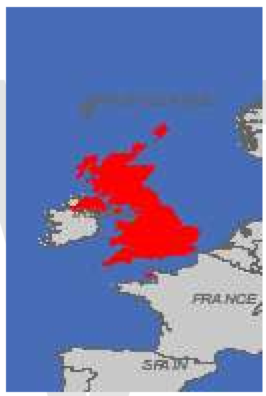
Cladistics

Oligokyphus is in the family Trityledontidae. The family is named after the shape of their teeth. Trityledontidae means "three knob teeth". The members of the family were all small to medium sized advanced synapsids with combined specialized structures for herbivorous eating. They were the last members of the non-mammalian synapsids. The first Trityledont was found in South Africa in the upper Jurassic rocks. It was first thought to be on of the earliest mammals. This classification has since been adjusted. These non-mammals became progressively more mammal-like. They are now classified as the closest relatives to the mammals and this is supported by their high, flat crested jaw, large zygomatic arches, well developed secondary palate and dentition.

There have also been comparisons between the cranial nerves of Trityledonts and mammals. The shoulder girdle and forelimb structures were suggestive of these animals digging. These animals are extremely active and burrow in leaf litter and dirt, which suggests characteristics of rodents and rabbits. They naturally have a metabolism that is partially or completely endothermic. They were thought to be driven out by relatives such as mammals, which were competitors for the same territory. Another reason that this animal could have gone extinct is due to new plant development. Some flowering plants, or angiosperms, can be detrimental to these animals since they may not be used to eating new plants.

Oligokyphus is placed into the subgroup Probainognathia. This forms a monophyletic group with the tritheledontid *Pachygenelus.*

The area in red indicates a heavily concentrated area where *Oligokyphus* fossils have been discovered in Apache County, Arizona, United States; collected by U.C.Party, circa 1968.



Map indicating locations of *Oligokyphus* fossil discoveries. This was collected in 1970 by W.A. Clemmens, as listed by Berkeley Natural History Museums. Somerset County, England, United Kingdom.

Fossil finds

Though *Oligokyphus* is very widespread, it was not until 1953 that representatives of this group were found. Information was first collected from the Kayenta Formation on Comb Ridge in northeastern Arizona. Numerous specimens of Oligokyphus were obtained by Harvard University and the Museum of Northern Arizona in the "Silty Facies". Many fossils have also been found throughout the UK, Germany and China. Some very small fragment remains have also been found in Antarctica. By these fossil records, one can see that Oligokyphus have a vertical humerus and a minor trochanter. This broad distribution indicates that there were no barriers to separate this terresterial vertebrate.

Habitat

Oligokyphus were small tetrapod, terrestrial animals. They have long been considered as mammaliomorphs, a link between reptiles and mammals. It is believed these animals were primarily land dwelling, living amongst small shrubs or bushes. It is also thought that *Oligokyphus* fed on seeds or nuts, as their teeth resemble those of modern animals that also feed on seeds and nuts. It is a rather difficult to estimate the social behaviors of *Oligokyphus* as most of it does not preserve in the fossil record. However, considering the conditions on the planet during the times that *Oligokyphus* was alive and thriving (late Triassic and early Jurassic) and also the locations of which fossils of these animals were found, some educated predictions can be made about their metabolism and feeding habits. *Oligokyhus*, with its conveniently placed leg and hip structures, likely was quick-moving and fed off of low-lying plant life. With its long weasel-like body, it may have even been possible for *Oligokyphus* to reach higher vegetation simply by standing on its hind legs. It probably had good use of its hands to manipulate seeds and other digestively pleasing foods. There has not been any support showing *Oligokyphus* had the ability to climb vertically, as some rodents are capable of doing today.

Parental care

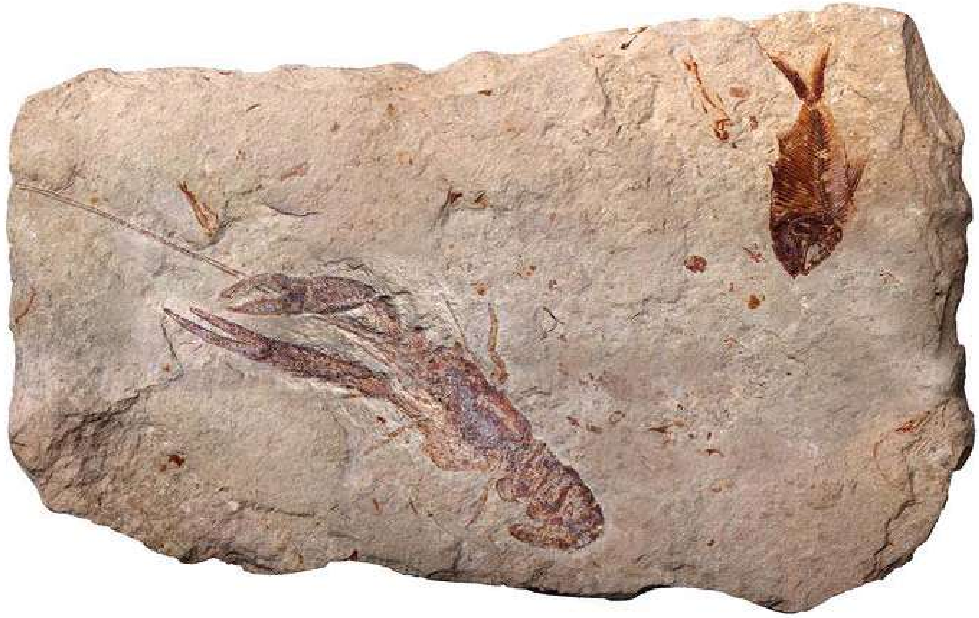
This illustration shows that there is a good possibility that *Oligokyphus* had parental care. This is assumed to be true because of the transitional state *Oligokyphus* was in from reptiles to mammalian. Today most mammals and some reptiles show parental care to their young. This makes a good argument to the possibility of parental care with *Oligokyphus*, but with all prehistoric creatures it is not a 100% assumption without actually seeing them interact.

Chapter- 15

Cretaceous

The **Cretaceous**, Latin for "chalky", usually abbreviated **K** for its German translation *Kreide* (chalk), is a geologic period and system from circa 145.5 ± 4 to 65.5 ± 0.3 million years (Ma) ago. In the geologic timescale, the Cretaceous follows on the Jurassic Period and is followed by the Paleogene Period of the Cenozoic Era. It is the youngest period of the Mesozoic Era, and at 80 million years long, the longest period of the Phanerozoic Eon. The end of the Cretaceous defines the boundary between the Mesozoic and Cenozoic eras. In many languages this period is known as "chalk period".

The Cretaceous was a period with a relatively warm climate and high eustatic sea level. The oceans and seas were populated with now extinct marine reptiles, ammonites and rudists; and the land by dinosaurs. At the same time, new groups of mammals and birds as well as flowering plants appeared. The Cretaceous ended with one of the largest mass extinctions in Earth history, the K-T extinction, when many species, including non-avian dinosaurs, pterosaurs, and large marine reptiles, disappeared.

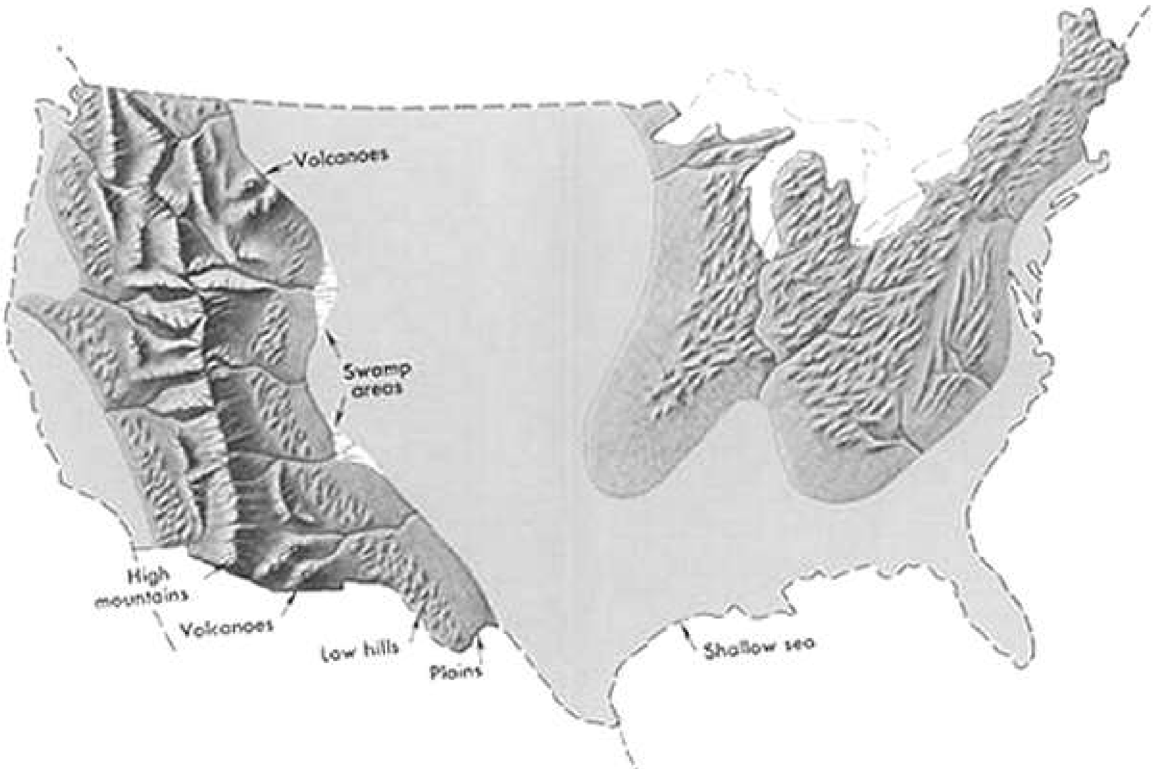


A plate with *Nematonotus sp.* , *Pseudostacus sp.*, and a partial *Dercetis triqueter* from Cretaceous found in Hakel, Lebanon

The Cretaceous world

Paleogeography

During the Cretaceous, the late-Paleozoic-to-early-Mesozoic supercontinent of Pangaea completed its tectonic breakup into present day continents, although their positions were substantially different at the time. As the Atlantic Ocean widened, the convergent-margin orogenies that had begun during the Jurassic continued in the North American Cordillera, as the Nevadan orogeny was followed by the Sevier and Laramide orogenies.



Geography of the US in the Late Cretaceous Period

Though Gondwana was still intact in the beginning of the Cretaceous, it broke up as South America, Antarctica and Australia rifted away from Africa (though India and Madagascar remained attached to each other); thus, the South Atlantic and Indian Oceans were newly formed. Such active rifting lifted great undersea mountain chains along the welts, raising eustatic sea levels worldwide. To the north of Africa the Tethys Sea continued to narrow. Broad shallow seas advanced across central North America (the Western Interior Seaway) and Europe, then receded late in the period, leaving thick marine deposits sandwiched between coal beds. At the peak of the Cretaceous transgression, one-third of Earth's present land area was submerged.

The Cretaceous is justly famous for its chalk; indeed, more chalk formed in the Cretaceous than in any other period in the Phanerozoic. Mid-ocean ridge activity—or rather, the circulation of seawater through the enlarged ridges—enriched the oceans in calcium; this made the oceans more saturated, as well as increased the bioavailability of the element for calcareous nanoplankton. These widespread carbonates and other sedimentary deposits make the Cretaceous rock record especially fine. Famous formations from North America include the rich marine fossils of Kansas's Smoky Hill Chalk Member and the terrestrial fauna of the late Cretaceous Hell Creek Formation. Other important Cretaceous exposures occur in Europe (e.g., the Weald) and China (the Yixian Formation). In the area that is now India, massive lava beds called the Deccan Traps were erupted in the very late Cretaceous and early Paleocene.

Climate

The Berriasian epoch showed a cooling trend that had been seen in the last epoch of the Jurassic. There is evidence that snowfalls were common in the higher latitudes and the tropics became wetter than during the Triassic and Jurassic. Glaciation was however restricted to alpine glaciers on some high-latitude mountains, though seasonal snow may have existed farther south. Rafting by ice of stones into marine environments occurred during much of the Cretaceous but evidence of deposition directly from glaciers is limited to the Early Cretaceous of the Eromanga Basin in southern Australia.

After the end of the Berriasian, however, temperatures increased again, and these conditions were almost constant until the end of the period. This trend was due to intense volcanic activity which produced large quantities of carbon dioxide. The development of a number of mantle plumes across the widening mid-ocean ridges further pushed sea levels up, so that large areas of the continental crust were covered with shallow seas. The Tethys Sea connecting the tropical oceans east to west also helped in warming the global climate. Warm-adapted plant fossils are known from localities as far north as Alaska and Greenland, while dinosaur fossils have been found within 15 degrees of the Cretaceous south pole.

A very gentle temperature gradient from the equator to the poles meant weaker global winds, contributing to less upwelling and more stagnant oceans than today. This is evidenced by widespread black shale deposition and frequent anoxic events. Sediment cores show that tropical sea surface temperatures may have briefly been as warm as 42 °C (107 °F), 17 °C (31 °F) warmer than at present, and that they averaged around 37 °C (99 °F). Meanwhile deep ocean temperatures were as much as 15 to 20 °C (27 to 36 °F) higher than today's.

Geology

Research history

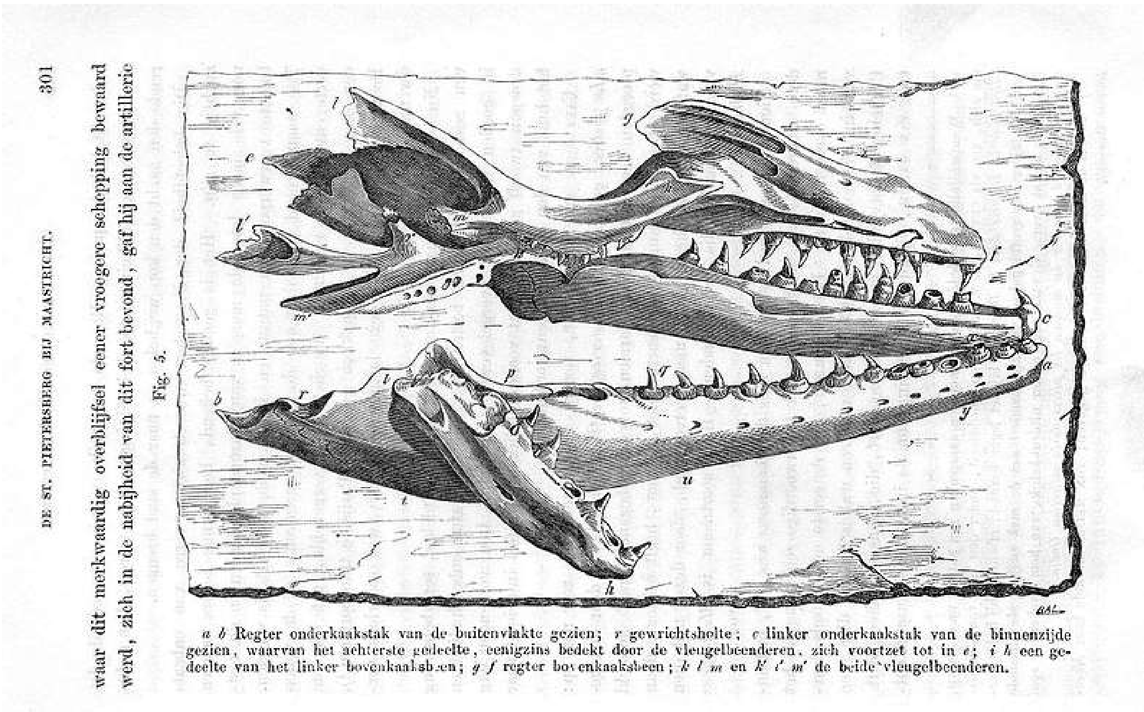
The Cretaceous as a separate period was first defined by a Belgian geologist Jean d'Omalius d'Halloy in 1822, using strata in the Paris Basin and named for the extensive beds of chalk (calcium carbonate deposited by the shells of marine invertebrates, principally coccoliths), found in the upper Cretaceous of western Europe. The name Cretaceous was derived from Latin *creta*, meaning *chalk*. The name of the island Crete has the same origin.

