Historical Geology & Palaeontology

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CULTURECOVERY

PALAEONTOLOGY

- **Palaeontology is the study of extinct organisms, their evolution and the flora and fauna of past geological**
- **Fossil is the remaining part of an organism (usually extinct), which had been preserved during geologic time (f. ex. in sedimentary rocks)**
- **The organic matter has been replaced by minerals but kept the physical structure of the organism.**
- **Organic matter can be preserved in biominerals**
- **In other case the preserved matter is *subfossil* matter such as organic remains found in turf**

PALAEONTOLOGY

- Natural moulds or preserved footprints can also be regarded as fossils

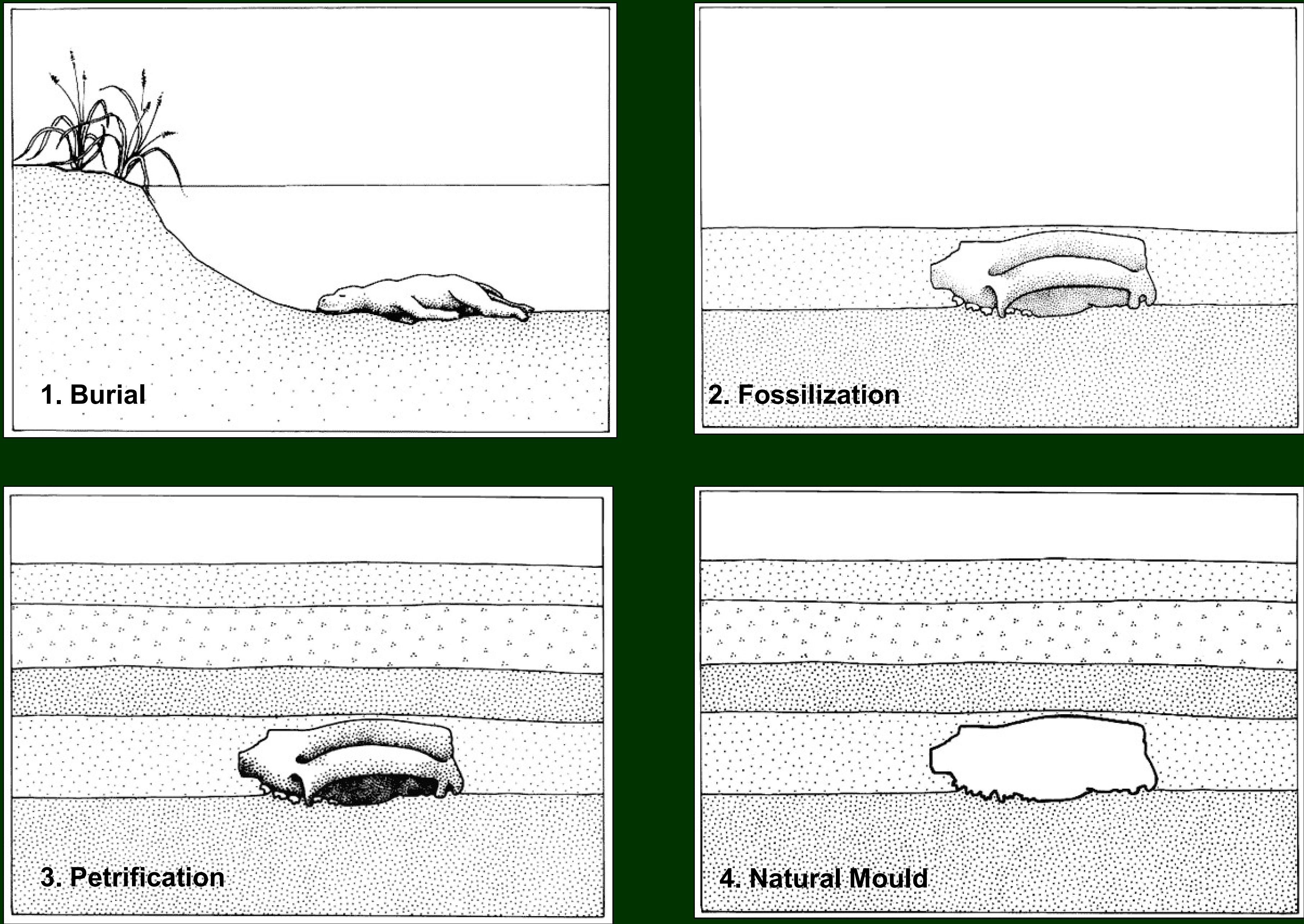
- Fossils can also be used to determine the age of the rock in which they were found

- A fossil typical for a geological layer is a signal fossil (*ledfossil*)

- Mostly the hard parts of organisms are preserved in the fossil record (bone, teeth, shells, wood, seeds etc.

- Microfossil or macrofossil – depends on size

- Bacteria can be preserved in the fossil record


1. Burial
2. Fossilization
3. Petrification
4. Natural Mould

Preservation of organic matter

- Proteins, peptides and amino acids
- Polysaccharides (special polymers, require conditions where hydrolysis is not possible)
- Chitin
- Lignin
- Plant cuticles
- Nucleic acids
- Humic substances
- Well preserved, species specific organic matter is mostly embedded in biominerals
- Chemical fossils

Optimal conditions for preservation of organic matter

- **Oxygen free clay or soil**
- **Dry deserts**
- **Salt**
- **Natural asphalt**
- **Ice**
- **Gum → Amber**
- **Turf marshes: oxygen free environment + tannins**
- **In some cases even DNA may be preserved**

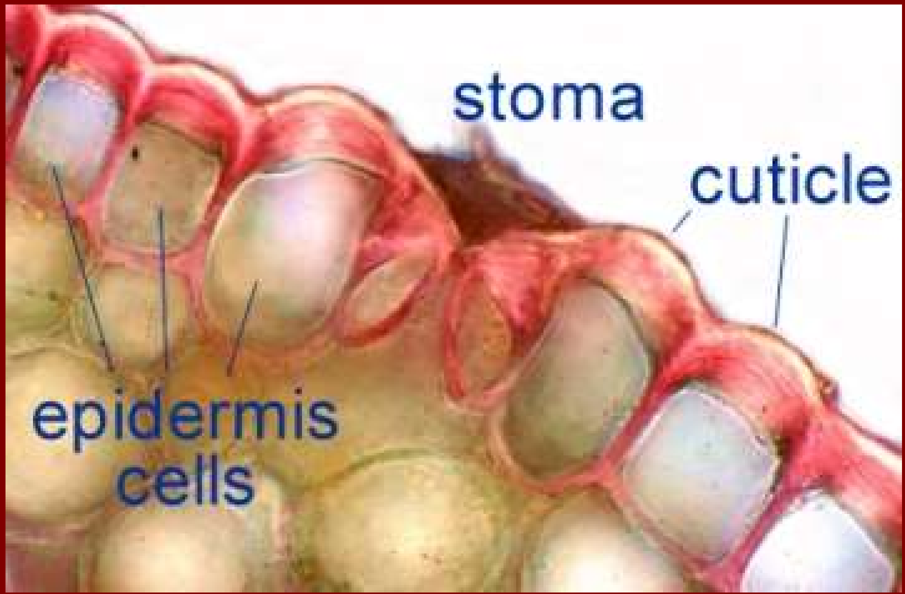
Insect preserved in amber, Oligocene, Baltic region.

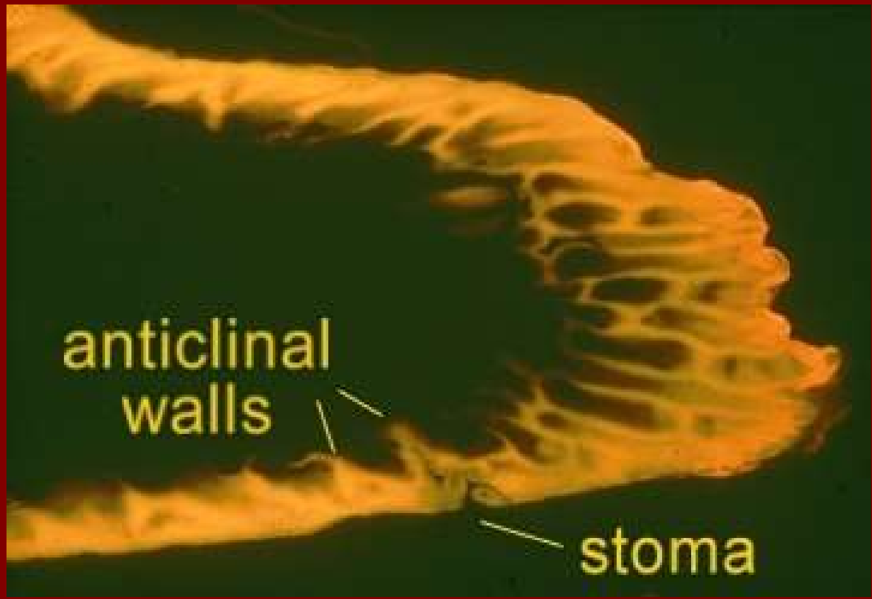
Plant fossils

Protective plant cuticles

- The cuticle is a non-cellular protective layer covering the outer cell layer (epidermis) of the green, aerial parts of land plants. Cuticles protect plants against desiccation, UV radiation and various kinds of physical, chemical and (micro) biological agents. Moreover, the cuticle also provides some support. In fact, the cuticle which protects the underlying tissues has basically the same function as our own skin. In several groups of plants cuticles are very resistant and they have a high fossilization potential; only few groups do not generally have highly resistant cuticles (lycopods, Equisetophytes and ferns).