Stratigraphic subdivisions

The Cretaceous is divided into Early and Late Cretaceous epochs or Lower and Upper Cretaceous series. In older literature the Cretaceous is sometimes divided into three series: Neocomian (lower/early), Gallic (middle) and Senonian (upper/late). A subdivision in eleven stages, all origining from European stratigraphy, is now used worldwide. In many parts of the world, alternative local subdivisions are still in use.

As with other older geologic periods, the rock beds of the Cretaceous are well identified but the exact ages of the system's top and base are uncertain by a few million years. No great extinction or burst of diversity separates the Cretaceous from the Jurassic. However, the top of the system is sharply defined, being placed at an iridium-rich layer found worldwide that is believed to be associated with the Chicxulub impact crater in Yucatan and the Gulf of Mexico. This layer has been tightly dated at 65.5 Ma.

Rock formations



Drawing of fossil jaws of *Mosasaurus hoffmanni*, from the Maastrichtian of Dutch Limburg, by Dutch geologist Pieter Harting (1866).

The high eustatic sea level and warm climate of the Cretaceous meant a large area of the continents was covered by warm shallow seas. The Cretaceous was named for the extensive chalk deposits of this age in Europe, but in many parts of the world, the Cretaceous system consists for a major part of marine limestone, a rock type that is formed under warm, shallow marine circumstances. Due to the high sea level there was extensive accommodation space for sedimentation so that thick deposits could form. Because of the relatively young age and great thickness of the system, Cretaceous rocks crop out in many areas worldwide.

Chalk is a rock type characteristic for (but not restricted to) the Cretaceous. It consists of coccoliths, microscopically small calcite skeletons of coccolithophores, a type of algae that prospered in the Cretaceous seas.

In northwestern Europe, chalk deposits from the Upper Cretaceous are characteristic for the Chalk Group, which forms the white cliffs of Dover on the south coast of England

and similar cliffs on the French Normandian coast. The group is found in England, northern France, the low countries, northern Germany, Denmark and in the subsurface of the southern part of the North Sea. Chalk is not easily consolidated and the Chalk Group still consists of loose sediments in many places. The group also has other limestones and arenites. Among the fossils it contains are sea urchins, belemnites, ammonites and sea reptiles such as *Mosasaurus*.

In southern Europe, the Cretaceous is usually a marine system consisting of competent limestone beds or incompetent marls. Because the Alpine mountain chains did not yet exist in the Cretaceous, these deposits formed on the southern edge of the European continental shelf, at the margin of the Tethys Ocean.

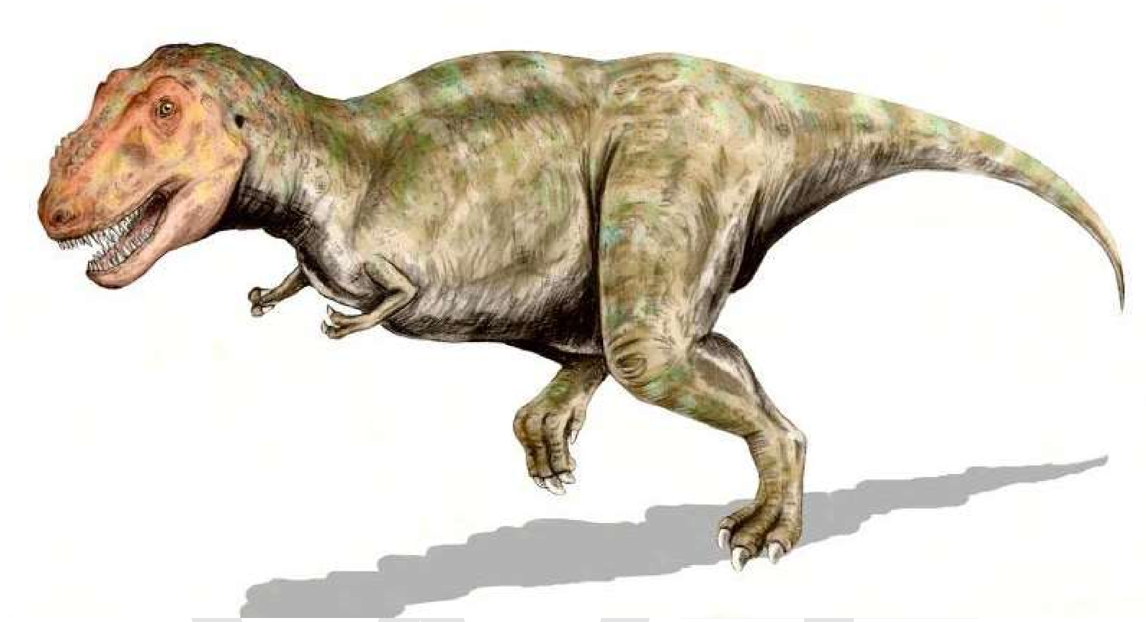
Stagnation of deep sea currents in middle Cretaceous times caused anoxic circumstances in the sea water. In many places around the world, dark anoxic shales were formed during this interval. These shales are an important source rock for oil and gas, for example in the subsurface of the North Sea.

Life

Plants

Flowering plants (angiosperms) spread during this period, although they did not become predominant until the Campanian stage near the end of the epoch. Their evolution was aided by the appearance of bees; in fact angiosperms and insects are a good example of coevolution. The first representatives of many leafy trees, including figs, planes and magnolias, appeared in the Cretaceous. At the same time, some earlier Mesozoic gymnosperms like Conifers continued to thrive; pehuéns (Monkey Puzzle trees, *Araucaria*) and other conifers being notably plentiful and widespread. Some fern orders such as Gleicheniales appeared as early in the fossil record as the Cretaceous, and achieved an early broad distribution. Gymnosperm taxa like Bennettitales died out before the end of the period.

Terrestrial fauna



Tyrannosaurus rex, one of the largest land predators of all time, lived during the late Cretaceous.

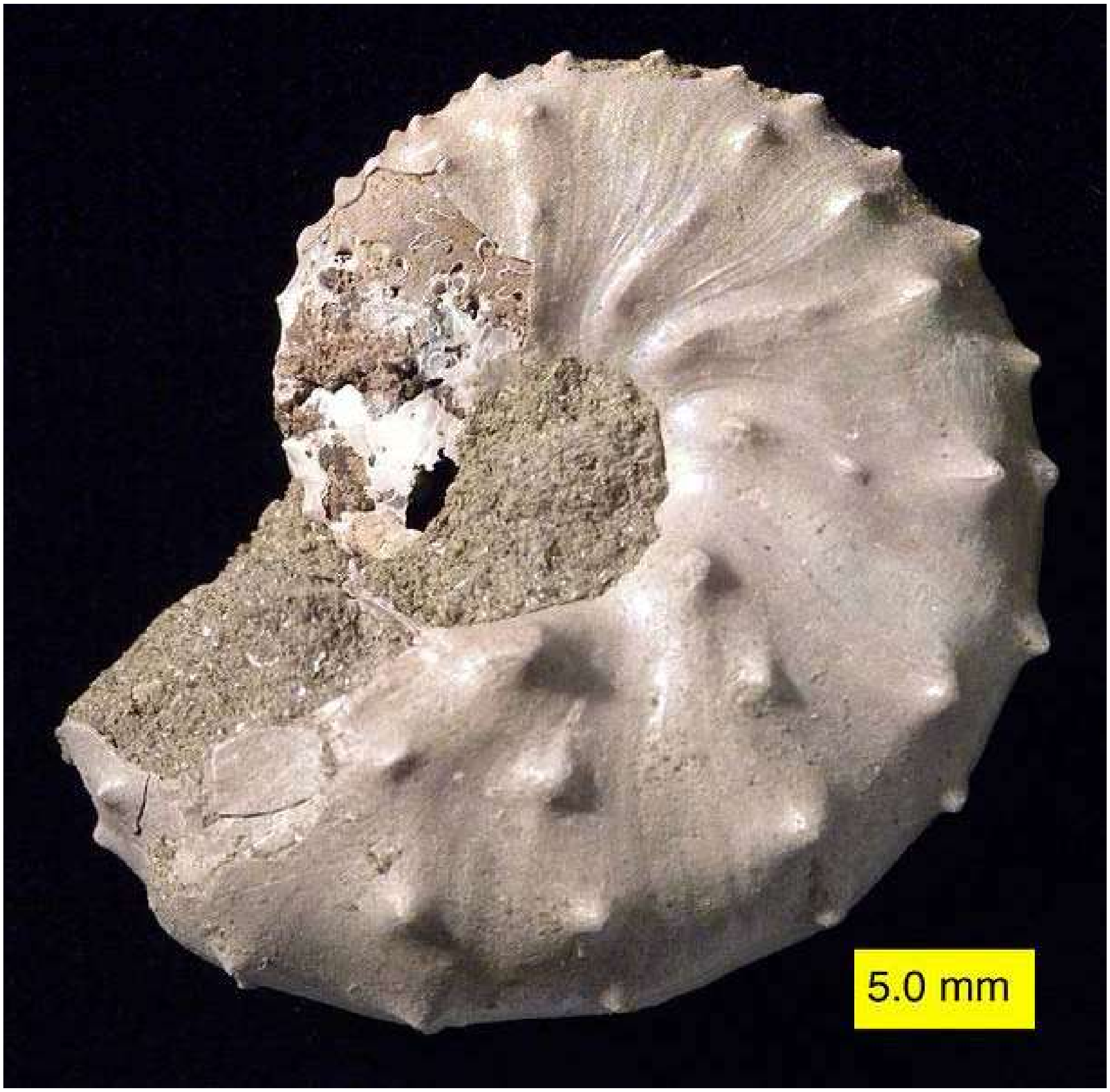
A pterosaur, *Anhanguera piscator*

On land, mammals were a small and still relatively minor component of the fauna. Early marsupial mammals evolved in the Early Cretaceous, with true placentals emerging in the Late Cretaceous period. The fauna was dominated by archosaurian reptiles, especially dinosaurs, which were at their most diverse stage. Pterosaurs were common in the early and middle Cretaceous, but as the Cretaceous proceeded they faced growing competition from the adaptive radiation of birds, and by the end of the period only two highly specialized families remained.

The Liaoning lagerstätte (Chaomidianzi formation) in China provides a glimpse of life in the Early Cretaceous, where preserved remains of numerous types of small dinosaurs, birds, and mammals have been found. The coelurosaur dinosaurs found there represent types of the group Maniraptora, which is transitional between dinosaurs and birds, and are notable for the presence of hair-like feathers.

During the Cretaceous, insects began to diversify, and the oldest known ants, termites and some lepidopterans, akin to butterflies and moths, appeared. Aphids, grasshoppers, and gall wasps appeared.

Marine fauna



Discoscaphites iris, Owl Creek Formation (Upper Cretaceous), Ripley, Mississippi.

In the seas, rays, modern sharks and teleosts became common. Marine reptiles included ichthyosaurs in the early and middle of the Cretaceous, becoming extinct during the late Cretaceous, plesiosaurs throughout the entire period, and mosasaurs appearing in the Late Cretaceous.

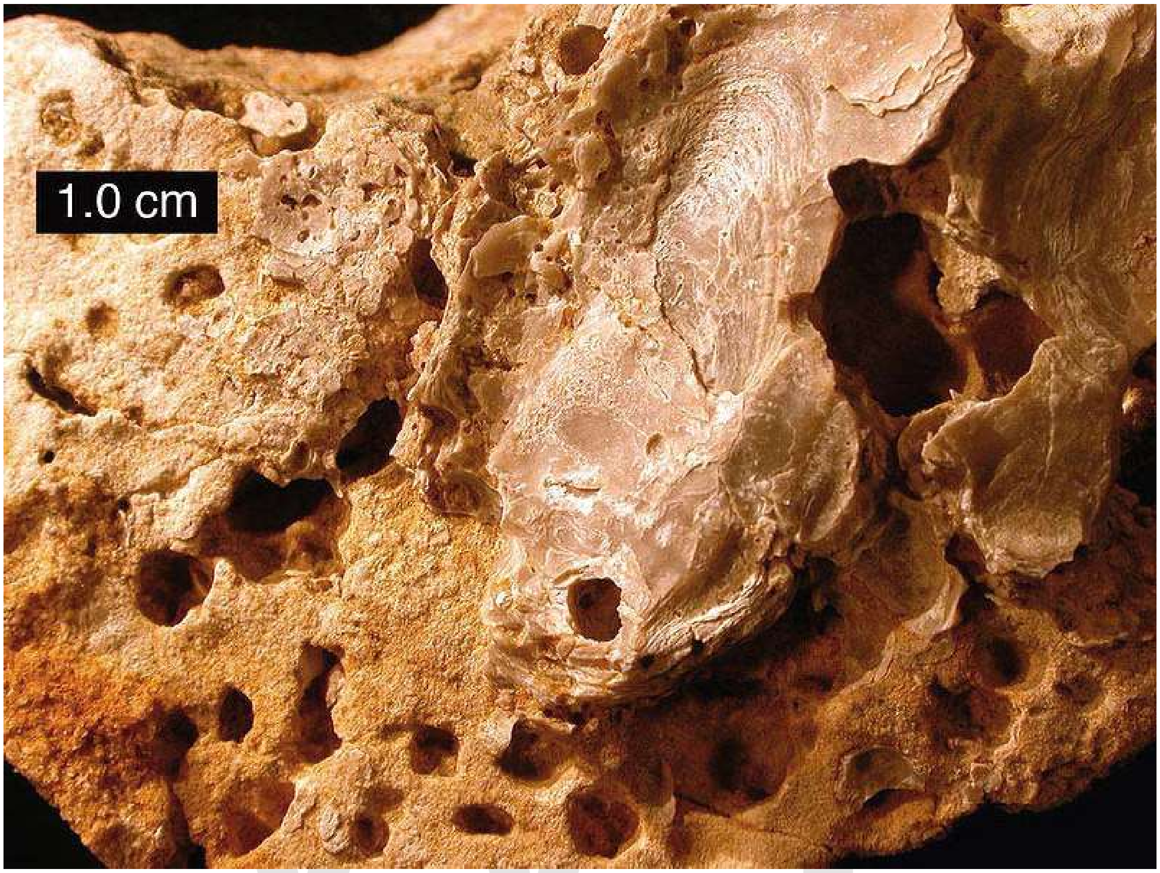
Baculites, an ammonite genus with a straight shell, flourished in the seas along with reef-building rudist clams. The Hesperornithiformes were flightless, marine diving birds that swam like grebes. Globotruncanid Foraminifera and echinoderms such as sea urchins and starfish (sea stars) thrived. The first radiation of the diatoms (generally siliceous, rather than calcareous) in the oceans occurred during the Cretaceous; freshwater diatoms did not appear until the Miocene. The Cretaceous was also an important interval in the evolution of bioerosion, the production of borings and scrapings in rocks, hardgrounds and shells (Taylor and Wilson, 2003).

Extinction

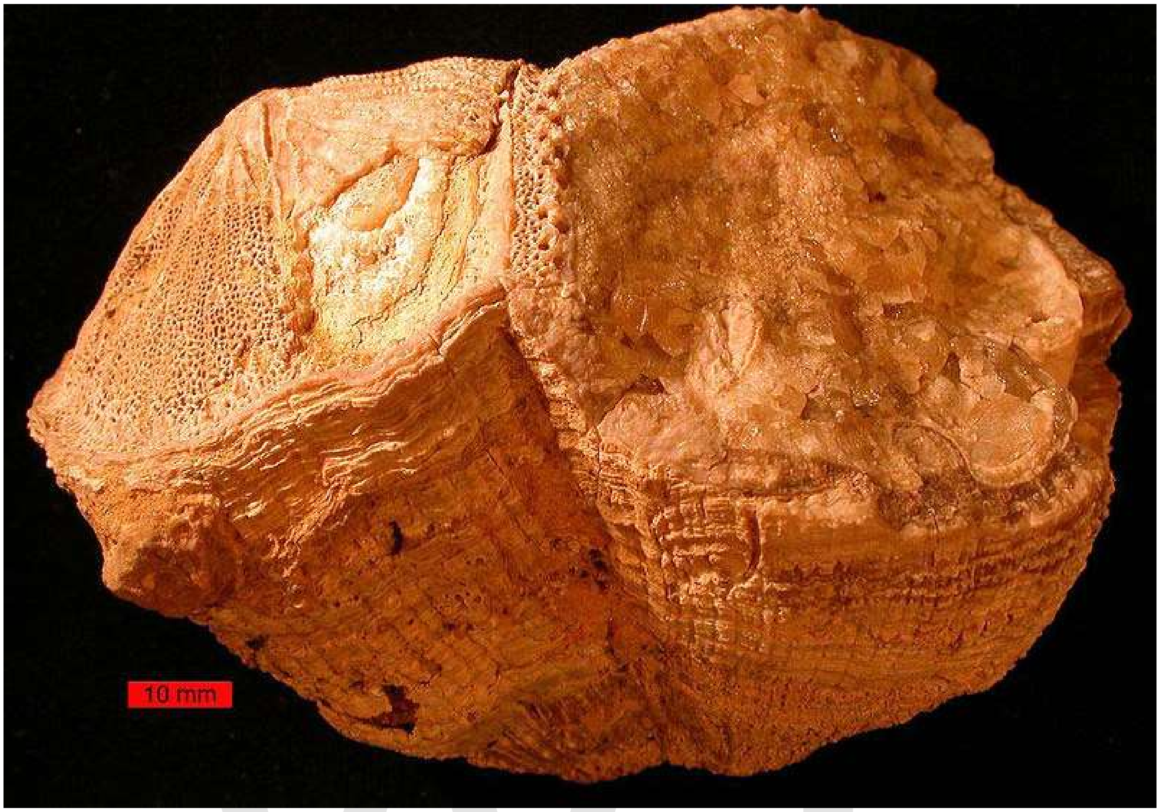
There was a progressive decline in biodiversity during the Maastrichtian stage of the Cretaceous Period prior to the suggested ecological crisis induced by events at the K-T boundary. Furthermore, biodiversity required a substantial amount of time to recover from the K-T event, despite the probable existence of an abundance of vacant ecological niches.

Despite the severity of this boundary event, there was significant variability in the rate of extinction between and within different clades. Species which depended on photosynthesis declined or became extinct because of the reduction in solar energy reaching the Earth's surface due to atmospheric particles blocking the sunlight. As is the case today, photosynthesizing organisms, such as phytoplankton and land plants, formed the primary part of the food chain in the late Cretaceous. Evidence suggests that herbivorous animals, which depended on plants and plankton as their food, died out as their food sources became scarce; consequently, top predators such as *Tyrannosaurus rex* also perished.

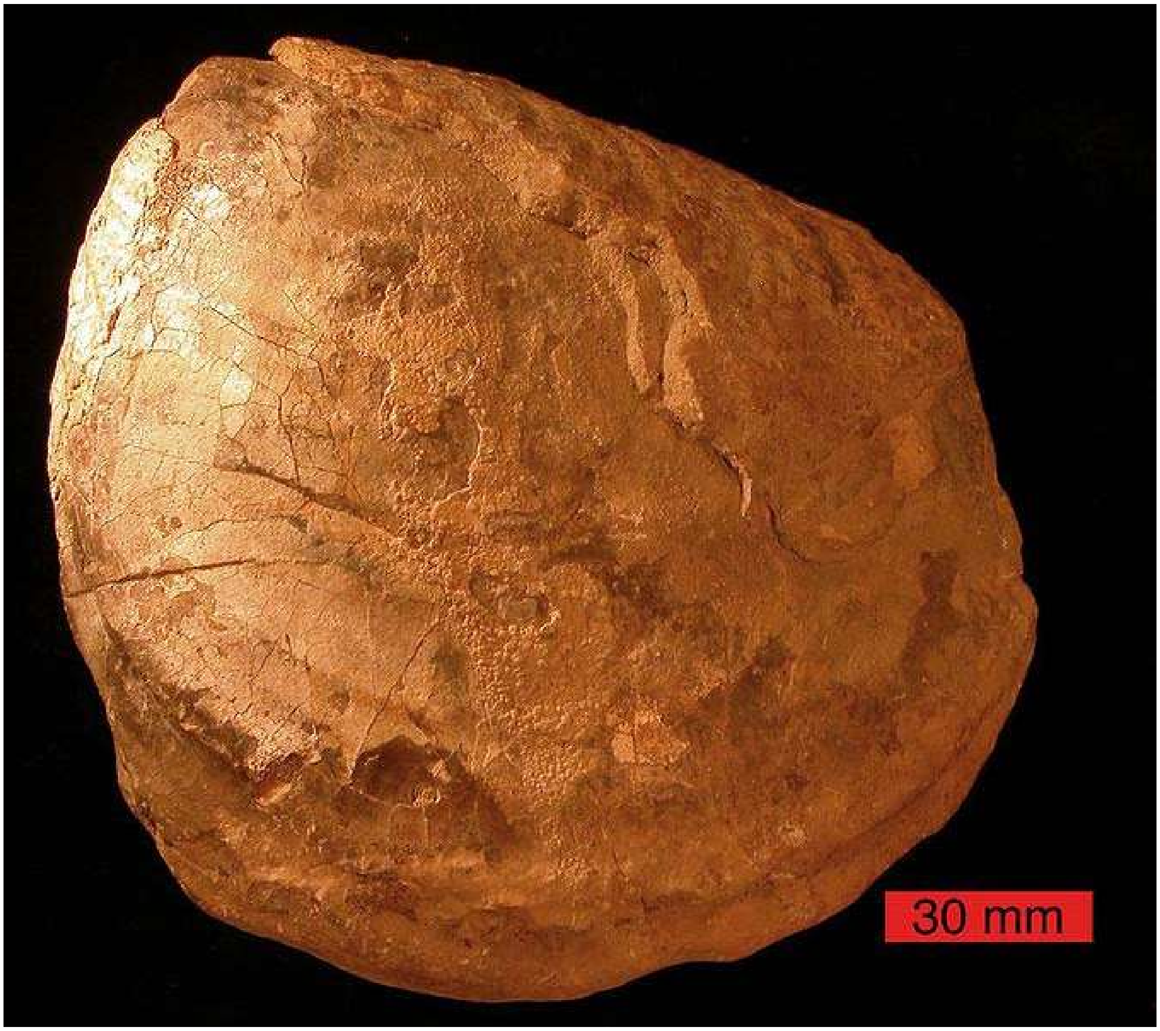
Numerous borings in a Cretaceous cobble, Faringdon, England; these are excellent examples of fossil bioerosion.



Cretaceous hardground from Texas with encrusting oysters and borings. The scale bar is 10 mm.



Rudist bivalves from the Cretaceous of the Omani Mountains, United Arab Emirates. Scale bar is 10 mm.



Inoceramus from the Cretaceous of South Dakota.

Coccolithophorids and molluscs, including ammonites, rudists, freshwater snails and mussels, as well as organisms whose food chain included these shell builders, became extinct or suffered heavy losses. For example, it is thought that ammonites were the principal food of mosasaurs, a group of giant marine reptiles that became extinct at the boundary.

Omnivores, insectivores and carrion-eaters survived the extinction event, perhaps because of the increased availability of their food sources. At the end of the Cretaceous there seem to have been no purely herbivorous or carnivorous mammals. Mammals and birds which survived the extinction fed on insects, larvae, worms, and snails, which in turn fed on dead plant and animal matter. Scientists theorise that these organisms survived the collapse of plant-based food chains because they fed on detritus.

In stream communities, few groups of animals became extinct. Stream communities rely less on food from living plants and more on detritus that washes in from land. This particular ecological niche buffered them from extinction. Similar, but more complex patterns have been found in the oceans. Extinction was more severe among animals living in the water column, than among animals living on or in the sea floor. Animals in the water column are almost entirely dependent on primary production from living phytoplankton, while animals living on or in the ocean floor feed on detritus or can switch to detritus feeding.

The largest air-breathing survivors of the event, crocodilians and champsosaurs, were semi-aquatic and had access to detritus. Modern crocodilians can live as scavengers and can survive for months without food, and their young are small, grow slowly, and feed largely on invertebrates and dead organisms or fragments of organisms for their first few years. These characteristics have been linked to crocodilian survival at the end of the Cretaceous.

Chapter- 16

Cretaceous–Tertiary Extinction Event

Artist's rendering of bolide impact

Badlands near Drumheller, Alberta, where erosion has exposed the K–T boundary

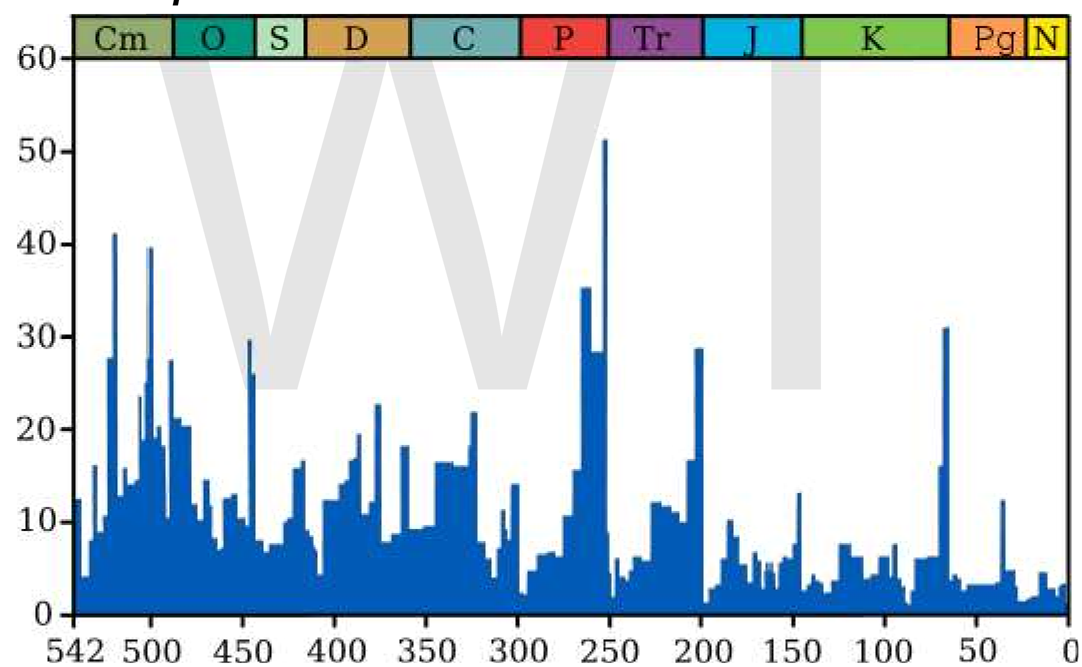
A Wyoming (US) rock with an intermediate claystone layer that contains 1000 times more iridium than the upper and lower layers. Picture taken at the San Diego Natural History Museum

The **Cretaceous–Tertiary extinction event**, which occurred approximately 65.5 million years ago (Ma), was a large-scale mass extinction of animal and plant species in a geologically short period of time. Widely known as the **K–T extinction event**, it is associated with a geological signature known as the K–T boundary, usually a thin band of sedimentation found in various parts of the world. *K* is the traditional abbreviation for the Cretaceous Period derived from the German name *Kreidezeit*, and *T* is the abbreviation for the Tertiary Period (a historical term for the period of time now covered by the Paleogene and Neogene periods). The event marks the end of the Mesozoic Era and the beginning of the Cenozoic Era. With "Tertiary" being discouraged as a formal time or rock unit by the International Commission on Stratigraphy, the K–T event is now called the **Cretaceous–Paleogene** (or **K–Pg**) **extinction event** by many researchers.

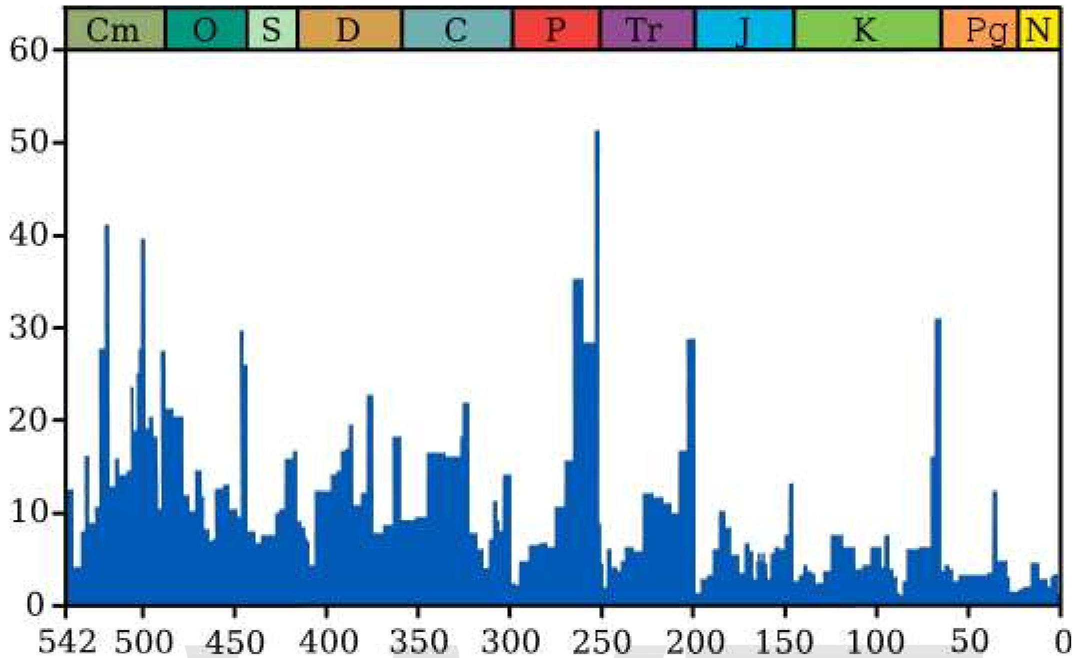
Non-avian dinosaur fossils are found only below the K–T boundary, indicating that non-avian dinosaurs became extinct immediately before, or during the event. A very small number of dinosaur fossils have been found above the K–T boundary, but they have been explained as *reworked*, that is, fossils that have been eroded from their original locations then preserved in later sedimentary layers. Mosasaurs, plesiosaurs, pterosaurs and many species of plants and invertebrates also became extinct. Mammalian and bird clades passed through the boundary with few extinctions, and evolutionary radiation from those Maastrichtian clades occurred well past the boundary. Rates of extinction and radiation varied across different clades of organisms.

Scientists theorize that the K–T extinctions were caused by one or more catastrophic events, such as massive asteroid impacts (like the Chicxulub impact), or increased volcanic activity. Several impact craters and massive volcanic activity, such as that in the Deccan traps, have been dated to the approximate time of the extinction event. These geological events may have reduced sunlight and hindered photosynthesis, leading to a massive disruption in Earth's ecology. Other researchers believe the extinction was more gradual, resulting from slower changes in sea level or climate. On March 4, 2010, a panel of 41 scientists agreed that the Chicxulub asteroid impact triggered the mass extinction.

Extinction patterns



K–T
Tr–J
P–Tr
Late D
O–S
Millions of years ago



Marine extinction intensity through time. The blue graph shows the apparent *percentage* (not the absolute number) of marine animal genera becoming extinct during any given time interval. It does not represent all marine species, just those that are readily fossilized.

Even though the boundary event was severe, there was significant variability in the rate of extinction between and within different clades. Species that depended on photosynthesis declined or became extinct as atmospheric particles blocked sunlight and reduced the solar energy reaching the Earth's surface. This plant extinction caused a major reshuffling of the dominant plant groups. Photosynthesizing organisms, including phytoplankton and land plants, formed the foundation of the food chain in the late Cretaceous as they do today. Evidence suggests that herbivorous animals died out when the plants on which they depended for food became scarce. Consequently, top predators such as *Tyrannosaurus rex* also perished.

Coccolithophorids and molluscs (including ammonites, rudists, freshwater snails and mussels, and those organisms whose food chain included these shell builders) became extinct or suffered heavy losses. For example, it is thought that ammonites were the principal food of mosasaurs, a group of giant marine reptiles that became extinct at the boundary.

Omnivores, insectivores and carrion-eaters survived the extinction event, perhaps because of the increased availability of their food sources. At the end of the Cretaceous there seem to have been no purely herbivorous or carnivorous mammals. Mammals and birds that survived the extinction fed on insects, worms, and snails, which in turn fed on dead plant and animal matter. Scientists hypothesize that these organisms survived the collapse of plant-based food chains because they fed on detritus (non-living organic material).

In stream communities few animal groups became extinct because stream communities rely less directly on food from living plants and more on detritus that washes in from land, buffering them from extinction. Similar, but more complex patterns have been found in the oceans. Extinction was more severe among animals living in the water column than among animals living on or in the sea floor. Animals in the water column are almost entirely dependent on primary production from living phytoplankton while animals living on or in the ocean floor feed on detritus or can switch to detritus feeding.