Plant fossils





Section through a leaf of a living plant showing the epidermis and the cuticle (stained red). Note the stoma with the substomatal chamber

Early Cretaceous conifer leaf photographed under UV- light. Only the cuticle is preserved. Note the anticlinal walls, and the stoma on the lower leaf surface.

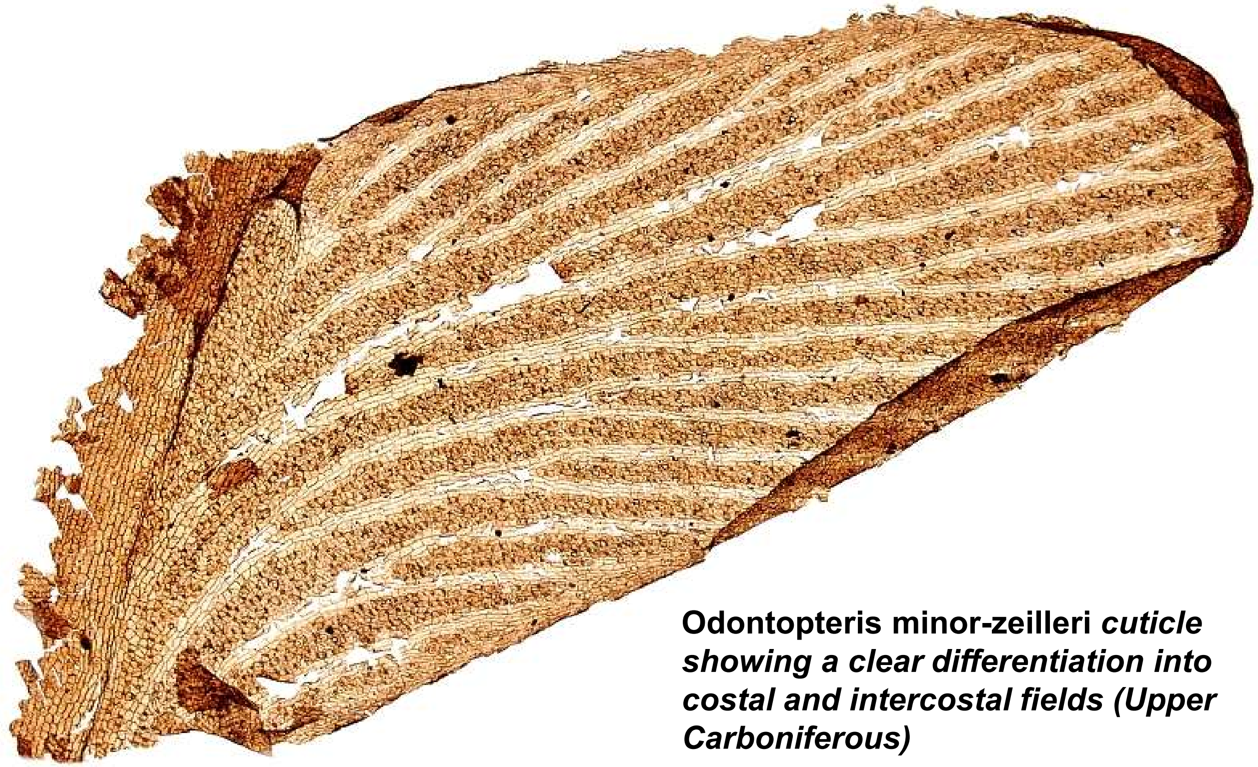
- **Epidermal cells usually do not exactly fit together, but there are small voids between the individual cells. These voids between individual epidermal cells are filled up by cuticle plugs which are termed anticlinal walls. The cuticle forms a perfect natural cast of the epidermis and the anticlinal wall reflect the cell pattern of the epidermis.**

Plant fossils

Pteridosperm cuticles from the Upper Carboniferous (left) and Upper Permian (right) clearly showing the relief of the anticlinal walls.

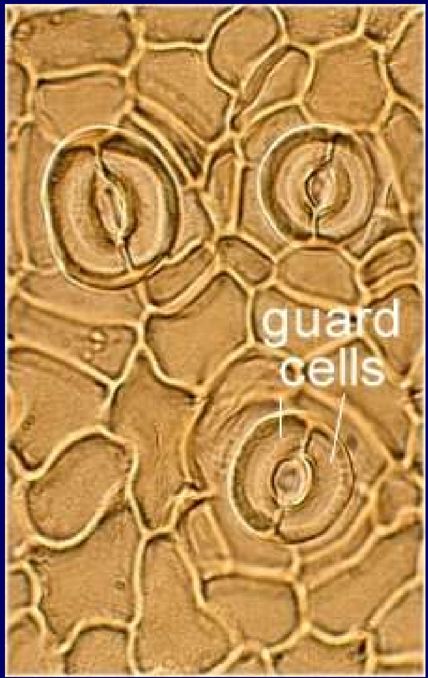
- **Each plant species has it own specific epidermal pattern. Therefore cuticles can be used for identifying plant remains. They are so to say the plant's "fingerprint ". Only small pieces of cuticle suffice for a justified identification. Only in some cases cuticles of closely related species within the same genus are so similar that they cannot be differentiated. Cuticles not only help to identify and classify fossil plant species, they are also a valuable source for further information, such as gross morphology, ecology and climate.**

Plant fossils



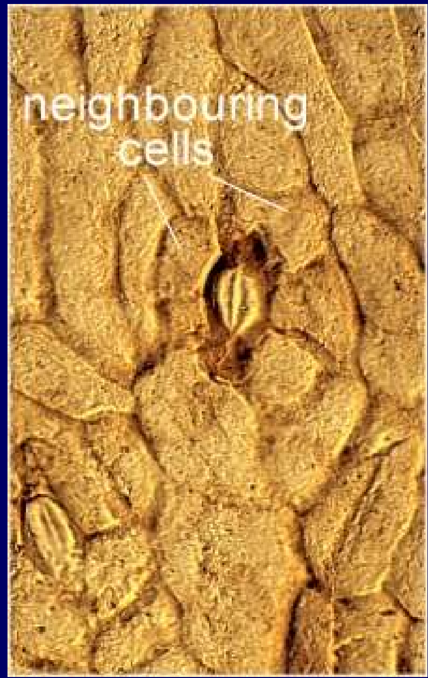
Odontopteris minor-zeilleri ***cuticle showing a clear differentiation into costal and intercostal fields (Upper Carboniferous)***

- **The form and arrangement of epidermal cells, differences between upper and lower leaf cuticles are some of the important characters. The illustration above shows a cuticle with a clear differentiation. The epidermal cells of the pinna axis are more or less rectangular and elongated, arranged in longitudinal rows. The cells overlying the veins are very similar but less cutinized. The cells in the areas between the veins are smaller, polygonal and here the so-called stomata occur.**



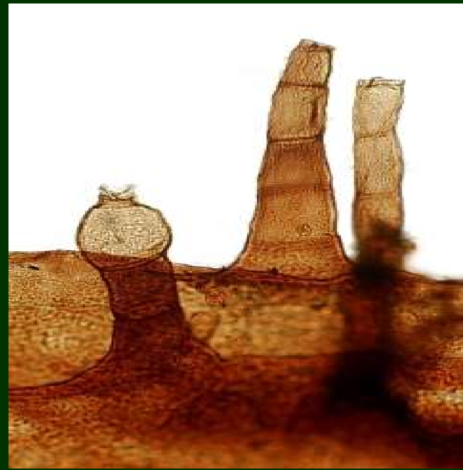
Leaf cuticle of* Symplocos hallensis *(Eocene) with three stomata each consisting of two guard cells

***Axial** cuticle of the Early Devonian land plant* Aglaophyton major *with stoma consisting of two guard cells*



Leaf cuticle of the Early Permian pteridosperm* Autunia conferta *with stomatal complexes

- **Very typical features are the so-called stomata which serve for gas exchange, i.e. the uptake of carbon dioxide and release of oxygen. Stomata consist of an opening or stomatal pore, and two kidney-shaped guard cells. The guard cells are used for opening and closing the stomatal pore, in order to regulate the transpiration and gas exchange. Early land plants and several angiosperms have such simple stomata. In many gymnosperms stomata and surrounded by cells that are differently shaped from the normal epidermal cells. Usually stomata are surrounded by one ring of neighbouring cells, occasionally a second ring of encircling cells occurs. The stoma together with the neighbouring (and encircling) cells is then called a stomatal complex or stomatal apparatus. Stomata are often more common on the lower leaf surfaces; not rarely they are completely restricted to lower leaf surfaces; being in the shade reduces the risk of excessive water loss. For the same reason stomata may also be sunken and stomatal pores may be covered by overhanging papillae (see below). Not only the shape of the stomata is typical, but also their distribution (e.g., concentrated, randomly, in rows) and the orientation are useful diagnostic characters.**



Short glandular trichome (foreground) and two longer multicellular trichomes (background) of B. praedentata *(Upper Carboniferous).*

Blanzyopteris praedentata (left) ***with numerous multicellular hairs, and*** **Ortiseia leonardii (*****right) with two stomatal complexes (subsidiary and encircling cells!) and numerous hair bases (upper Carboniferous)***

- **Other typical features include hairs and papillae. Papillae are small thickenings of the cuticle, which may be hollow or solid. Papillae may occur on normal epidermal cells and on neighbouring (and encircling) cells of stomatal complexes; other they are restricted to the latter. In such cases papillae may partly cover the stomatal pores. Larger structures are classified as hairs or trichomes. These can be unicellular to multicellular and have various functions, varying from extra protection against desiccation to protection against arthropods. Many trichomes are glandular and have a secretory function.**

Applications of cuticular studies in palaeobotany

Lescuropteris genuina
from the Upper Carboniferous

- **Identification and classification of fossil plant remains on the basis of biological criteria**
  In palaeobotany leaf remains are usually classified according to their outline and venation in form-genera and form-species However, this is a very artificial system because such leaf shapes are not necessarily typical for s specific group of plants. Cuticular analysis provides a sound basis for biological classification.