The largest air-breathing survivors of the event, crocodyliforms and champsosaurs, were semi-aquatic and had access to detritus. Modern crocodilians can live as scavengers and can survive for months without food, and their young are small, grow slowly, and feed largely on invertebrates and dead organisms or fragments of organisms for their first few years. These characteristics have been linked to crocodilian survival at the end of the Cretaceous.

After the K–T event, biodiversity required substantial time to recover, despite the existence of abundant vacant ecological niches.

Microbiota

The K–T boundary represents one of the most dramatic turnovers in the fossil record for various calcareous nanoplankton that formed the calcium deposits that gave the Cretaceous its name. The turnover in this group is clearly marked at the species level. Statistical analysis of marine losses at this time suggests that the decrease in diversity was caused more by a sharp increase in extinctions than by a decrease in speciation. The K–T boundary record of dinoflagellates is not as well-understood, mainly because only microbial cysts provide a fossil record, and not all dinoflagellate species have cyst-forming stages, thereby likely causing diversity to be underestimated. Recent studies indicate that there were no major shifts in dinoflagellates through the boundary layer.

Radiolaria have left a geological record since at least the Ordovician times, and their mineral fossil skeletons can be tracked across the K–T boundary. There is no evidence of mass extinction of these organisms, and there is support for high productivity of these species in Southern high latitudes as a result of cooling temperatures in the early Paleocene. Approximately 46% of diatom species survived the transition from the Cretaceous to the Upper Paleocene. This suggests a significant turnover in species, but not a catastrophic extinction of diatoms, across the K–T boundary.

The occurrence of planktonic foraminifera across the K–T boundary has been studied since the 1930s. Research spurred by the possibility of an impact event at the K–T boundary resulted in numerous publications detailing planktonic foraminiferal extinction at the boundary. However, there is debate ongoing between groups that believe the evidence indicates substantial extinction of these species at the K–T boundary, and those who believe the evidence supports multiple extinctions and expansions through the boundary.

Numerous species of benthic foraminifera became extinct during the K–T event, presumably because they depend on organic debris for nutrients, since the biomass in the ocean is thought to have decreased. However, as the marine microbiota recovered, it is thought that increased speciation of benthic foraminifera resulted from the increase in food sources. Phytoplankton recovery in the early Paleocene provided the food source to support large benthic foraminiferal assemblages, which are mainly detritus-feeding. Ultimate recovery of the benthic populations occurred over several stages lasting several hundred thousand years into the early Paleocene.

Marine invertebrates

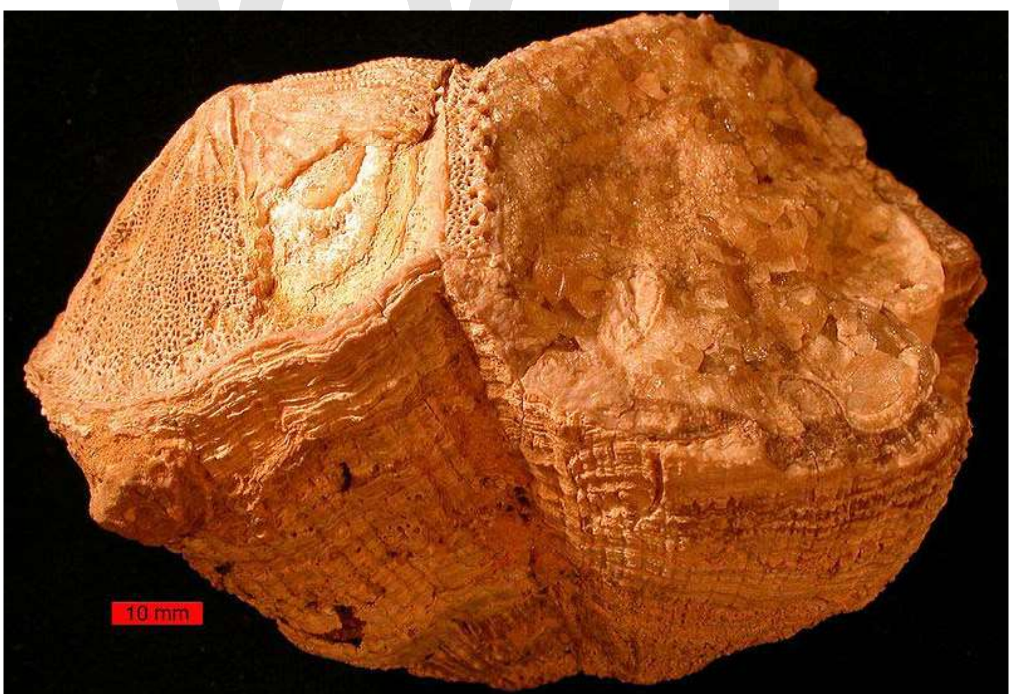
An ammonite fossil

There is variability in the fossil record as to the extinction rate of marine invertebrates across the K–T boundary. The apparent rate is influenced by the lack of fossil records rather than actual extinction.

Ostracodes, a class of small crustaceans that were prevalent in the upper Maastrichtian, left fossil deposits in a variety of locations. A review of these fossils shows that ostracode diversity was lower in the Paleocene than any other time in the Tertiary. However, current research cannot ascertain whether the extinctions occurred prior to or during the boundary interval itself.

Approximately 60% of late-Cretaceous Scleractinia coral genera failed to cross the K–T boundary into the Paleocene. Further analysis of the coral extinctions shows that approximately 98% of colonial species, ones that inhabit warm, shallow tropical waters, became extinct. The solitary corals, which generally do not form reefs and inhabit colder and deeper (below the photic zone) areas of the ocean were less impacted by the K–T boundary. Colonial coral species rely upon symbiosis with photosynthetic algae, which collapsed due to the events surrounding the K–T boundary. However, the use of data from coral fossils to support K–T extinction and subsequent Paleocene recovery must be weighed against the changes that occurred in coral ecosystems through the K–T boundary.

The numbers of cephalopod, echinoderm, and bivalve genera exhibited significant diminution after the K–T boundary. Most species of brachiopods, a small phylum of marine invertebrates, survived the K–T event and diversified during the early Paleocene.



Rudist bivalves from the Late Cretaceous of the Omani Mountains, United Arab Emirates. Scale bar is 10 mm.

Except for nautiloids (represented by the modern order Nautilida) and coleoids (which had already diverged into modern octopodes, squids, and cuttlefish) all other species of the molluscan class Cephalopoda became extinct at the K–T boundary. These included the ecologically significant belemnoids, as well as the ammonoids, a group of highly diverse, numerous, and widely distributed shelled cephalopods. Researchers have pointed out that the reproductive strategy of the surviving nautiloids, which rely upon few and larger eggs, played a role in outsurviving their ammonoid counterparts through the extinction event. The ammonoids utilized a planktonic strategy of reproduction (numerous eggs and planktonic larvae), which would have been devastated by the K–T boundary event. Additional research has shown that subsequent to this elimination of ammonoids from the global biota, nautiloids began an evolutionary radiation into shell shapes and complexities theretofore known only from ammonoids.

Approximately 35% of echinoderm genera became extinct at the K–T boundary, although taxa that thrived in low-latitude, shallow-water environments during late Cretaceous had the highest extinction rate. Mid-latitude, deep-water echinoderms were much less affected at the K–T boundary. The pattern of extinction points to habitat loss, specifically the drowning of carbonate platforms, the shallow-water reefs in existence at that time, by the extinction event.

Other invertebrate groups, including rudists (reef-building clams) and inoceramids (giant relatives of modern scallops), also became extinct at the K–T boundary.

Fish

There are substantial fossil records of jawed fishes across the K–T boundary, which provides good evidence of extinction patterns of these classes of marine vertebrates. Within cartilaginous fish, approximately 80% of the sharks, rays, and skates families survived the extinction event, and more than 90% of teleost fish (bony fish) families survived. There is evidence of a mass kill of bony fishes at a fossil site immediately above the K–T boundary layer on Seymour Island near Antarctica, apparently precipitated by the K–T boundary event. However, the marine and freshwater environments of fishes mitigated environmental effects of the extinction event.

Terrestrial invertebrates

Insect damage to the fossilized leaves of flowering plants from fourteen sites in North America were used as a proxy for insect diversity across the K–T boundary and analyzed to determine the rate of extinction. Researchers found that Cretaceous sites, prior to the extinction event, had rich plant and insect-feeding diversity. However, during the early Paleocene, flora were relatively diverse with little predation from insects, even 1.7 million years after the extinction event.

Terrestrial plants

There is overwhelming evidence of global disruption of plant communities at the K–T boundary. However, there were important regional differences in plant succession. In North America, the data suggest massive devastation and mass extinction of plants at the K–T boundary sections, although there were substantial megafloral changes before the boundary.

In high southern hemisphere latitudes, such as New Zealand and Antarctica the mass die-off of flora caused no significant turnover in species, but dramatic and short-term changes in the relative abundance of plant groups. In North America, approximately 57% of plant species became extinct. The Paleocene recovery of plants began with recolonizations by fern species, represented as a fern spike in the geologic record; this same type of fern recolonization was observed after the 1980 Mount St. Helens eruption.

Due to the wholesale destruction of plants at the K–T boundary there was a proliferation of saprotrophic organisms such as fungi that do not require photosynthesis and use nutrients from decaying vegetation. The dominance of fungal species lasted only a few years while the atmosphere cleared and there was plenty of organic matter to feed on. Once the atmosphere cleared, photosynthetic organisms like ferns and other plants returned. Polyploidy appears to have enhanced the ability of flowering plants to survive the extinction, probably because the additional copies of the genome such plants possessed allowed them to more readily adapt to the rapidly changing environmental conditions which followed the impact.

Amphibians

There is no evidence of K–T boundary mass extinctions of amphibians, and there is strong evidence that most amphibians survived the event relatively unscathed. Several in-depth studies of salamander genera in fossil beds in Montana show that six of seven genera were unchanged after the event.

Frog species appear to have survived into the Paleocene with few species becoming extinct. However, the fossil record for frog families and genera is uneven. An extensive survey of three genera of frogs in Montana show that they were unaffected by the K–T event and survived apparently unchanged. The data show little or no evidence for extinction of amphibian families that bracket the K–T event. Amphibian survival resulted from the clade's ability to seek shelter in water or to build burrows in sediments, soil, wood, or beneath rocks.

Non-archosaur reptiles

The two living non-archosaurian reptile taxa, testudines (turtles) and lepidosaurs (snakes, lizards, and worm lizards), along with choristoderes (semi-aquatic archosauromorphs which died out in the early Miocene), survived through the K–T boundary. Over 80% of Cretaceous turtle species passed through the K–T boundary. Additionally, all six turtle families in existence at the end of the Cretaceous survived into the Tertiary and are represented by current species.

Living lepidosaurs include Rhynchocephalia (tuataras) and Squamata. The Rhynchocephalia were a widespread and relatively successful group of lepidosaurs in the early Mesozoic, but began to decline by the mid-Cretaceous. They are represented today by a single genus located exclusively in New Zealand.

The order Squamata, which is represented today by lizards, snakes, and amphisbaenia, radiated into various ecological niches during the Jurassic and were successful throughout the Cretaceous. They survived through the K–T boundary and are currently the most successful and diverse group of living reptiles with more than 6,000 extant species. No known family of terrestrial squamates became extinct at the boundary, and fossil evidence indicates they did not suffer any significant decline in numbers. Their small size, adaptable metabolism, and ability to move to more favorable habitats were key factors in their survivability during the late Cretaceous and early Paleocene.

Non-archosaurian marine reptiles including mosasaurs and plesiosaurs, giant aquatic reptiles that were the top marine predators, became extinct by the end of the Cretaceous.

Archosaurs

The archosaur clade includes two living orders, crocodilians (of which Alligatoridae, Crocodylidae and Gavialidae are the only surviving families) and dinosaurs (of which birds are the sole surviving members), along with the extinct non-avian dinosaurs and pterosaurs.

Crocodyliforms

Ten families of crocodilians or their close relatives are represented in the Maastrichtian fossil records, of which five died out prior to the K–T boundary. Five families have both Maastrichtian and Paleocene fossil representatives. All of the surviving families of crocodyliforms inhabited freshwater and terrestrial environments, except for the Dyrosauridae which lived in freshwater and marine locations. Approximately 50% of crocodyliform representatives survived across the K–T boundary, the only apparent trend being that no large crocodiles survived. Crocodyliform survivability across the boundary may have resulted from their aquatic niche and ability to burrow, which reduced susceptibility to negative environmental effects at the boundary. Jouve and colleagues suggested in 2008 that juvenile marine crocodyliforms lived in freshwater environments like modern marine crocodile juveniles, which would have helped them survive where other marine reptiles became extinct; freshwater environments were not as strongly affected by the K–T event as marine environments.

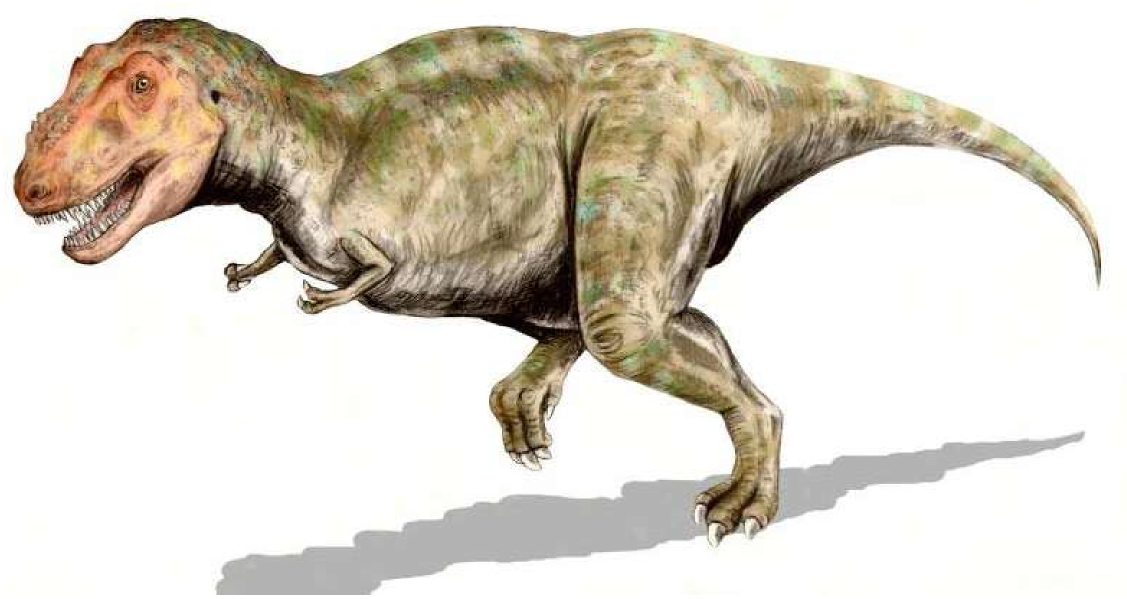
Pterosaurs

Only one family of pterosaurs, Azhdarchidae, was definitely present in the Maastrichtian, and it became extinct at the K–T boundary. These large pterosaurs were the last representatives of a declining group that contained 10 families during the mid-Cretaceous. Smaller pterosaurs became extinct prior to the Maastrichtian during a period that saw a decline in smaller animal species while larger species became more prevalent. While this was occurring, modern birds were undergoing diversification and replacing archaic birds and pterosaur groups, possibly due to direct competition, or they simply filled empty niches.

Avian dinosaurs (birds)

Most paleontologists regard birds as the only surviving dinosaurs. However, all non-neornithean birds became extinct, including flourishing groups like enantiornithines and hesperornithiforms. Several analyses of bird fossils show divergence of species prior to the K–T boundary, and that duck, chicken and ratite bird relatives coexisted with non-avian dinosaurs. Neornithine birds survived the K–T boundary as a result of their abilities to dive, swim, or seek shelter in water and marshlands. Many species of birds can build burrows, or nest in tree holes or termite nests, all of which provided shelter from the environmental effects at the K–T boundary. Long-term survival past the boundary was assured as a result of filling ecological niches left empty by extinction of non-avian dinosaurs.