- **Correlation of isolated organs**
  Foliage and fructifications are rarely found in organic connection. With the help of cuticular analysis dispersed organs can easily be correlated.

- **Reconstructions of fossil plants**
  Some features are rarely or never found as compression fossils but can easily be recognized in bulk-macerated samples. Good examples are various types of climbing hooks and tendrils.

- **Ecological interpretations**
  Cuticles can show a number of features which can provide helpful information on the palaeoecology.

- **Palaeoclimatic studies and estimations of past carbondioxide concentrations**
  Cuticles can also given important information on the palaeoclimate. Stomata densities and indexes are popular proxies for carbon dioxide concentrations.

Pseudofossils

Pseudo or false fossil, dendrites of Manganese dioxide.

- A variety of mineral formations look remarkably like fossils, but are not fossils at all. They are known as 'false' or 'pseudo' fossils, and include concretions, dendrites and other crystal growths. All are formed by inorganic (non-living) processes.
- Concretions are irregularly shaped mineral nodules that form around a nucleus of some sort within sedimentary rock. Their composition differs from that of the surrounding rock. Concretions made up of pyrite or goethite, in particular, may sometimes resemble fossils.
- Dendrites look as though they are plant fossils of some kind, as they have a branched, fern or tree-like appearance, and occur in sedimentary rock. They are actually crystalline growths, often of the manganese mineral pyrolusite.
- Crystals of various other minerals can also, with a little imagination, be confused with fossils. Examples include malachite, which occasionally has a bulbous appearance, and imprints of gypsum crystals in mud, which may resemble animal shapes.

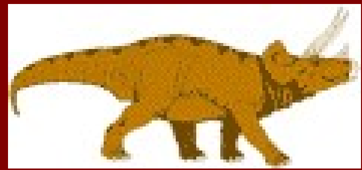
Taxonomy and phylogeny

- **Taxonomy** **(from Greek *taxis* meaning arrangement or division and *nomos* meaning law) :**
  - ***Practice of classifying plants and animals according to their presumed natural relationships***
  - ***Study of the general principles of scientific classification***
  - ***Classification of organisms into groups based on similarities of structure or origin etc***
- **Phylogeny, phylogenesis:**
  - ***The sequence of events involved in the evolutionary development of a species or taxonomic group of organisms***

Carl Linnaeus (1707-1778)

- Carl Linnaeus, also known as Carl von Linné or Carolus Linnaeus, is often called the Father of Taxonomy. His system for naming, ranking, and classifying organisms is still in wide use today (with many changes). His ideas on classification have influenced generations of biologists during and after his own lifetime, even those opposed to the philosophical and theological roots of his work.

Taxonomy

Linnean rank			
kingdom	Animalia	Animalia	Animalia
phylum	Mollusca	Chordata	Chordata
class	Gastropoda	Reptilia	Mammalia
order	Mesogastropoda	Ornithischia (Predentata)	Primates
family	Cypraeidae	Ceratopsidae	Hominidae
genus	*Cypraea*	*Triceratops*	*Homo*
species	*tigris*	*horridus*	*sapiens*

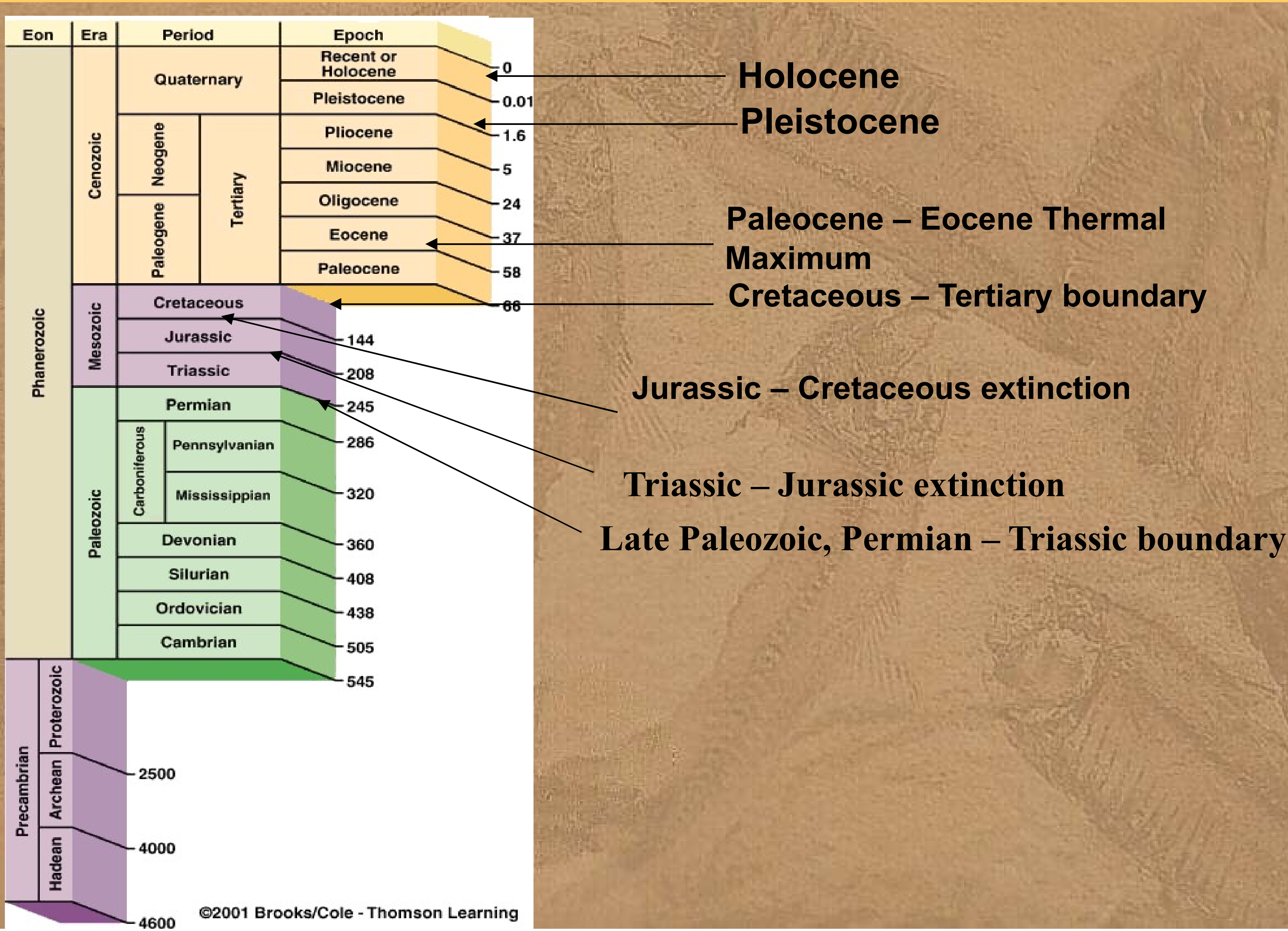
Phylogeny

"The affinities of all the beings of the same class have sometimes been represented by a great tree... As buds give rise by growth to fresh buds, and these if vigorous, branch out and overtop on all sides many a feebler branch, so by generation I believe it has been with the great Tree of Life, which fills with its dead and broken branches the crust of the earth, and covers the surface with its ever branching and beautiful ramifications."

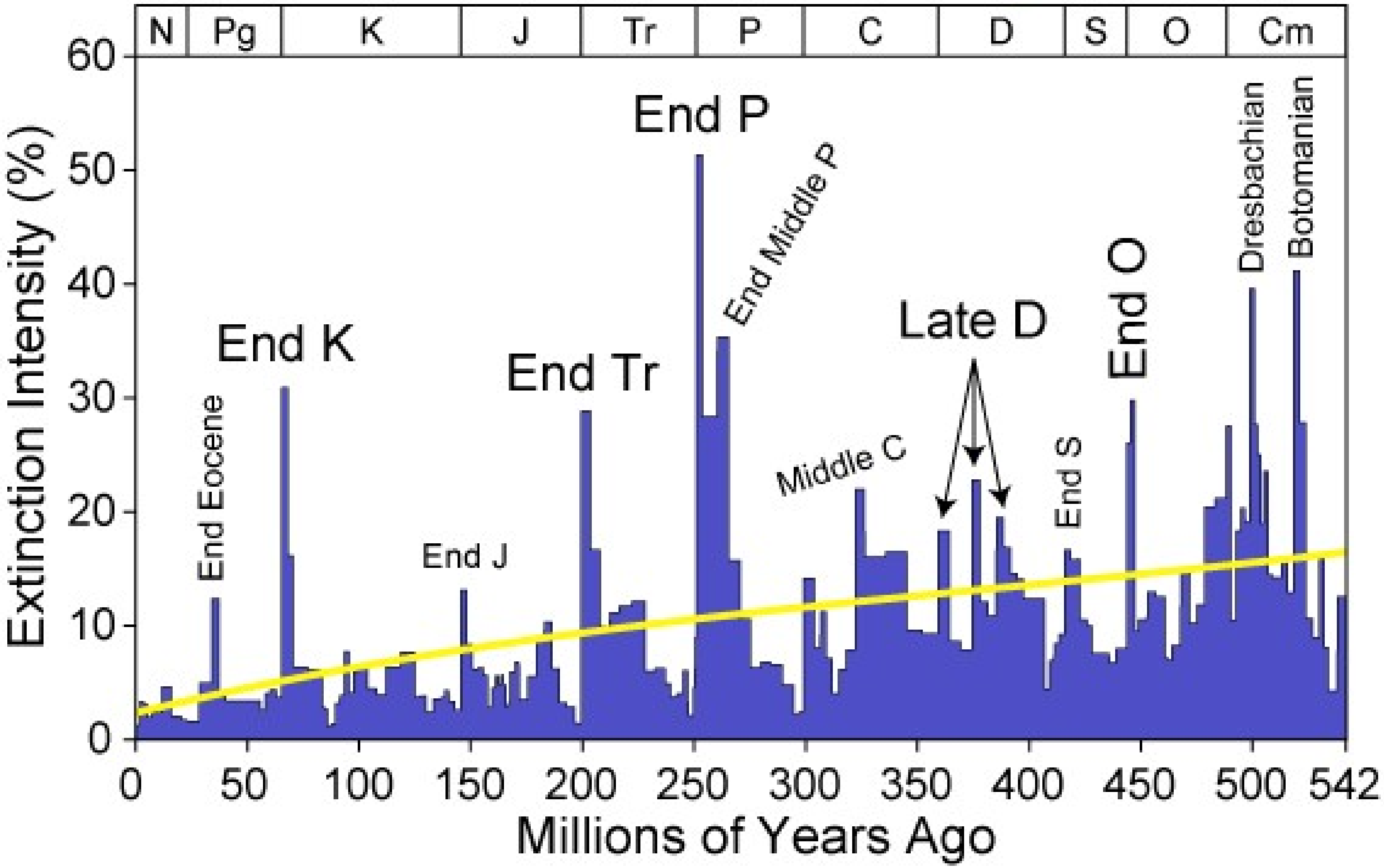
» **Charles Darwin, 1859**

The role of extinctions

Geologic Time Scale

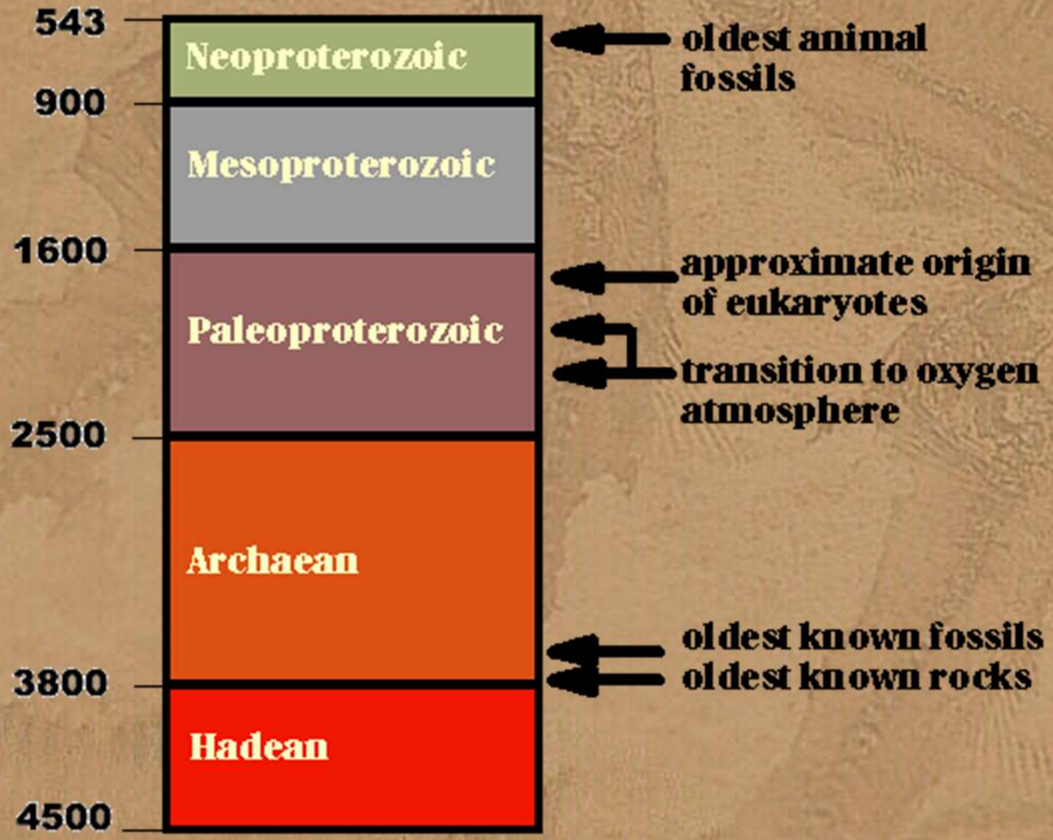


Marine Genus Biodiversity: Extinction Intensity

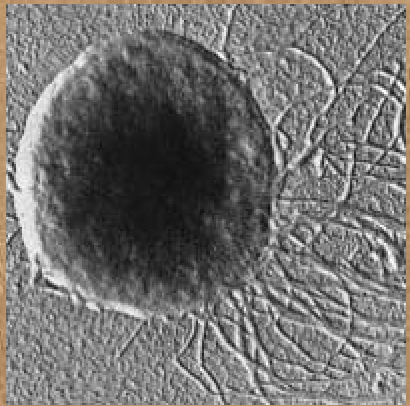
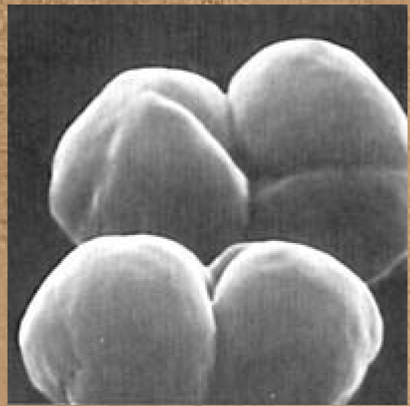
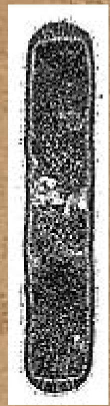
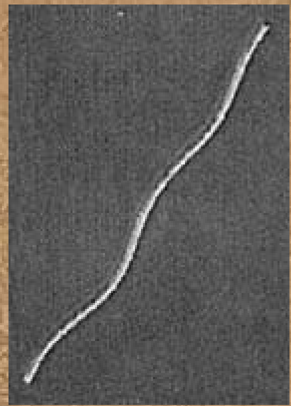


When did it begin?