Non-avian dinosaurs



Tyrannosaurus was one of the last dinosaurs to thrive on Earth before the extinction

Excluding a few controversial claims, scientists agree that all non-avian dinosaurs became extinct at the K–T boundary. The dinosaur fossil record has been interpreted to show both a decline in diversity and no decline in diversity during the last few million years of the Cretaceous, and it may be that the quality of the dinosaur fossil record is simply not good enough to permit researchers to distinguish between the options. Since there is no evidence that late Maastrichtian nonavian dinosaurs could burrow, swim or dive, they were unable to shelter themselves from the worst parts of any environmental stress that occurred at the K–T boundary. It is possible that small dinosaurs (other than birds) did survive, but they would have been deprived of food as both herbivorous dinosaurs would have found plant material scarce, and carnivores would have quickly found prey to be in short supply. The growing consensus about the endothermy of dinosaurs helps to understand their full extinction in contrast with their close relatives, the crocodilians. Ectothermic ("cold-blooded") crocodiles have very limited needs for food (they can survive several months without eating) while endothermic ("warm-blooded") animals of similar size need much more food in order to sustain their faster metabolism. Thus, under the circumstances of food chain disruption previously mentioned, non-avian dinosaurs died while some crocodiles survived. In this context, the survival of other endothermic animals, such as some birds and mammals, could be due, among other reasons, to their smaller needs for food, related to their small size at the extinction epoch.

Whether the extinction occurred gradually or very suddenly is debatable, as both views have support in the fossil record. A study of 29 fossil sites in Catalan Pyrenees of Europe in 2010 support that dinosaurs there had great diversity until the proposed asteroid impact. Others have interpreted the fossil bearing rocks along Red Deer River in Alberta, Canada, as supporting a gradual extinction of non-avian dinosaurs; during the last 10 million years of the Cretaceous layers there, the number of dinosaur species seems to have decreased from about 45 to about 12. Other scientists have pointed out the same.

Several researchers have argued for Paleocene dinosaurs. These arguments are based on the discovery of dinosaur remains in the Hell Creek Formation up to 1.3 metres (4 ft 3 in) above and 40,000 years later than the K–T boundary. Pollen samples recovered near a fossilized hadrosaur femur recovered in the Ojo Alamo Sandstone at the San Juan River indicate that the animal lived during the Tertiary, approximately 64.5 Ma (about 1 million years after the K–T event). If their existence past the K–T boundary can be confirmed, these hadrosaurids would be considered a Dead Clade Walking. Current research indicates that these fossils were eroded from their original locations and then re-buried in much later sediments (reworked).

Hell Creek formation

Mammals

All major Cretaceous mammalian lineages, including monotremes (egg-laying mammals), multituberculates, marsupials and placentals, dryolestoideans, and gondwanatheres survived the K–T event, although they suffered losses. In particular, marsupials largely disappeared from North America, and the Asian deltatheroidans, primitive relatives of extant marsupials, became extinct. In the Hell Creek beds of North America, at least half of the ten known multituberculate species and all eleven marsupial species are not found above the boundary.

Mammalian species began diversifying approximately 30 million years prior to the K–T boundary. Diversification of mammals stalled across the boundary. Current research indicates that mammals did not explosively diversify across the K–T boundary, despite the environment niches made available by the extinction of dinosaurs. Several mammalian orders have been interpreted as diversifying immediately after the K–T boundary, including Chiroptera (bats) and Cetartiodactyla (a diverse group that today includes whales and dolphins and even-toed ungulates), although recent research concludes that only marsupial orders diversified after the K–T boundary.

K–T boundary mammalian species were generally small, comparable in size to rats; this small size would have helped them to find shelter in protected environments. In addition, it is postulated that some early monotremes, marsupials, and placentals were semiaquatic or burrowing, as there are multiple mammalian lineages with such habits today. Any burrowing or semiaquatic mammal would have had additional protection from K–T boundary environmental stresses.

Evidence

North American fossils

In North American terrestrial sequences, the extinction event is best represented by the marked discrepancy between the rich and relatively abundant late-Maastrichtian palynomorph record and the post-boundary fern spike.

At present the most informative sequence of dinosaur-bearing rocks in the world from the K–T boundary is found in western North America, particularly the late Maastrichtian-age Hell Creek Formation of Montana, US. This formation, when compared with the older (approximately 75 Ma) Judith River/Dinosaur Park Formations (from Montana and Alberta, Canada, respectively) provides information on the changes in dinosaur populations over the last 10 million years of the Cretaceous. These fossil beds are geographically limited, covering only part of one continent.

The middle–late Campanian formations show a greater diversity of dinosaurs than any other single group of rocks. The late Maastrichtian rocks contain the largest members of several major clades: *Tyrannosaurus*, *Ankylosaurus*, *Pachycephalosaurus*, *Triceratops* and *Torosaurus*, which suggests food was plentiful immediately prior to the extinction.

In addition to rich dinosaur fossils, there are also plant fossils that illustrate the reduction in plant species across the K–T boundary. In the sediments below the K–T boundary the dominant plant remains are angiosperm pollen grains, but the actual boundary layer contains little pollen and is dominated by fern spores. Normal pollen levels gradually resume above the boundary layer. This is reminiscent of areas blighted by modern volcanic eruptions, where the recovery is led by ferns which are later replaced by larger angiosperm plants.

Marine fossils

The mass extinction of marine plankton appears to have been abrupt and right at the K–T boundary.- Ammonite genera became extinct at or near the K–T boundary; however, there was a smaller and slower extinction of ammonite genera prior to the boundary that was associated with a late Cretaceous marine regression. The gradual extinction of most inoceramid bivalves began well before the K–T boundary, and a small, gradual reduction in ammonite diversity occurred throughout the very late Cretaceous. Further analysis shows that several processes were in progress in the late Cretaceous seas and partially overlapped in time, then ended with the abrupt mass extinction.

Duration

The length of time taken for the extinction to occur is a controversial issue, because some theories about the extinction's causes require a rapid extinction over a relatively short period (from a few years to a few thousand years) while others require longer periods. The issue is difficult to resolve because of the Signor-Lipps effect; that is, the fossil record is so incomplete that most extinct species probably died out long after the most recent fossil that has been found. Scientists have also found very few continuous beds of fossil-bearing rock which cover a time range from several million years before the K–T extinction to a few million years after it.

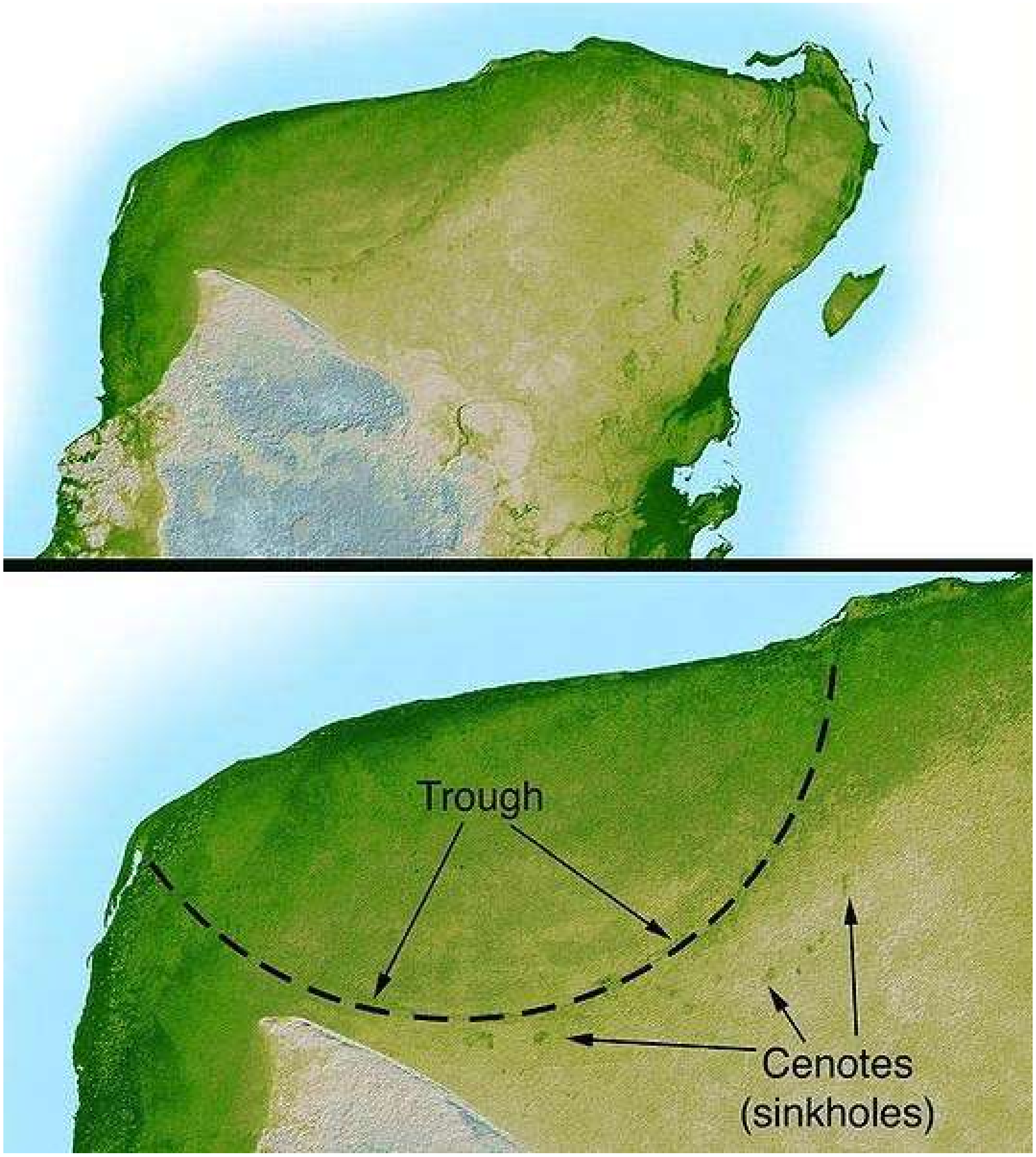
Causes of extinctions

There have been several theories on the cause of the K–T boundary which led to the massive extinction. These theories have centered on either impact events or increased volcanism; some include elements of both.

Impact event

The K–T boundary exposure in Trinidad Lake State Park, in the Raton Basin of Colorado, shows an abrupt change from dark- to light-colored rock.


White line added to mark the transition.



Radar topography reveals the 180 km (112 mi) wide ring of the Chicxulub Crater.

In 1980, a team of researchers consisting of Nobel prize-winning physicist Luis Alvarez, his son geologist Walter Alvarez, and chemists Frank Asaro and Helen Michel discovered that sedimentary layers found all over the world at the Cretaceous–Tertiary boundary contain a concentration of iridium many times greater than normal (30 times and 130 times background in the two sections originally studied). Iridium is extremely rare in the earth's crust because it is a siderophile, and therefore most of it travelled with the iron as it sank into the earth's core during planetary differentiation. As iridium remains abundant in most asteroids and comets, the Alvarez team suggested that an asteroid struck the earth at the time of the K–T boundary. There were other earlier speculations on the possibility of an impact event, but this was the first evidence uncovered.

Such an impact would have inhibited photosynthesis by generating a dust cloud, which would block sunlight for a year or less, and by injecting sulfuric acid aerosols into the stratosphere, which would reduce sunlight reaching the Earth's surface by 10–20%. It would take at least ten years for those aerosols to dissipate, which would account for the extinction of plants and phytoplankton, and of organisms dependent on them (including predatory animals as well as herbivores). Small creatures whose food chains were based on detritus would have a reasonable chance of survival. The consequences of reentry of ejecta into Earth's atmosphere would include a brief (hours long) but intense pulse of infrared radiation, killing exposed organisms. Global firestorms may have resulted from the heat pulse and the fall back to Earth of incendiary fragments from the blast. High O_2 levels during the late Cretaceous would have supported intense combustion. The level of atmospheric O_2 plummeted in the early Tertiary Period. If widespread fires occurred, they would have increased the CO_2 content of the atmosphere and caused a temporary greenhouse effect once the dust cloud settled, and this would have exterminated the most vulnerable organisms that survived the period immediately after the impact.

The impact may also have produced acid rain, depending on what type of rock the asteroid struck. However, recent research suggests this effect was relatively minor, lasting for approximately 12 years. The acidity was neutralized by the environment, and the survival of animals vulnerable to acid rain effects (such as frogs) indicate this was not a major contributor to extinction. Impact theories can only explain very rapid extinctions, since the dust clouds and possible sulfuric aerosols would wash out of the atmosphere in a fairly short time—possibly under ten years.

Subsequent research identified the Chicxulub Crater buried under Chicxulub on the coast of Yucatán, Mexico as the impact crater which matched the Alvarez hypothesis dating. Identified in 1990 based on the work of Glen Penfield done in 1978, this crater is oval, with an average diameter of about 180 kilometers (112 mi), about the size calculated by the Alvarez team. The shape and location of the crater indicate further causes of devastation in addition to the dust cloud. The asteroid landed in the ocean and would have caused megatsunamis, for which evidence has been found in several locations in the Caribbean and eastern United States—marine sand in locations which were then inland, and vegetation debris and terrestrial rocks in marine sediments dated to the time of the impact. The asteroid landed in a bed of gypsum (calcium sulfate), which would have produced a vast sulfur dioxide aerosol. This would have further reduced the sunlight reaching the Earth's surface and then precipitated as acid rain, killing vegetation, plankton and organisms which build shells from calcium carbonate (coccolithophores and molluscs). In February 2008, a team of researchers used seismic images of the crater to determine that the impactor landed in deeper water than was previously assumed. They argued that this would have resulted in increased sulfate aerosols in the atmosphere, which could have made the impact deadlier by altering climate and by generating acid rain.

Most paleontologists now agree that an asteroid did hit the Earth about 65 Ma ago, but there is an ongoing dispute whether the impact was the sole cause of the extinctions. There is evidence that there was an interval of about 300 ka from the impact to the mass extinction. In 1997, paleontologist Sankar Chatterjee drew attention to the proposed and much larger 600 km (373 mi) Shiva crater and the possibility of a multiple-impact scenario.

In 2007, a hypothesis was put forth that argued the impactor that killed the dinosaurs 65 Ma ago belonged to the Baptistina family of asteroids. Concerns have been raised regarding the reputed link, in part because very few solid observational constraints exist of the asteroid or family. Indeed, it was recently discovered that 298 Baptistina does not share the same chemical signature as the source of the K–T impact. Although this finding may make the link between the Baptistina family and K–T impactor more difficult to substantiate, it does not preclude the possibility.

In March 2010 an international panel of scientists endorsed the asteroid hypothesis, specifically the Chicxulub impact, as being the cause of the extinction. A team of 41 scientists reviewed 20 years of scientific literature and in so doing also ruled out other theories such as massive volcanism. They had determined that a 10–15 km (6–9 mi) space rock hurtled into earth at Chicxulub on Mexico's Yucatan Peninsula. The collision would have released the same energy as 100,000 gigatonnes of TNT or 420,000 EJ or over a billion times the energy of the bombs dropped on Nagasaki and Hiroshima.

Deccan Traps

Before 2000, arguments that the Deccan Traps flood basalts caused the extinction were usually linked to the view that the extinction was gradual, as the flood basalt events were thought to have started around 68 Ma and lasted for over 2 million years. The most recent evidence shows that the traps erupted over 800,000 years spanning the K–T boundary, and therefore may be responsible for the extinction and the delayed biotic recovery thereafter.

The Deccan Traps could have caused extinction through several mechanisms, including the release of dust and sulfuric aerosols into the air which might have blocked sunlight and thereby reduced photosynthesis in plants. In addition, Deccan Trap volcanism might have resulted in carbon dioxide emissions which would have increased the greenhouse effect when the dust and aerosols cleared from the atmosphere.

In the years when the Deccan Traps hypothesis was linked to a slower extinction, Luis Alvarez (who died in 1988) replied that paleontologists were being misled by sparse data. While his assertion was not initially well-received, later intensive field studies of fossil beds lent weight to his claim. Eventually, most paleontologists began to accept the idea that the mass extinctions at the end of the Cretaceous were largely or at least partly due to a massive Earth impact. However, even Walter Alvarez has acknowledged that there were other major changes on Earth even before the impact, such as a drop in sea level and massive volcanic eruptions that produced the Indian Deccan Traps, and these may have contributed to the extinctions.

Multiple impact event

Several other craters also appear to have been formed about the time of the K–T boundary. This suggests the possibility of near simultaneous multiple impacts, perhaps from a fragmented asteroidal object, similar to the Shoemaker-Levy 9 cometary impact with Jupiter. In addition to the 180-km (112 mi) Chicxulub Crater, there is the 24-km (15 mi) Boltysh crater in Ukraine (65.17 ± 0.64 Ma), the 20-km (12 mi) Silverpit crater, a suspected impact crater in the North Sea (60–65 Ma), and the controversial and much bigger 600-km (370 mi) Shiva crater. Any other craters that might have formed in the Tethys Ocean would have been obscured by tectonic events like the relentless northward drift of Africa and India.