The Divisions of Precambrian Time

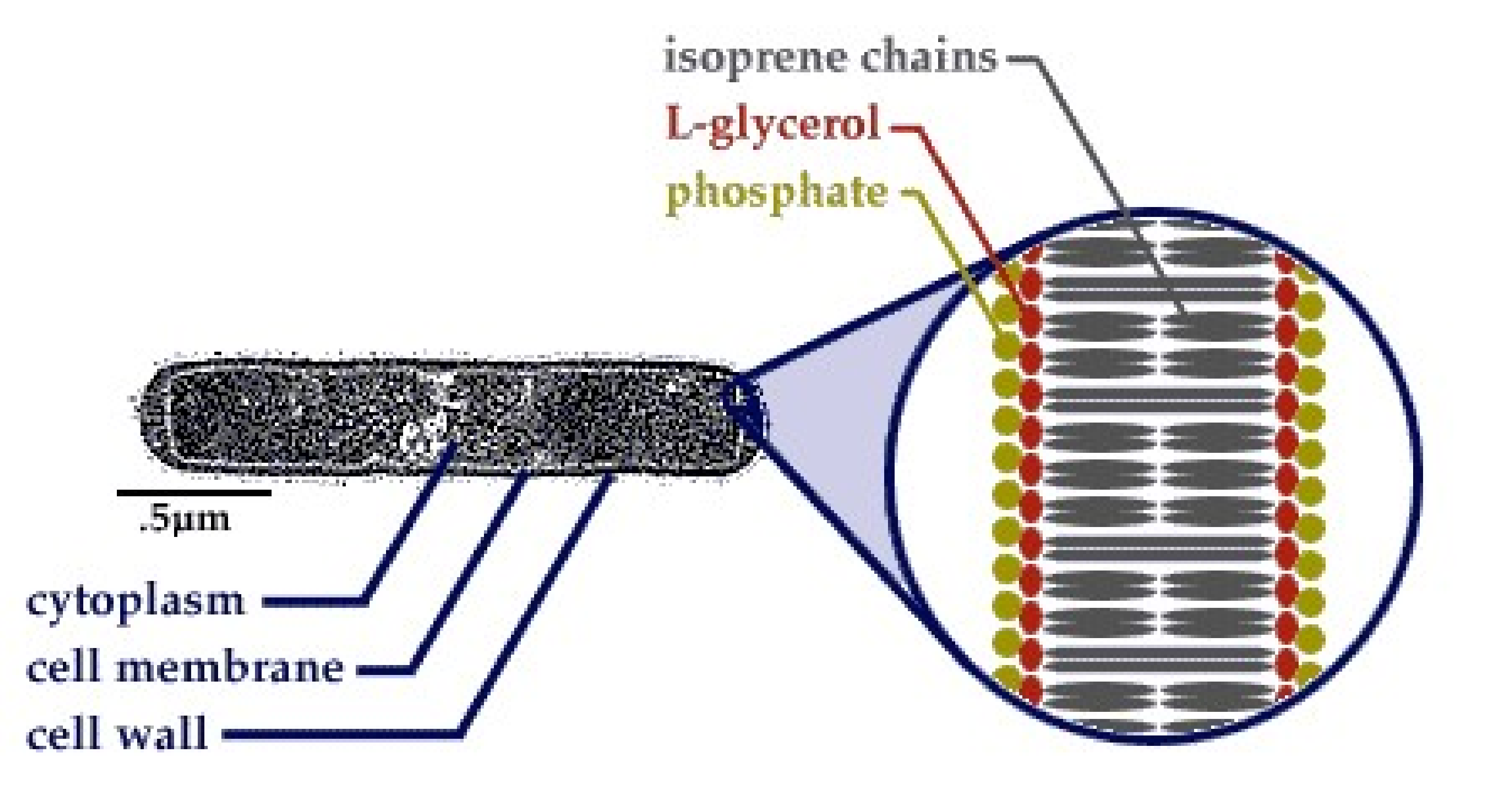


Archaea

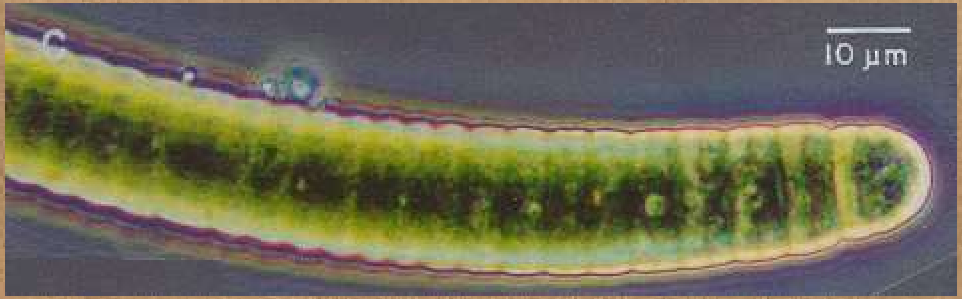
- **Basic Archaeal Shapes : At far left, *Methanococcus janaschii*, a coccus form with numerous flagella attached to one side. At left center, *Methanosarcina barkeri*, a lobed coccus form lacking flagella. At right center, *Methanothermus fervidus*, a short bacillus form without flagella. At far right, *Methanobacterium thermoautotrophicum*, an elongate bacillus form.**

Archea

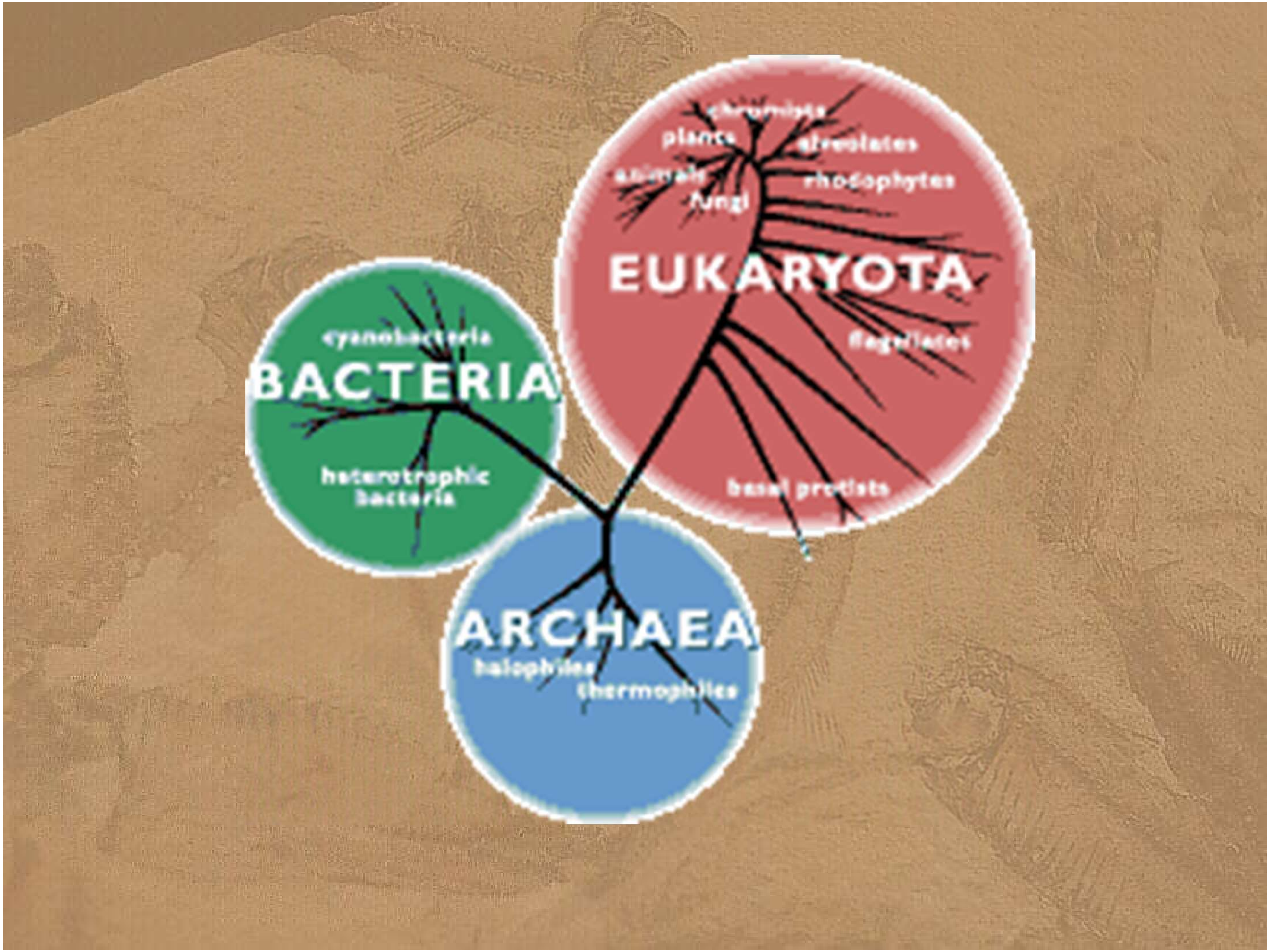


Basic Archaeal Structure : The three primary regions of an archaeal cell are the cytoplasm, cell membrane, and cell wall. Above, these three regions are labelled, with an enlargement at right of the cell membrane structure. Archaeal cell membranes are chemically different from all other living things, including a "backwards" glycerol molecule and isoprene derivatives in place of fatty acids.

Bacteria: Fossil Record



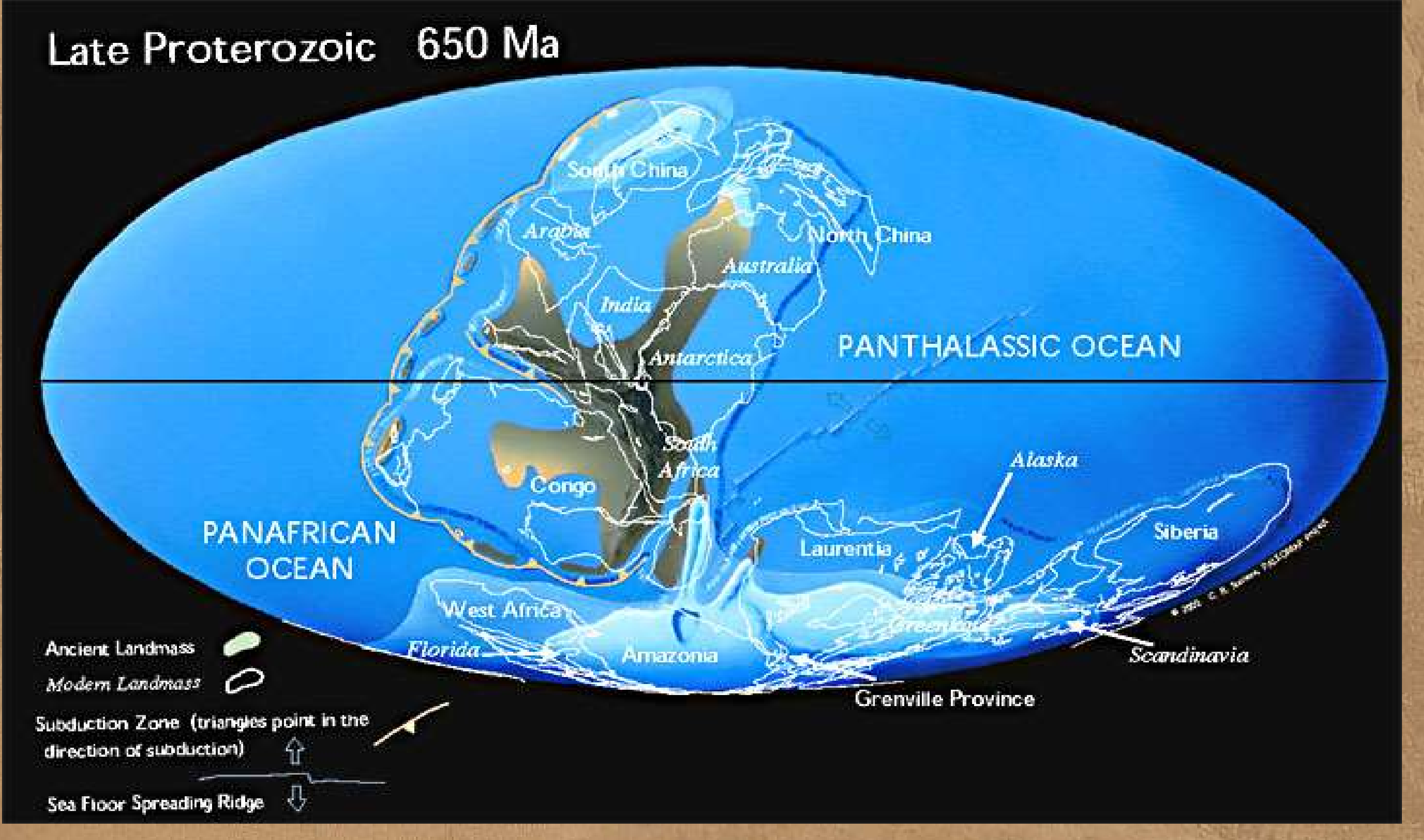
- It may seem surprising that bacteria can leave fossils at all. However, one particular group of bacteria, the cyanobacteria or "blue-green algae," have left a fossil record that extends far back into the Precambrian - the oldest cyanobacteria-like fossils known are nearly 3.5 billion years old, among the oldest fossils currently known. Cyanobacteria are larger than most bacteria, and may secrete a thick cell wall. More importantly, cyanobacteria may form large layered structures, called stromatolites (if more or less dome-shaped) or oncolites (if round). These structures form as a mat of cyanobacteria grows in an aquatic environment, trapping sediment and sometimes secreting calcium carbonate. When sectioned very thinly, fossil stromatolites may be found to contain exquisitely preserved fossil cyanobacteria and algae.


plants
alveolates
rhodophytes
fungi
EUKARYOTA
flagellates
basal protists
cyanobacteria
BACTERIA
heterotrophic bacteria
ARCHAEA
halophiles
thermophiles

Hydrothermal vents

Late Precambrian Supercontinent and Ice House

This map illustrates the break-up of the Supercontinent, Rodinia, which formed 1100 million years ago.

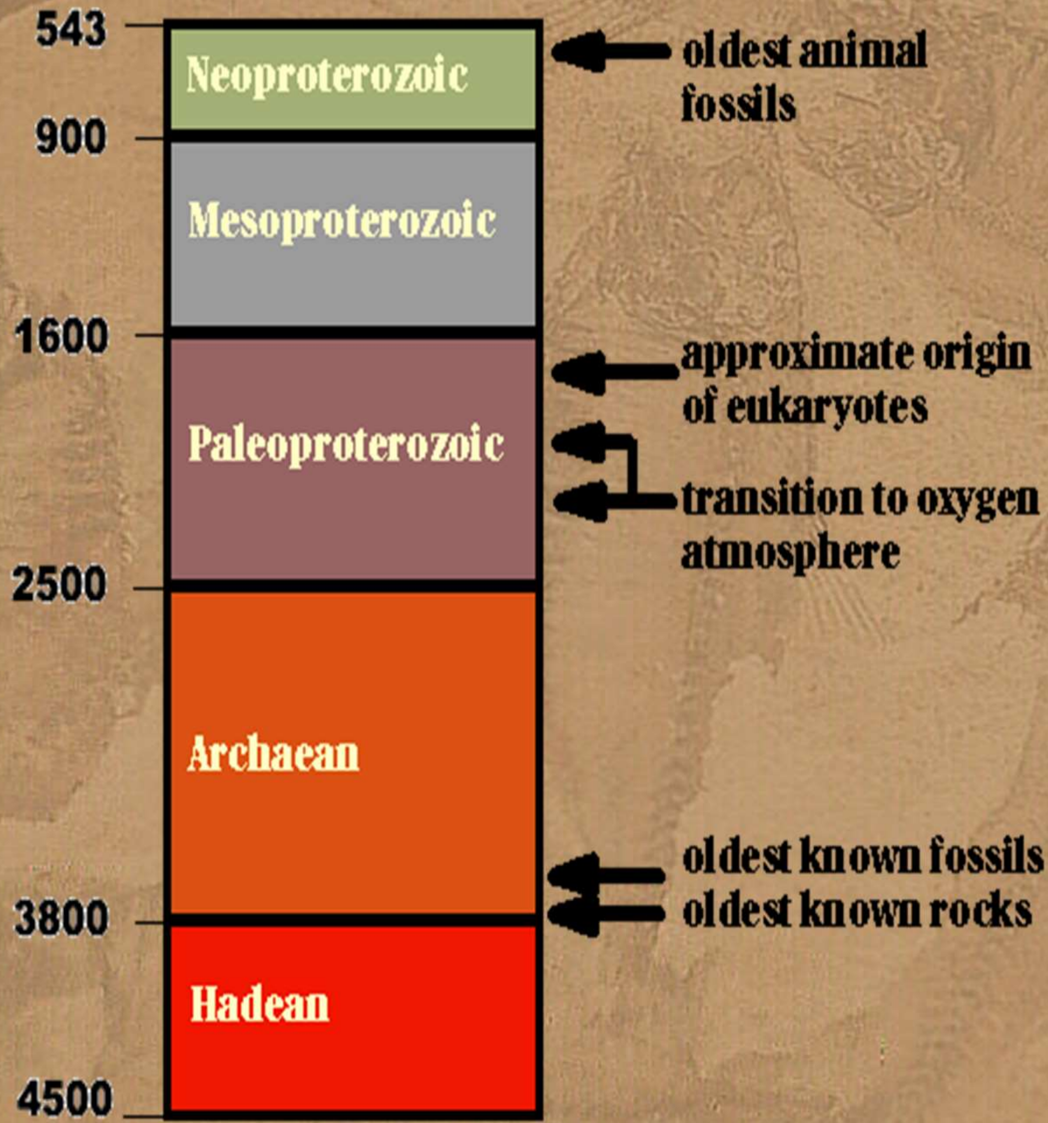


Late Precambrian

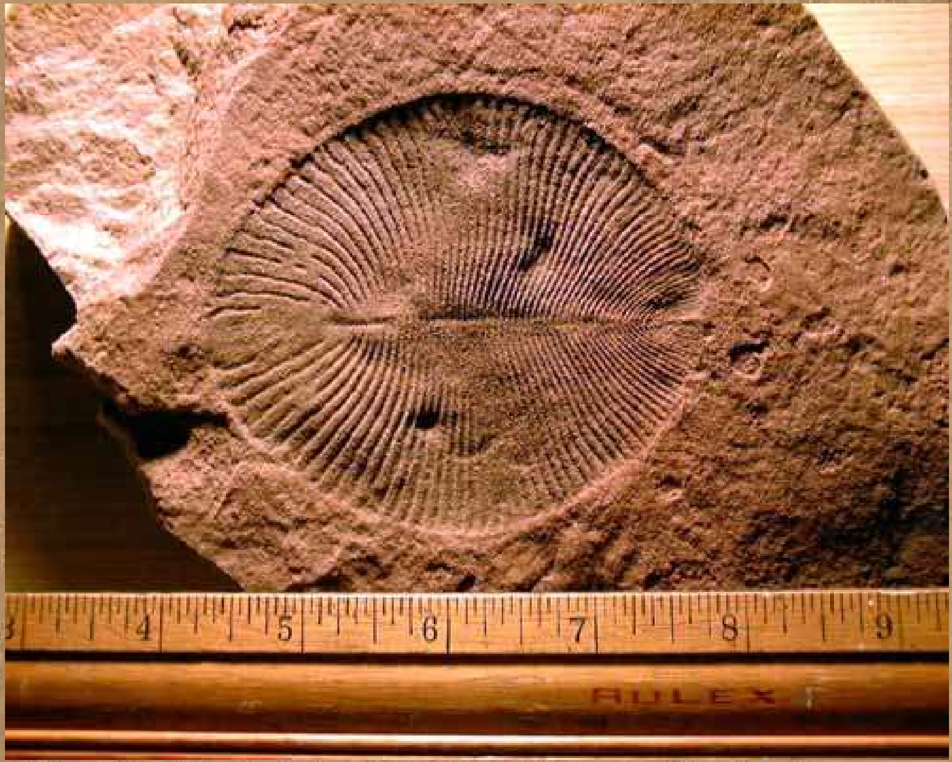
- Pannotia, the Supercontinent that formed at the end of the Precambrian Era, approximately 600 to 550 million years ago, had already begun to break apart by the beginning of the Paleozoic Era.
-
- A new ocean, the Iapetus Ocean, widened between the ancient continents of Laurentia (North America), Baltica (Northern Europe), and Siberia.

- Gondwana, the Supercontinent that was assembled during the Pan-African orogeny, was the largest continent at this time, stretching from the Equator to the South Pole.

Vendian fossils



- *Cyclomedusa* is probably the most common and widespread Vendian fossil. It also has one of the largest size ranges, ranging from a few millimeters to about a meter in diameter. Formerly thought to represent a planktonic (floating) jellyfish of some sort, *Cyclomedusa* is now considered by some to have been a benthic (bottom-dwelling) polyp, somewhat like a sea anemone. It reproduced by division in two or by budding. This specimen is about 5 cm across and comes from the Winter Coast of the White Sea.



- *Dickinsonia* is known from Vendian rocks of south Australia and north Russia. It is often considered to be an annelid worm because of its apparent similarity to one genus of extant polychaete, *Spinther*. However, in the opinion of some, it may in fact be a cnidarian polyp, like a soft-bodied version of the "banana coral," *Fungia*.

- The specimen pictured left is an adult one from the Ediacara Hills of southern Australia.