Maastrichtian sea-level regression

There is clear evidence that sea levels fell in the final stage of the Cretaceous by more than at any other time in the Mesozoic era. In some Maastrichtian stage rock layers from various parts of the world, the later ones are terrestrial; earlier ones represent shorelines and the earliest represent seabeds. These layers do not show the tilting and distortion associated with mountain building, therefore, the likeliest explanation is a "regression", that is, a drop in sea level. There is no direct evidence for the cause of the regression, but the explanation which is currently accepted as the most likely is that the mid-ocean ridges became less active and therefore sank under their own weight.

A severe regression would have greatly reduced the continental shelf area, which is the most species-rich part of the sea, and therefore could have been enough to cause a *marine* mass extinction. However research concludes that this change would have been insufficient to cause the observed level of ammonite extinction. The regression would also have caused climate changes, partly by disrupting winds and ocean currents and partly by reducing the Earth's albedo and therefore increasing global temperatures.

Marine regression also resulted in the loss of epeiric seas, such as the Western Interior Seaway of North America. The loss of these seas greatly altered habitats, removing coastal plains that ten million years before had been host to diverse communities such as are found in rocks of the Dinosaur Park Formation. Another consequence was an expansion of freshwater environments, since continental runoff now had longer distances to travel before reaching oceans. While this change was favorable to freshwater vertebrates, those that prefer marine environments, such as sharks, suffered.

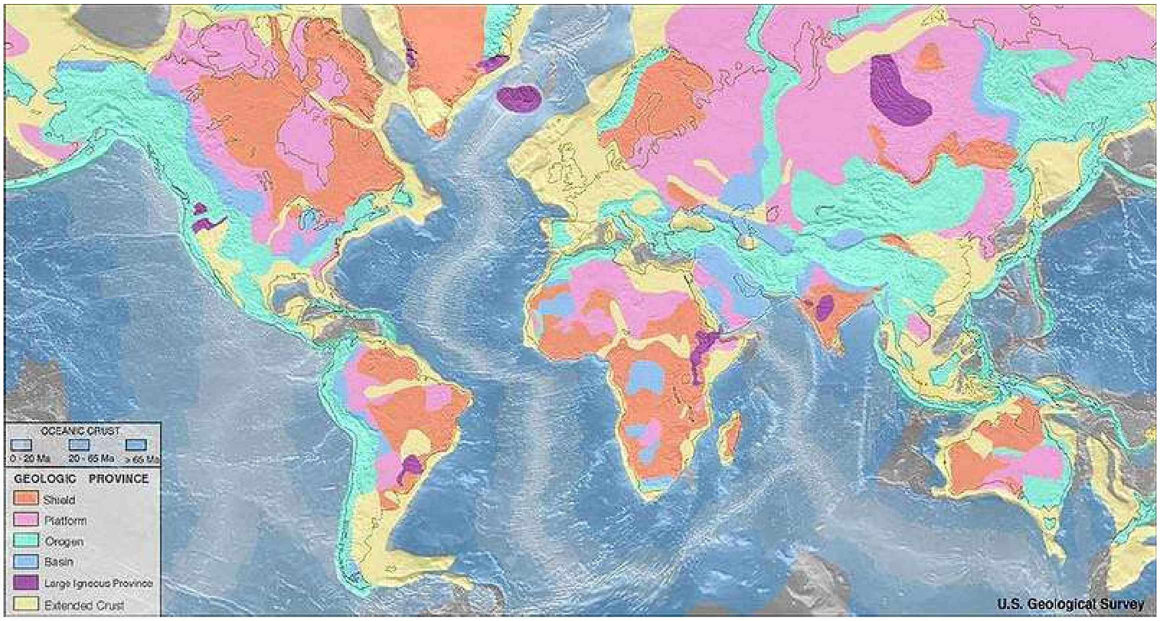
Multiple causes

In a review article, J. David Archibald and David E. Fastovsky discussed a scenario combining three major postulated causes: volcanism, marine regression, and extraterrestrial impact. In this scenario, terrestrial and marine communities were stressed by the changes in and loss of habitats. Dinosaurs, as the largest vertebrates, were the first to be affected by environmental changes, and their diversity declined. At the same time, particulate materials from volcanism cooled and dried areas of the globe. Then, an impact event occurred, causing collapses in photosynthesis-based food chains, both in the already-stressed terrestrial food chains and in the marine food chains. The major difference between this hypothesis and the single-cause hypotheses is that its proponents view the suggested single causes as either not sufficient in strength to cause the extinctions or not likely to produce the taxonomic pattern of the extinction.

Chapter- 17

Deccan Traps

The Deccan Traps as seen from Matheran, MH, India



The Deccan Traps shown as dark purple spot on the geographic map of India

Deccan Traps near Matheran, east of Mumbai

The Deccan Traps near Pune

The **Deccan Traps** are a large igneous province located on the Deccan Plateau of west-central India (between 17–24N, 73–74E) and one of the largest volcanic features on Earth. They consist of multiple layers of solidified flood basalt that together are more than 2,000 m (6,562 ft) thick and cover an area of 500,000 km^2 (193,051 sq mi) and a volume of 512,000 km^3 (123,000 cu mi). The term 'trap', used in geology for such rock formations, is derived from the Dutch word for stairs, referring to the step-like hills forming the landscape of the region.

History

The Deccan Traps formed between 60 and 68 million years ago, at the end of the Cretaceous period. The bulk of the volcanic eruption occurred at the Western Ghats (near Mumbai) some 66 million years ago. This series of eruptions may have lasted less than 30,000 years in total.

The original area covered by the lava flows is estimated to have been as large as 1.5 million km^2, approximately half the size of modern India. The Deccan Traps region was reduced to its current size by erosion and plate tectonics; the present area of directly observable lava flows is around 512,000 km^2 (197,684 sq mi).

Influence

The release of volcanic gases, particularly sulfur dioxide, during the formation of the traps contributed to contemporary climate change. Data point to an average fall in temperature of 2 °C in this period.

Due to the volcanic gases and subsequent temperature drop, the formation of the traps is seen as a major stressor on biodiversity at the time. This is confirmed by a mass extinction topping 17 families per million years (about 15 families per million years above the average). Sudden cooling due to sulfurous volcanic gases released by the formation of the traps and localised gas concentrations may have been enough to drive a less significant mass extinction, but the impact of the meteoroid that formed the Chicxulub Crater (which made a sunlight blocking dust cloud that killed much of the plants, called an impact winter) made this one of the most pronounced mass extinctions in the Phanerozoic.

Because of its magnitude, scientists formerly speculated that the gases released during the formation of the Deccan Traps played a role in the Cretaceous–Tertiary extinction event, which included the extinction of the non-avian dinosaurs. The current consensus among the scientific community is that the extinction was triggered by the Chicxulub impact event in Central America.

Chemical composition

Within the Deccan Traps at least 95% of the lavas are tholeiitic basalts, however other rock types occur:

- Alkali basalts
- Nephelinites
- Lamprophyre
- Carbonatites

Mantle xenoliths have been described from Kachchh (northwestern India) and elsewhere in the western Deccan.

Fossils

The Deccan Traps are famous for the beds of fossils that have been found between layers of traps lava. Particularly well known species include the frog *Oxyglossus pusillus* (Owen) of the Eocene of India and the toothed bufonid toad *Indobatrachus*, similar to Australian forms.

Theories of formation

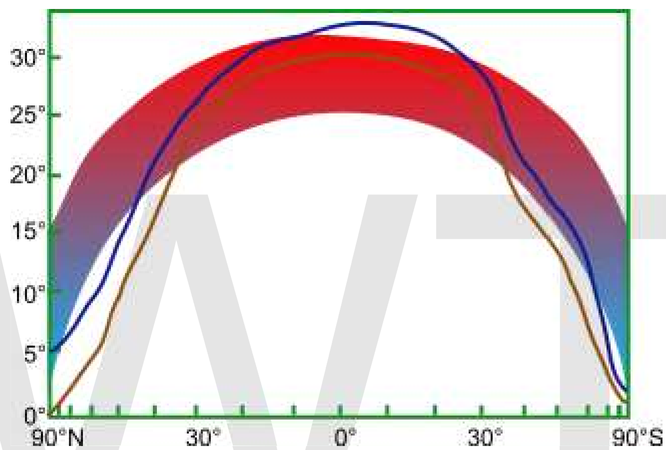
It is postulated that the Deccan Traps eruption was associated with a deep mantle plume. The area of long-term eruption (the hotspot), known as the Réunion hotspot, is suspected of both causing the Deccan Traps eruption and opening the rift that once separated the Seychelles plateau from India. Seafloor spreading at the boundary between the Indian and African Plates subsequently pushed India north over the plume, which now lies under Réunion island in the Indian Ocean, southwest of India. The mantle plume model has, however, been challenged.

Link to Shiva Crater

A large impact crater has been claimed to exist in the sea floor off the west coast of India. Called the Shiva crater, it has also been dated at sixty-five million years, right at the K–T boundary. The researchers suggest that the impact may have been the triggering event for the Deccan Traps as well as contributing to the acceleration of the Indian plate in the early Tertiary. However, opinion in the geologic community is not unanimous that this feature is actually an impact crater. Also, the reported age is in the middle of the ages given for the Deccan rocks.

Chapter- 18

Cool Tropics Paradox



The cool tropics paradox. The geological evidence appeared to constrain temperatures to the red/blue band, whereas models produced the brown line taking just continental configuration into account, and the blue line when they included increased atmospheric CO_2. Vertical axis: Temperature; horizontal:latitude.

The **cool tropics paradox** refers to an apparent difference between modelled estimates of tropical temperatures during warm, ice-free periods of the Cretaceous and Eocene, and the colder temperatures which proxies suggested were present. The long-standing paradox was resolved when it became clear that the proxies were misleading, meaning that tropics were warmer than previously believed.

Origin of the paradox

Proxy-based reconstructions of paleotemperature appeared to predict a low temperature gradient between the tropics and poles. Data from surface-dwelling foramanifera suggested that during the late Cretaceous, an unusually warm period, sea surface temperatures were cooler than today's. The term was later applied to similar situations, for example during the Eocene.

Climate models which worked during the Tertiary failed to produce this low temperature gradient; in order to match the observed data, they predicted that the tropics should be

40°C or more - much hotter than the proxies said they were. To attempt to match the data, bizarre models involving unreasonable eddies were required.

Models

Models were developed to predict and explain the lack of ice during the warm periods of the Cretaceous and Eocene. Models are developed according to the fundamental principle that they should be kept as simple as possible. Consequently, the first models attempted to explain the lack of ice using solely the different continental configuration. These could not produce an ice-free state without using an increased atmospheric concentration of CO_2; this assumption was checked against the evidence and found to be valid. This introduced a new difficulty: more CO_2 would produce warmer tropical sea temperatures, and the evidence suggested they were the same or even colder than today's.

Data supporting cool tropical oceans

Foramaniferal data, suggesting tropical temperatures cooler than today's, disagreed with terrestrial proxies, which spoke of warmer temperatures - although most of the terrestrial figures are based on extrapolation of data from outside the tropics.

Sources of error

Analytical error is around 2-3°C for individual specimens, but this drops to 0.5-1.0°C when a sample is analysed - not enough to explain the discrepancy. Other factors mean that any pristine sample can be considered to have an associated error of up to 3°C. Changes in salinity, kinetic and diagenesis, can also confound analysis: the latter two are each estimated to reduce estimated temperatures by 1-2°C, and are difficult to quantify.

Reconciling the data with the model

Taking the data to be true, how could they be reconciled with the predictions of the model? The only way the model could be "tweaked" was by fiddling with the parameterisation of clouds, one of the most unpredictable aspects of any model. The model was adjusted to assume that the higher CO_2 levels produced more tropical cloud, shielding these regions from the sun's heat. However, there was no evidence for this behaviour, and still left problems. The poles were still *warmer* than the models predicted. Further feedbacks, including increased poleward heat transport by the oceans, and vegetational responses at high latitudes, were proposed, but these didn't fully explain behaviour in the southern hemisphere, and winter, respectively.

Unravelling the paradox

Hints of warmth - terrestrial proxies

Data from terrestrial proxies suggested that the equator may have reached 30°C - however, this figure is based upon extrapolation of data found outside the tropics. This would imply that the foramaniferal proxies were wrong - the tests may perhaps have been overprinted by diagenesis. Researchers turned to shallow marine molluscs as it is easy to determine whether their shells had been altered by diagenesis.

Detecting diagenesis in molluscs

Many mollusc shells are constructed from aragonite, a mineral that is quickly replaced by calcite by diagenetic alteration. Also, near-shore molluscs preserve seasonal variability in their shells, a feature that would be lost in the presence of a diagenetic signal. This removes ambiguity about whether or not a shell has been affected by post-deposition processes.

Data from molluscs

Evidence from the molluscs suggested a cooling between the Eocene and Oligocene. Taken from the Mississippi embayment, they recorded temperatures of around 26°C in the Eocene, and 22°C in the Oligocene; this cooling was markedly seasonal, with reconstructed water temperatures being 5° cooler in the summer, but just 3° cooler in winter. This trend fits best if CO_2 was the dominant force for cooling.

The winter temperatures of molluscs match well with the foramaniferal temperatures, suggesting that foramanifera predominantly grew during the winter months. The overall temperatures corresponded well with terrestrial and modelled estimates of a sea surface temperature around 4-5° warmer than today's.

Reassessment of the foramaniferal record

The magnesium/calcium paleothermometer is a recently developed alternative to the $\delta^{18}O$ method, and avoids many of the uncertainties inherent in the latter method. Use of this technique generates results more consistent with those expected, in contrast to the original $\delta^{18}O$ records from the same sites. Further painstaking studies targeted solely those foramanifera which could be demonstrated not to have undergone any diagenesis in fact give a $\delta^{18}O$ signature similar to that expected, suggesting that poor preservation was responsible for the original confusion.

Chapter- 19

Cretaceous Geologic Formations

Cedar Mountain Formation

The **Cedar Mountain Formation** is the name given to distinctive sedimentary rocks in eastern Utah that occur between the underlying Morrison Formation and overlying Naturita Formation (sometimes incorrectly called the Dakota Formation). It is composed of non-marine sediments, that is, sediments deposited in rivers, lakes and on flood plains. Based on various fossils and radiometric dates, the Cedar Mountain Formation was deposited during the last half of the Early Cretaceous, about 127 - 98 million years ago (mya).