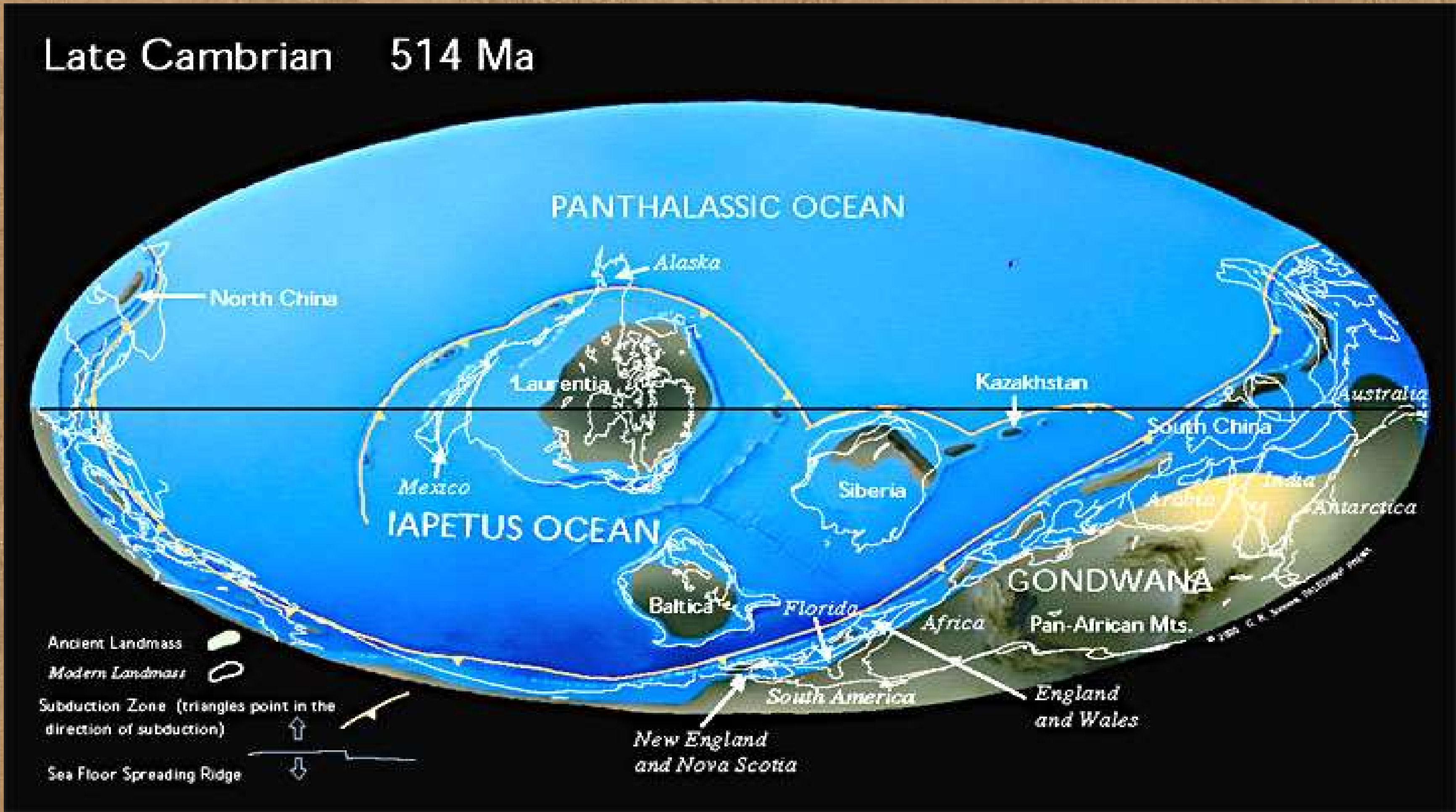
- The striking Vendian fossil *Spriggina* (shown here) and its close relative *Marywadea* make up the Sprigginida, a clade of soft-bodied organisms that are restricted to the Precambrian. *Spriggina* is known largely from the Ediacara Hills of south Australia, near Adelaide. The organism had a crescent-shaped head and numerous segments tapering to the posterior end; it is only about three centimeters long.

- *Spriggina* was described as an annelid (segmented worm), but it now appears to be related to the arthropods, although *Spriggina* had no hard parts, and it is unclear exactly what kind of appendages it had. Compare it to our pictures of trilobites and see what you think!

- **Few fossils of Ediacaran animals are so compellingly bizarre as this unusual disc-shaped form with three-part (triradial) symmetry. Named *Tribrachidium heraldicum*, its affinities are still mysterious, although distant relationships have been proposed with either the Cnidaria (corals and anemones) or Echinodermata (urchins and seastars).**

Cambrian: the beginning of the Paleozoic Era

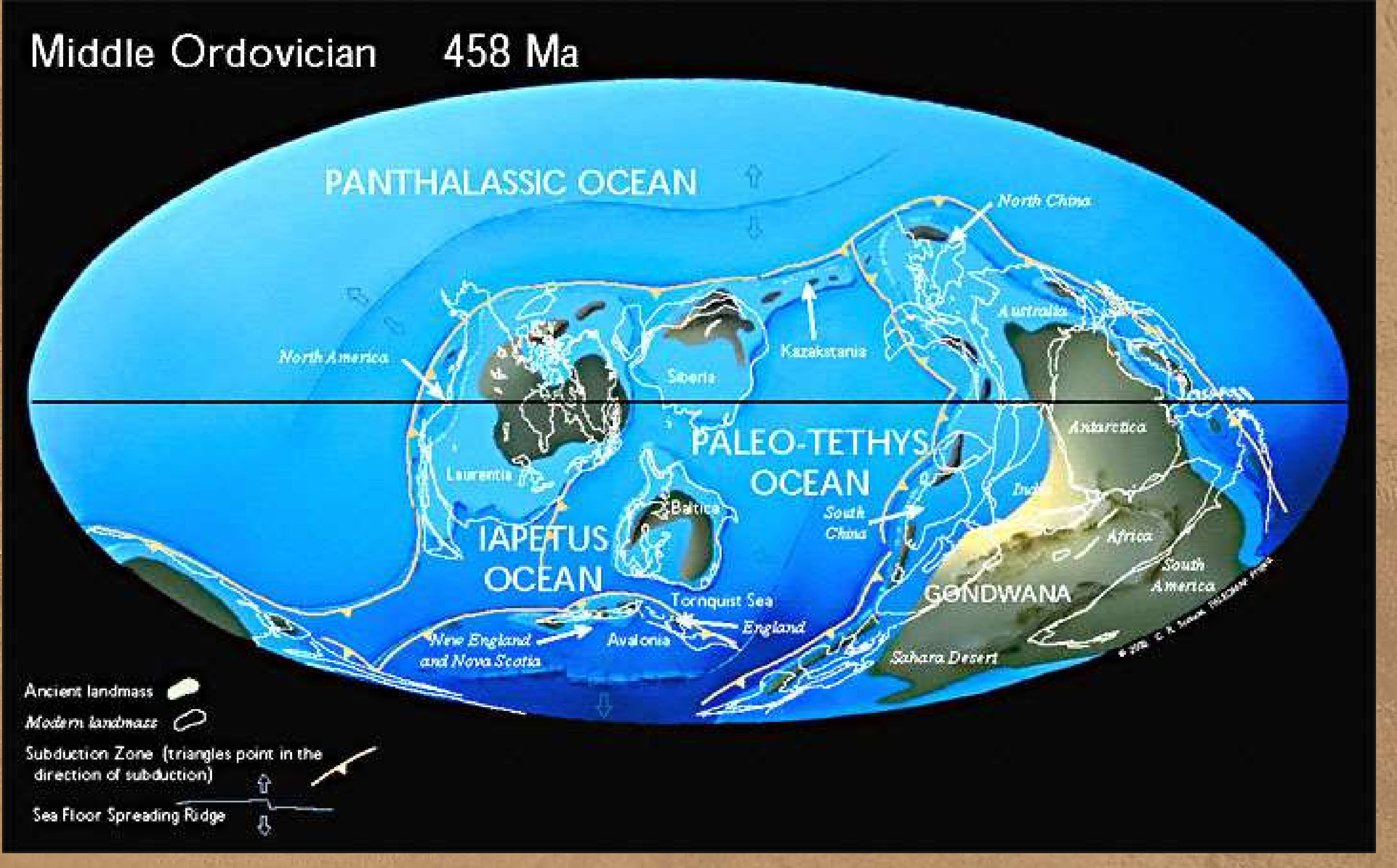
Animals with hard-shells appeared in great numbers for the first time during the Cambrian. The continents were flooded by shallow seas. The Supercontinent of Gondwana had just formed and was located near the South Pole.



The Cambrian Fossil Explosion

- EXTINCTION OF FIRST GREAT EXPANSION OF MARINE LIFE
- FIRST ANIMALS WITH HARD SKELETONS, (LIKE MOLLUSKS, CORALS) DEVELOP
- FIRST CHORDATES EVOLVE (GIVES RISE TO VERTEBRATES) BURGESS SHALE CREATURES
- FIRST TRACES OF VASCULAR PLANTS