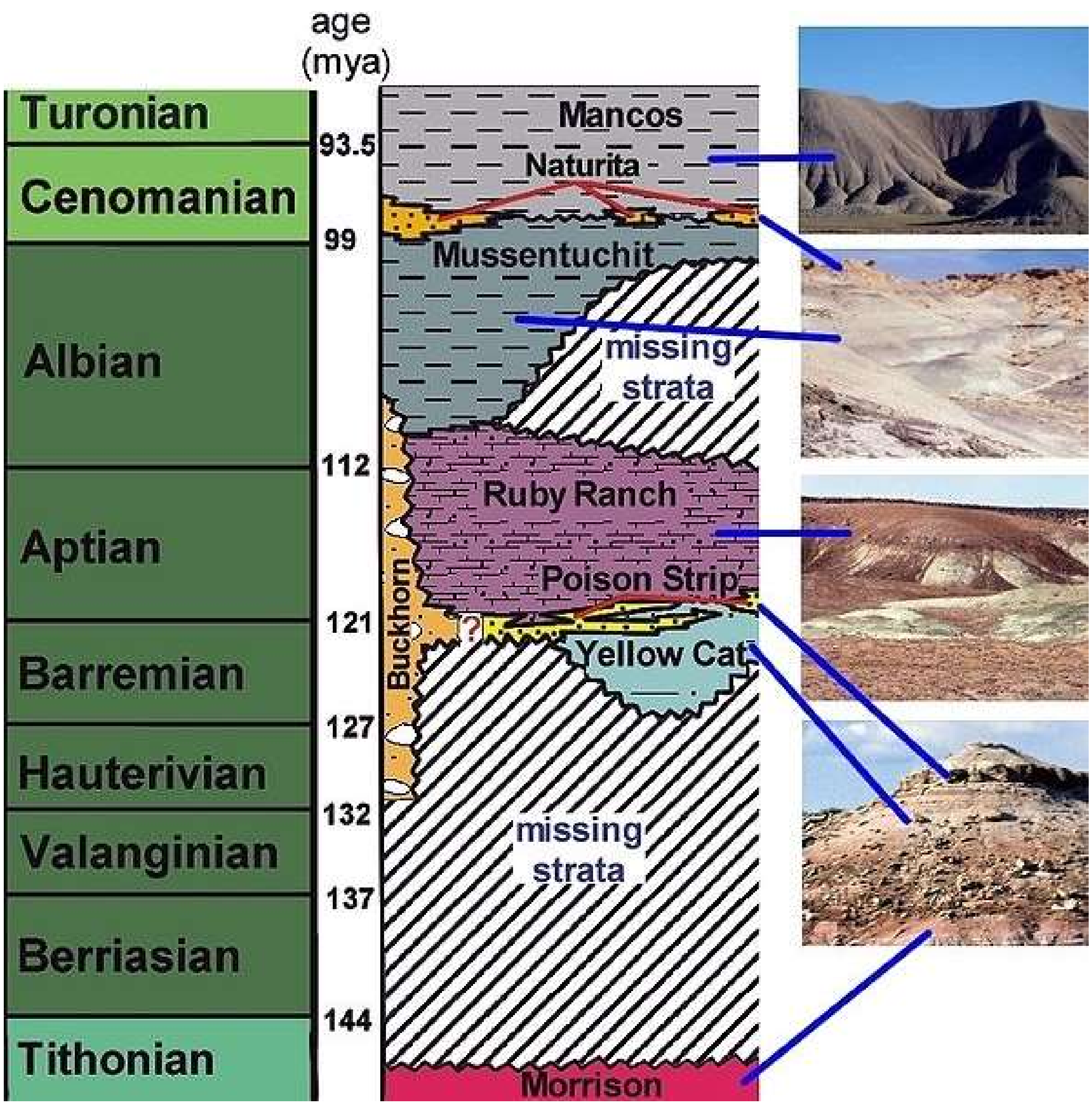
Dinosaurs occur throughout the formation, but their study has only occurred since the early 1990s. The dinosaurs in the lower part of the formation differ from those in the upper part. These two dinosaur assemblages, characterized by distinct dinosaurs, show the replacement of older, European-like dinosaurs with younger, Asian-like dinosaurs as the North American Continental Plate drifted westward. A middle dinosaur assemblage may be present, but the fossil record is not clear.

The formation was named for Cedar Mountain in northern Emery County, Utah, where William Lee Stokes first studied the exposures in 1944. Only recently did the 125 m (410 ft) thick formation get subdivided into smaller, distinctive beds called members. There is a debate as to whether there are five members or four depending whether the Buckhorn Conglomerate is considered to be at the top of the Morrison Formation or at the base of the Cedar Mountain Formation; most geologists and paleontologist consider it part of the Cedar Mountain Formation. In ascending order the remaining members are the Yellow Cat Member, Poison Strip Sandstone, Ruby Ranch Member, and the Mussentuchit Member. Each of these members are named after a geographic area where they were first studied.

The drab-colored lower portion of the Cedar Mountain Formation overlying the brighter Morrison Formation.

Stratigraphy

The Cedar Mountain Formation is sandwiched between the Morrison Formation below and the Naturita Formation and Mancos Shale above. The youngest date for Morrison just below the Cedar Mountain Formation is 148.1 ± 0.5 Ma . or lower Tithonian. Typically, the Jurassic-Cretaceous boundary in western North America is marked by an unconformity of variable length, and typically signifies 10-49 million years of missing geologic time. This boundary between the Morrison and Cedar Mountain is commonly marked by a horizon of carbonate nodules or by highly polished pebbles that are allegedly gastroliths.



Stratigraphic column showing the various members that make up the Cedar Mountain Formation and their approximate geologic age. Missing strata either were not deposited or were deposited, but later eroded

- The **Buckhorn Conglomerate** is considered the lowermost member of the Cedar Mountain Formation in the region of the San Raphael Swell by Stokes. It is named for exposures near Buckhorn Reservoir near Cedar Mountain. Its position immediately below the Ruby Ranch Member suggests that it may be equivalent to the channel sandstones in the Yellow Cat Member and the Poison Strip Sandstone farther to the east. This idea is strengthened by the similar composition of the gravels in these members, but a direct correlation has not yet been established.

- The **Yellow Cat Member** is named for exposures near the Yellow Cat mining area north of Arches National Park. It is limited to the eastern portions of the formation and is thickest near Arches National Monument. The member is composed of drab greyish mudstones and some lenses of sandstone. The mudstones were deposited on flood plains, and show evidence of ancient soil development called paleosols. The mudstones originated as flood deposits from river channels that are marked by the sandstone lenses. A recent radiometric date of 126 ± 2.5 Ma places Yellow Cat Member in the Barremian, which verifies previous estimates based on fossil evidence

- The **Poison Strip Sandstone** was named for prominent, cliff-forming sandstones in the Poison Strip uranium district north of Arches National Monument. It is actually a series of sandstones that were deposited in river channels, and lesser amounts of mudstones and limestones that were deposited on the flood plain and small ponds. Based on the position of the Poison Strip between the Yellow Cat and Ruby Ranch members, it probably was latest Barremian to earliest Aptian.

- The **Ruby Ranch Member** is the most widespread and distinctive member of the Cedar Mountain. It was named for exposures on the Ruby Ranch located southeast of Green River, Utah. The member is composed of maroon mudstones with irregular spheres of carbonate nodules. The nodules formed in ancient soils that developed in the mud deposited on the flood plain in a strongly seasonal, semiarid climate. Evaporation of groundwater during the dry season concentrated calcium carbonate and other minerals in the upper parts of the soil horizon. Radiometric dates place the upper portions of the Ruby Ranch in the late Aptian. Exhumed river channels in the Ruby Ranch indicate that stream flow during the Aptian was towards the northeast, the direction of the encrouching Western Interior Seaway.

- The **Mussentuchit Member** is the uppermost member of the Cedar Mountain Formation. It was named for exposures along Mussentuchit Wash southwest of the San Rafael Swell. It is predominantly composed of grey mudstones high in organic carbon from fossil plant material, as well as volcanic ash. The mudstones were originally deposited on a broad coastal plain with a high water table or with abundant rainfall. Thus, carbonate nodules are rare. A radiometric date of 98.37 ± 0.07 Ma places the upper part of the member in the Lower Cenomanian, while lower portions of the member have been dated to 104.46 ± 0.95 Ma, in the Albian stage.

- Although not part of the Cedar Mountain Formation, the **Naturita Formation** immediately overlies the Cedar Mountain and marks the encroaching Western Interior Seaway. The Naturita is not uniformly distributed and was eroded away in places by the advancing Seaway so that the marine shales of the Mancos Formation lay directly on the Mussentuchit or its equivalent. The name Dakota Formation has been improperly used for these strata.

Dinosaurs

The Cedar Mountain Formation is one of the last major dinosaur-bearing formations to be studied in the United States. Although sporadic bone fragments were known prior to 1990, serious research did not begin until that year. Since then, several organizations have conducted field work collecting dinosaurs, chiefly the Oklahoma Museum of Natural History, the Denver Museum of Nature & Science, the College of Eastern Utah, the Utah Geological Survey, Brigham Young University, and Dinosaur National Monument staff. This research indicates that at least two, possibly three dinosaur assemblages are contained within the formation.

Example of dinosaurs from the Cedar Mountain Formation include the polacanthid ankylosaur *Gastonia* from the Yellow Cat Member (upper left), *Utahraptor* from the Yellow Cat Member (upper right), a large theropod represented by a tooth from the Ruby

Ranch Member (lower left), and *Tenontosaurus* from the base of the Mussentuchit (lower right).

The oldest of these assemblages is from the Yellow Cat, Poison Strip and basal Ruby Ranch members. The small, *Ornitholestes*-like theropod *Nedcolbertia* and the brachiosaurid sauropod *Cedarosaurus* may be considered as relics, with their closest relatives in the Morrison Formation. In contrast, the polacanthid ankylosaur *Gastonia* and a yet unnamed iguanodontid are similar to related forms from the Lower Cretaceous of southern England. These dinosaurs show that the connection between North America and Europe still existed during the Barremian. All of this changes, however, with the upper dinosaur assemblage from the top of the Ruby Ranch and Mussentuchit members. This upper assemblage shows greater similarities with Asian dinosaur assemblages from the same time. For example, the primitive ankylosaurid *Cedarpelta* is related to *Gobisaurus* and *Shamosaurus* from Mongolia, but is more primitive than either because it has teeth in the premaxilla. The upper assemblage also has a tyrannosaurid, a ceratopsian, and a pachycephalosaur. Although not a dinosaur, the primitive mammal *Gobiconodon* is known from both Mongolia and the Mussentuchit Member. Evidence for a middle dinosaur assemblage between the older and younger ones is controversial because the evidence mostly depends on a single specimen of the ornithopod *Tenontosaurus* from high in the Ruby Ranch Member and the sauropod *Astrodon* from low in the Ruby Ranch. Regardless, the upper and lower dinosaur assemblages in the Cedar Mountain Formation document the separation of North America and Europe, the westward drift of North America, and its connection with Asia 10 to 15 million years later.

Data from Carpenter (2006), Cifelli et al. (1999), Kirkland and Madsen (2007), and The Paleobiology Database.

Ornithischians

New genus and species of iguanodont present in the Ruby Ranch and Yellow Cat members. Indeterminate neoceratopsian present in the Mussentuchit Member. Indeterminate pachycephalosaurid present in the Mussentuchit Member.

Cloverly Formation

The **Cloverly Formation** are Lower Cretaceous strata located in Montana and Wyoming, in the western United States. The term now includes strata that had formerly been called the Dakota Formation in central and southern Wyoming.

Members

In the Bighorn Basin region along the Montana - Wyoming border, the Cloverly is divided into several members.

Brightly colored Himes Member of the Cloverly Formation near Shell, Wyoming. These Lower Cretaceous rocks have produced numerous dinosaurs.

- **Pryor Conglomerate** lies at the base and contains abundant black chert. It is named from thick beds exposed on the west side of the Pryor Mountains.
- The **Little Sheep Member** lies in the middle and is composed of pale-purple, gray to almost white, bentonitic mudstone. A radiometric date of 115 +/- 10 MA has been obtained from low in the member (Chen and Lubin 1997), and other near the top at 108.5 +/- 0.2 MA (Burton et al. 2006). These dates confirm that the Cloverly is Aptian-Albian in age.
- The uppermost member is the **Himes Member** contains some coarse grained channel deposits, but is primarily brightly, multicolored (variegated) mudstones.

Vertebrate fauna

Animals recovered include the dinosaurs *Deinonychus*, *Microvenator Tenontosaurus*, *Zephyrosaurus* and *Sauropelta* as well as fragmentary remains of Titanosaurs and Ornithomimids. As well, two genera of turtle *Naomichelys* and *Glyptops* and the lungfish *Ceratodus*.

Dinosaur eggs have been found in Montana.

References for data: Ostrom 1970; Cifelli et al. 1998; Cifelli 1999; Nydam and Cifelli 2002. Possible goniopholidid remains are known from the formation.

Fruitland Formation

The **Fruitland Formation** is a sedimentary geological formation containing layers of sandstone, shale, and coal. It was laid down in marshy delta conditions, with poor drainage and frequent flooding, under a warm, humid and seasonal climate. It is dated from the late Campanian (part of the Cretaceous period), and is found in the San Juan Basin in the states of New Mexico and Colorado, in the United States of America.

The Fruitland is underlain by the Pictured Cliffs Sandstone, and overlain by the more recent Kirtland Formation. The sequence of rocks represents the final filling of the Cretaceous seaway. The underlying Pictured Cliffs is a marginal marine sandstone, deposited in an environment similar to offshore barrier islands of the southeast United States. As the seaway retreated, the Pictured Cliffs was covered by the Fruitland Formation, which was deposited in near-shore swampy lowlands.

The Fruitland Formation contains beds of bituminous coal that are mined in places along the outcrop.

Since the 1980s, the coal beds of the Fruitland Formation have yielded large quantities of coalbed methane. The productive area for coalbed methane straddles the Colorado-New Mexico state line, and is one of the most productive areas for coalbed methane in the United States.

Laramie Formation

Typical exposure of the Laramie Formation in northeastern Colorado. Dinosaur bones have been found in the area.

The **Laramie Formation** is a geologic formation of Cretaceous age, named by Clarence King in 1876 for exposures in northeastern Colorado, in the United States.

The formation is exposed around the edges of the Denver Basin and ranges from 400–500 feet on the western side of the basin and 200–300 feet thick on the eastern side. The Laramie conformably overlies the Fox Hills Sandstone and unconformably underlies the Arapahoe Conglomerate. The formation can be divided into a lower unnamed member containing bedded sandstone, clay, and coal and an upper unnamed member composed predominately of 90 to 190 m of drab-colored mudstone, some sandstone, and thin coal beds. Nodular ironstone concretions occur in the mudstones that contain plant remains. The coal and clay were once economically important. The Laramie Formation was deposited on a coastal plain containing coastal swamp. Some of the material in the sandstones originated from silicic volcanoes far to the west.

Paleofauna

Skull of *Triceratops* from the Laramie Formation. This skull may be the oldest known for the genus. Currently on display at the courthouse in Greeley, Colorado

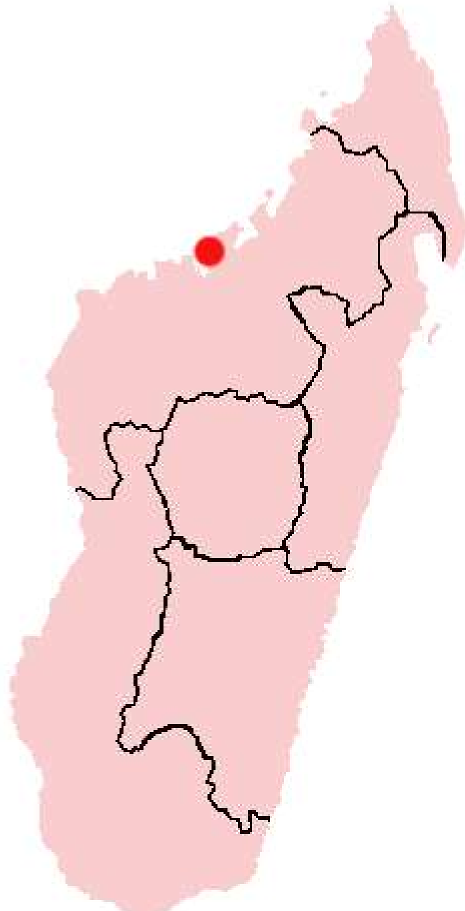
Fossil vertebrates from the Laramie Formation were among the first dinosaurs to be discovered in the American West (Carpenter and Young 2003). In 1873, Edward D. Cope accompanied Ferdinand V. Hayden, who was leader of the U.S. Geological and Geographical Survey of the Territories. The route of the expedition included eastern Colorado where Cope collected specimens in what is now the Laramie Formation along Bijou Creek on the east side of the Denver Basin (Cope, 1874).

Cope named three species of dinosaurs without description: *Cinodon arctatus* (later changed to *Cionodon arctatus*), *Polyonax mortuarius* and *Agathaumas milo* (later renamed *Hadrosaurus occidentalis*). These specimens are currently in the American Museum of Natural History. These specimens are very scrappy and the names no longer considered valid. Subsequent discoveries of dinosaurs occur through the formation, and include a nearly complete skull of *Triceratops*. Non-dinosaur vertebrates also occur (Carpenter 1979).

Maevarano Formation

The **Maevarano Formation** is an Upper Cretaceous sedimentary rock formation found in the Mahajanga Province of northwestern Madagascar. It is most likely Maastrichtian in age, and records a seasonal, semiarid environment with rivers that had greatly varying discharges. Notable animal fossils recovered include the theropod dinosaur *Majungasaurus* and the early birds *Rahonavis* and *Vorona*, the titanosaurian sauropod *Rapetosaurus*, and the giant frog *Beelzebufo*.

Description



The Maevarano Formation outcrops in the Mahajanga Province of Madagascar, particularly within 50 kilometers (30 miles) southeast of the provincial capital, Mahajanga (marked with a red dot on the map).

The Maevarano Formation is well-exposed in the Mahajanga Basin, in particular near the village of Berivotra near the northwestern coast of the island where its outcrops have been heavily dissected by erosion. At the time it was being deposited, its latitude was between 30°S and 25°S as Madagascar drifted northward after splitting from India about 88 million years ago. It is composed of three smaller units or members. The lowest is the Masorobe Member, which is usually reddish and is at least 80 meters thick (262 ft). Its rocks are mostly poorly-sorted coarse-grained sandstones with some finer-grained beds. It is separated by an erosional disconformity from the next member, the Anembalemba Member. The lower portion of the Anembalemba Member is fine to coarse clay-rich sandstone, whitish or light grey in color, with cross-bedding. The upper portion of this member is made of poorly-sorted clay-rich sandstone, light olive-grey in color, that lacks cross-bedding. Most vertebrate fossils come from the Anembalemba Member, especially from the upper portion. The Miadana Member, the third and uppermost member, is not always present, and is up to 25 meters thick (82 ft); in some places. Elsewhere, it is replaced by the marine Berivotra Formation. The Miadana Member is made up of claystone, siltstone, and sandstone, lacks cross-bedding, and has several colors of rock. The Maevarano Formation as a whole is underlain by the Marovoay beds and capped by the Berivotra Formation.

The age of the Maevarano Formation has been debated; the Berivotra Formation, which is partially contemporaneous with the upper portions of the formation, shows that at least the upper part of the Maevarano is Maastrichtian in age. There is no evidence that it is Campanian, despite previous reports to that effect. The Berivotra Formation appears to include near its top a magnetic reversal, interpreted as the shift from Chron 30N to Chron 29R, which occurred approximately 65.8 million years ago (about 300 000 years before the K–T boundary and associated Cretaceous–Tertiary extinction event. This suggests that Maevarano organisms also lived shortly before (geologically speaking) the extinction event.

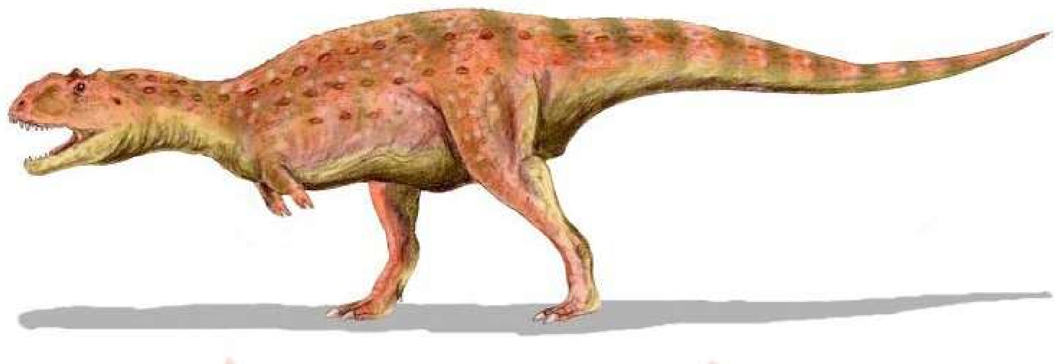
History of exploration

The Maevarano Formation was first explored by French military physician Dr. Félix Salètes and his staff officer Landillon in 1895, and fossils and geologic data were sent to paleontologist Charles Depéret. He briefly described the formation and named two dinosaurs from the remains (*Titanosaurus madagascariensis* and *Megalosaurus crenatissimus*, now *Majungasaurus*). Similar collections were made throughout the 20th century, yielding mostly fragmentary fossils; one such specimen, a rough partial skull roof, became the holotype of supposed pachycephalosaur (bonehead dinosaur) *Majungatholus* in 1979. (This specimen was later shown to be part of the skull ornamentation of a *Majungasaurus*.) Large scale expeditions (seven to date), under the banner of the Mahajanga Basin Project, began in 1993. These expeditions, conducted jointly by Stony Brook University and the University of Antananarivo, have greatly expanded knowledge of this formation and the organisms that lived while it was being deposited.

Paleoenvironment

The Maevarano Formation is interpreted as a low-relief alluvial plain that over time was covered by a marine transgression. Broad, shallow rivers flowed to the northwest from central highlands; evidence for debris flows suggests that the discharges of the rivers varied greatly, with periods of dilute water flow, and periods of rapid erosion dumping sediment into the channels. Paleosols are reddish and include root casts. The paleosols and other sedimentologic evidence indicate well-drained floodplains with abundant vegetation adapted to a relatively dry climate, strongly seasonal (rainy and dry seasons) and at times semiarid (not unlike the present climate of the area).

Vertebrate paleofauna



Majungasaurus crenatissimus, top land predator of the Maevarano Formation.

Animals found in the formation include frogs (including *Beelzebufo ampinga*), turtles, snakes, lizards, at least seven species of crocodyliforms (including species of *Mahajangasuchus* and *Trematochampsa*), abelisaurid theropod *Majungasaurus*, noasaurid *Masiakosaurus*, two types of titanosaurian sauropods (*Rapetosaurus* and an unnamed second form), and at least five species of birds or very bird-like dinosaurs, including *Rahonavis*. The 6 to 7 meter long (20 to 23 ft) *Majungasaurus* was likely the apex predator in the terrestrial environment. Crocodyliforms were very diverse and abundant.

Naturita Formation

The **Naturita Formation** was named by Robert G. Young (1960, 1965) for Cretaceous sedimentary rocks exposed near Naturita, Colorado.

Naturita Formation exposed above the town of Naturita Colorado.

The formation lies between the Cedar Mountain Formation (sometimes called the Burro Canyon Formation in Colorado) and Mancos Shale, thus occupies the position for sedimentary strata that have historically been called the Dakota Formation. However, as Witzke and Ludvigson (1994) noted, the term cannot be used for Cretaceous strata that were deposited on the western side of the Cretaceous Seaway.

Naturita Formation exposed in a roadcut in eastern Utah. A coal seam is visible below the sandstone bed. A thin volcanic ash (white layer) occurs in the upper portion of the coal.

In most areas, the Naturita Formation is composed of a lower unit of conglomeratic sandstone, a middle part of lignitic mudstones and coal, and fine- to medium-grained sandstones in the upper part. The Naturita is not uniform in thickness and in many places is very thin or missing so that the Mancos Formation is in direct contact with the Cedar Mountain Formation. Where missing, a lag of conglomerate may be present to indicate winnowing of sediments, which occurred by advancing Cretaceous sea. In other places, deposition of Naturita sediments did not occur, and these areas may have been quiet lagoons. Coastal coal swamps also formed in low areas as the encroaching sea raised the base level of rivers and the water table.

Fossils from the Naturita including dinosaur bone fragments of ceratopsians, a possible primitive tyrannosaurid, nodosaurid ankylosaurs, and a brachiosaurid sauropod (Carpenter 2006). Abundant fossil plants are also known from the coal-rich layers (Rushforth 1971)

Raton Formation

The **Raton Formation** is a geological formation of Upper Cretaceous and Paleocene age which outcrops in the Raton Basin of northeast New Mexico and southeast Colorado.

The Raton Formation was originally named "Raton Hills Group" by Hayden in 1869 for coal beds in the Raton Hills in Colfax County, New Mexico. In 1913, Lee changed the name to Raton Formation. Lee described the formation as a coal with carbonaceous shale with brown to buff sandstone and conglomerate (usually at the base). The Raton Formation is about 1140 feet thick at the type locality. The formation unconformably overlies the Vermejo Formation, and unconformably (?) underlies the Poison Canyon Formation.

In 1954, Brown determined that the Raton Formation was of Late Cretaceous and Paleocene age.

Pillmore measured the formation thickness as 2000 feet, and divided the Raton Formation into three divisions. The lowest division is a basal sandstone and conglomerate of quartzite, chert and gneiss pebbles and cobbles in a coarse-grained quartzose to arkosi sandstone matrix. The middle division is fine to coarse grained sandstone, with some siltstone, mudstone, and coal. The upper division is coal-bearing and contains sandstone, siltstone, mudstone, shale, and mineable coal.

Because the Raton Formation is a well-preserved sequence of rocks spanning the Cretaceous-Tertiary boundary, it has been studied for evidence of a large meteor impact at the end of the Cretaceous that is thought to have caused the Cretaceous–Tertiary extinction event. The boundary is represented by a 1-cm thick tonstein clay layer which has been found to contain anomalously high concentrations of iridium. The boundary clay layer is accessible to the public at Trinidad Lake State Park, among other places in the Raton Basin.

Santa Marta Formation

The **Santa Marta Formation** is a geologic formation in Antarctica. It, along with the Mount Kirkpatrick Formation and the Snow Hill Island Formation, are the only formations yet known on the continent where dinosaur fossils have been found. The formation outcrops on James Ross Island off the coast of the northern tip of the Antarctic Peninsula. In its entirety, the Santa Marta Formation is on average one kilometer thick.

Stratigraphy

The Santa Marta Formation was deposited during the Santonian and Campanian ages of the Late Cretaceous. It overlies the Gustav Group laid down during the Barremian and Santonian ages and is succeeded by the Snow Hill Island Formation of late Campanian age. Together, the Santa Marta Formation, Snow Hill Island Formation, the overlying López de Bertodano Formation (deposited from the late Campanian age of the Late Cretaceous to the early Paleocene epoch of the early Paleogene), and the Sobral Formation (deposited during the early Paleocene) form the Marambio Group.

Originally the formation was subdivided into three informal members termed the Alpha, Beta, and Gamma members. The names were later changed to the Lachman Crags, Herbert Sound, and Rabot members. The Lachman Crags and Herbert Sound members, named after the areas in which they outcrop, are found in the northern part of James Ross Island. Both members are late Campanian in age. The Lachman Crags Member, the older of the two, is around 500 meters thick. The lower section of the member consists of tuffaceous mudstone while the upper section consists of tuffaceous turbidites formed by underwater avalanches. Bioturbation is evident in tuff beds throughout the member due to the disruption of sediments by benthic life during the time of deposition. The Herbert Sound member is also around 500 meters thick and also can be divided into two distinct sections. Channeled debris flows interbedded with turbides make up the lower portion of the member and are overlain by fine sandstones (followed by coarser sandstones and coquinas) that make up the upper portion of the member.

The depositional environment is thought to have been a system of abyssal fans radiating out from a large river delta. The rapid aggradation of sediments from the delta produced a steep delta slope, which may have resulted in occasional debris flows that formed the turbides. A high degree of tectonic activity in the region at the time may explain the intermittent tuff beds throughout the formation.

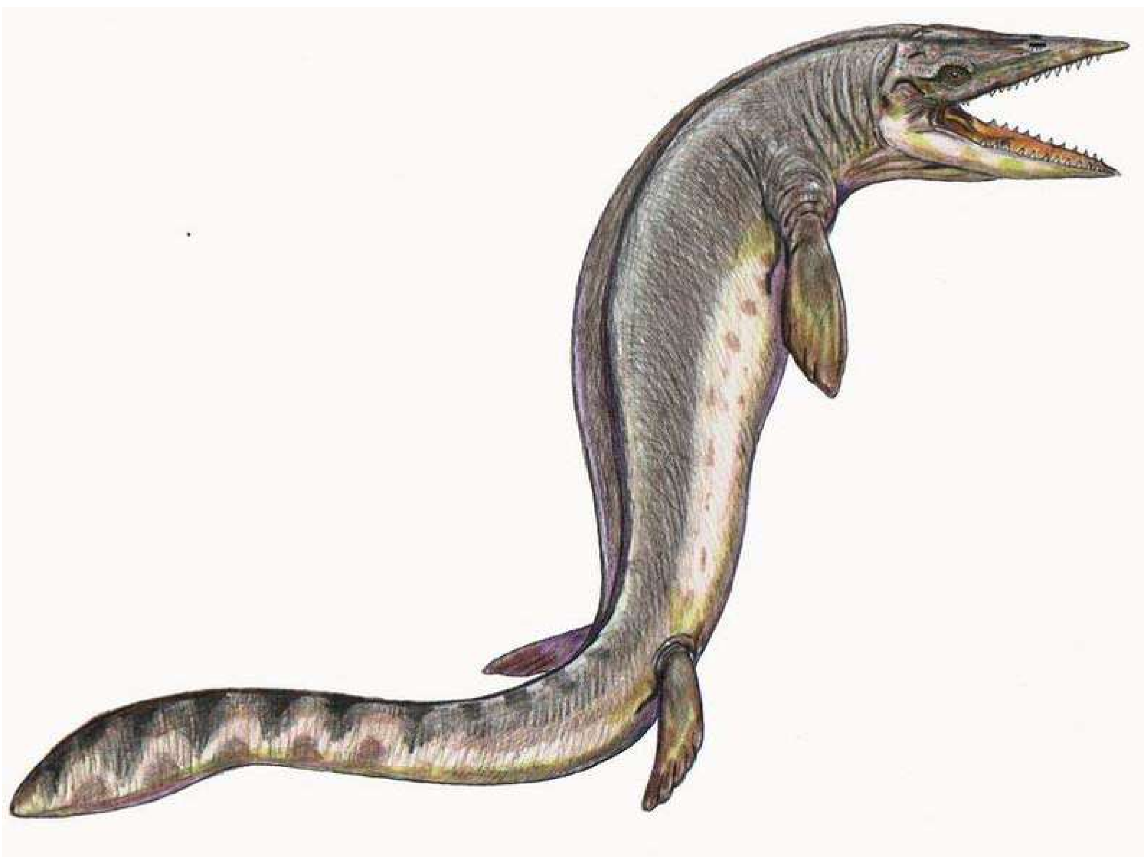
The Rabot Member of the Santa Marta Formation is confined to the southeastern part of James Ross Island and dates back to the early to late Campanian. Outcroppings of the member are separated from those of other members in the northern part of the island. Originally the member was regarded as its own formation, and now it is considered to be the lateral equivalent of both the Lachman Crags and Herbert Sound members. Like the Lachman Crags and Herbert Sound members, the Rabot member consists of mudstones and beds of tuff that are often highly bioturbated, and also consists of rare conglomerates. Recently a fourth member has been assigned to the formation called the Hamilton Point Member. The beds of this member used to be considered part of the upper portion of the Rabot member, but now are considered to be their own distinct member.

Flora and fauna

A wide variety of microorganisms inhabited the coastal waters at the time of the deposition of the Santa Marta Formation. Microfossils include ostracods and dinoflagellates.

Invertebrates were also common. Fossils of ammonites can be found in the formation, often embedded vertically in the bedding plane. Originally it was thought that dead ammonites could only be oriented this way in sediment if they were in shallow waters below a certain pressure, but there is evidence to support that due to specific conditions during burial, it was possible for these ammonites to be vertically oriented at greater depths. Ammonite genera present in the formation include *Anagaudryceras*, *Anapachydiscus*, *Eupachydiscus*, *Gaudryceras*, *Maorites*, *Natalites*, *Parasolenoceras*, *Yezoites*, and the heteromorph ammonites *Ainoceras*, *Eubostrychoceras*, *Ryugasella* and *Baculites*. Many bivalve fossils have been found such as *Cucullaea*, *Panopea*, *Pinna*, and *Pterotrigonia*. Polychaete annelid worms such as *Rotularia* and gastropods such as the cerithiid sea snail *Cerithium* have also been discovered in beds within the formation.

Numerous ichnofossils provide evidence of benthic activity, along with the bioturbated sediments previously mentioned. Vertical spreite trace fossils have been found as part of fodinichnia dominated ichnocoenosis and were assigned to ichnogenre such as *Paradictyodora*. Trackways thought to belong to decapods have also been found.



Taniwhasaurus

Fish were present, including one of the first frilled sharks, *Chlamydoselachus thomsoni*. Other marine vertebrates included the small mosasaur *Taniwhasaurus antarcticus*, previously known as *Lakumasaurus antarcticus*. The close relation of *T. antarcticus* to other species of *Taniwhasaurus* found in New Zealand and Patagonia provides evidence for a Gondwanan endemism.

Antarctopelta oliveroi, an ankylosaur, was discovered in 1986 on the northern part of James Ross Island about 2 kilometers south of Santa Marta Cove in beds that were part of the Santa Marta Formation. It was the first dinosaur found in Antarctica. It may be a possible nodosaur but there has been no formal phylogenic analysis to prove its relationship with other ankylosaurs. Although the formation is made up of only marine deposits, the bodies of these animals along with other debris may have frequently been washed out to sea to later sink to the bottom and be buried by sediment.

Leaves and fragments of plants are commonly found as fossils throughout the formation as well as large tree trunks in the lower members. This is evidence of the forested environment that covered Antarctica during the Late Cretaceous due to the overall warmer global temperature and milder climate. At that time the river delta had much vegetation, and was able to support large herbivores such as *Antarctopelta*.