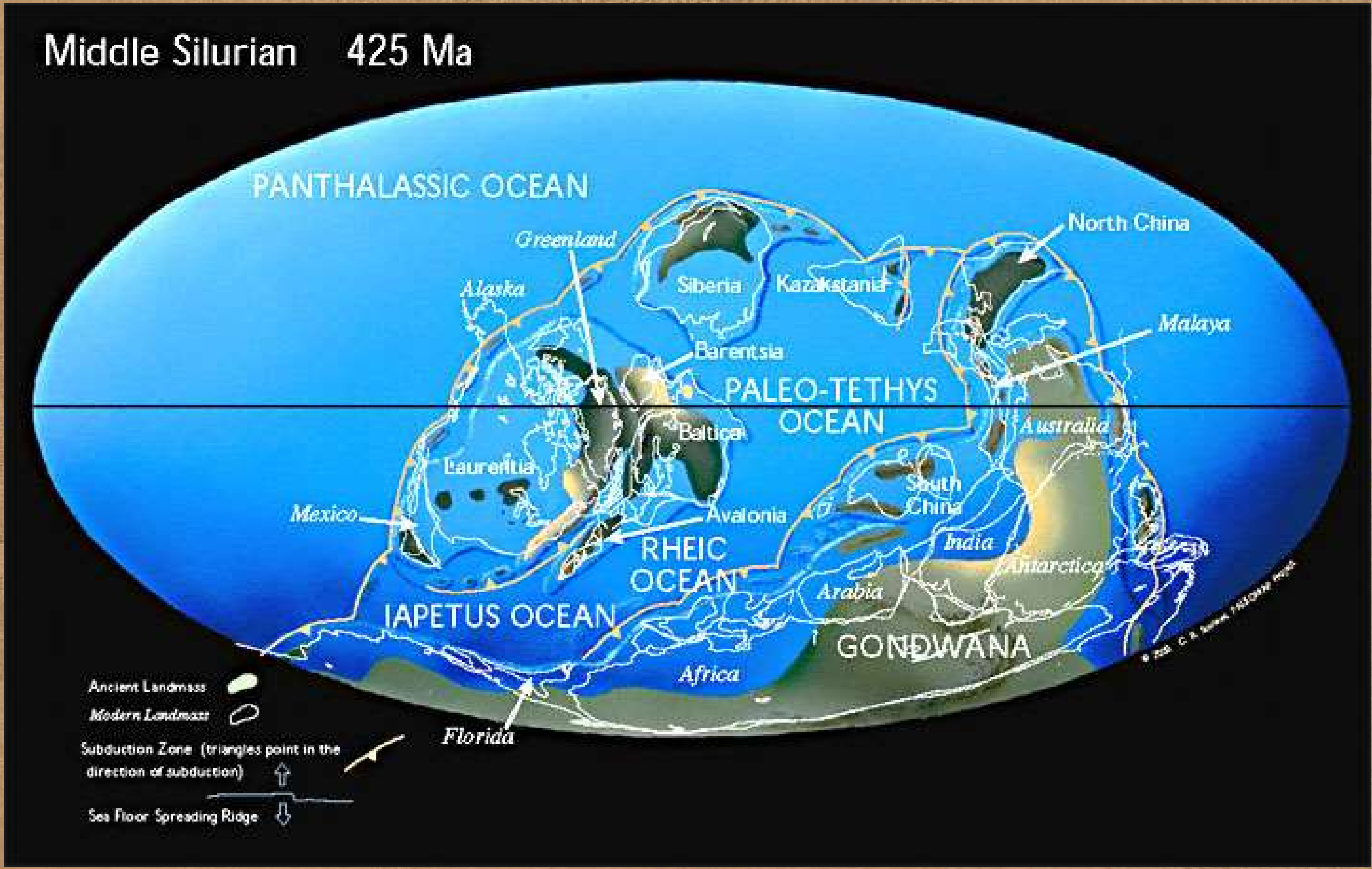
Ancient Oceans Separate the Continents during the Ordovician ancient oceans separated the barren continents of Laurentia, Baltica, Siberia and Gondwana. The end of the Ordovician was one of the coldest times in Earth history. Ice covered much of the southern region of Gondwana.



Ordovician

- During the Ordovician Period, warm water deposits, such as limestones and salt, were found in the equatorial regions of Gondwana (Australia, India, China, and Antarctica), while glacial deposits and ice-rafted debris occurred in the south polar areas of Gondwana (Africa and South America).

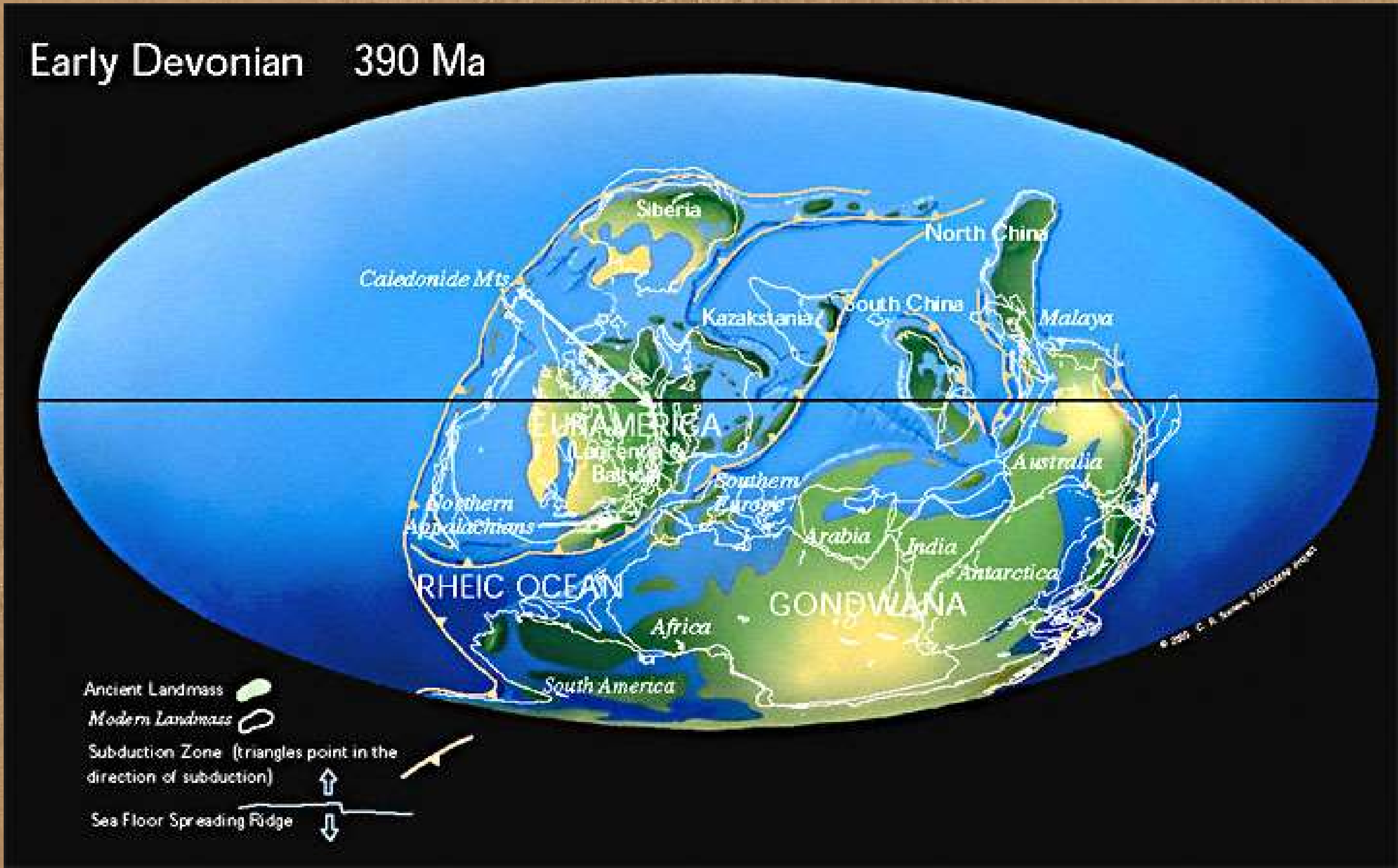
Continents begin to collide as Paleozoic Oceans close



SILURIAN

- Laurentia collides with Baltica closing the northern branch of the Iapetus Ocean and forming the "Old Red Sandstone" or “Old Red Continent” also called Euamerica. Coral reefs expand and land plants begin to colonize the barren continents.
- By middle Paleozoic time, approximately 400 million years ago, the Iapetus Ocean had closed bringing Laurentia and Baltica crashing together.
- This continental collision, preceded in many places by the obduction of marginal island arcs, resulted in the formation of the Caledonide mountains in Scandinavia, northern Great Britain and Greenland, and the Northern Appalachian mountains along the eastern seaboard of North America.
- It is also likely that by middle Paleozoic times, North China and South China had rifted away from the Indo-Australian margin of Gondwana, and were headed northwards across the Paleo-Tethys Ocean.
- Throughout the Early and Middle Paleozoic, the expansive Panthalassic Ocean covered much of the northern hemisphere. Surrounding this ocean was a subduction zone, much like the modern "ring-of-fire" that surrounds the Pacific Ocean.

The Devonian Was the Age of Fish!



DEVONIAN LIFE

- AMPHIBIANS APPEAR
- FISH GROUPS DEVELOP
- INSECTS APPEAR
- FIRST FORESTS
- ADVANCED PLANTS EVOLVE

Univ. of Michigan Exhibit Museum of Natural History -- Life Through the Ages Diroama

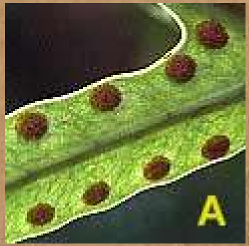

Archaeopteris

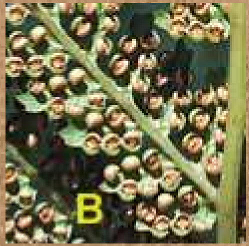
DEVONIAN

- By the Devonian the early Paleozoic oceans were closing, forming a "pre- Pangea".
- The Devonian was the Age of Fishes.
- Freshwater fish were able to migrate from the southern hemisphere continents to North America and Europe.
- Forests grew for the first time in the equatorial regions of Artic Canada.
- Surrounding this ocean was a subduction zone, much like the modern "ring-of-fire" that surrounds the Pacific Ocean.

Fish evolved jaws early in the Devonian and became the top predators by the end of this Period.

- Plants took over the land and became so abundant that the first coal deposits formed in the tropical swamps that covered much of the Canadian Arctic Islands, northern Greenland, and Scandinavia.

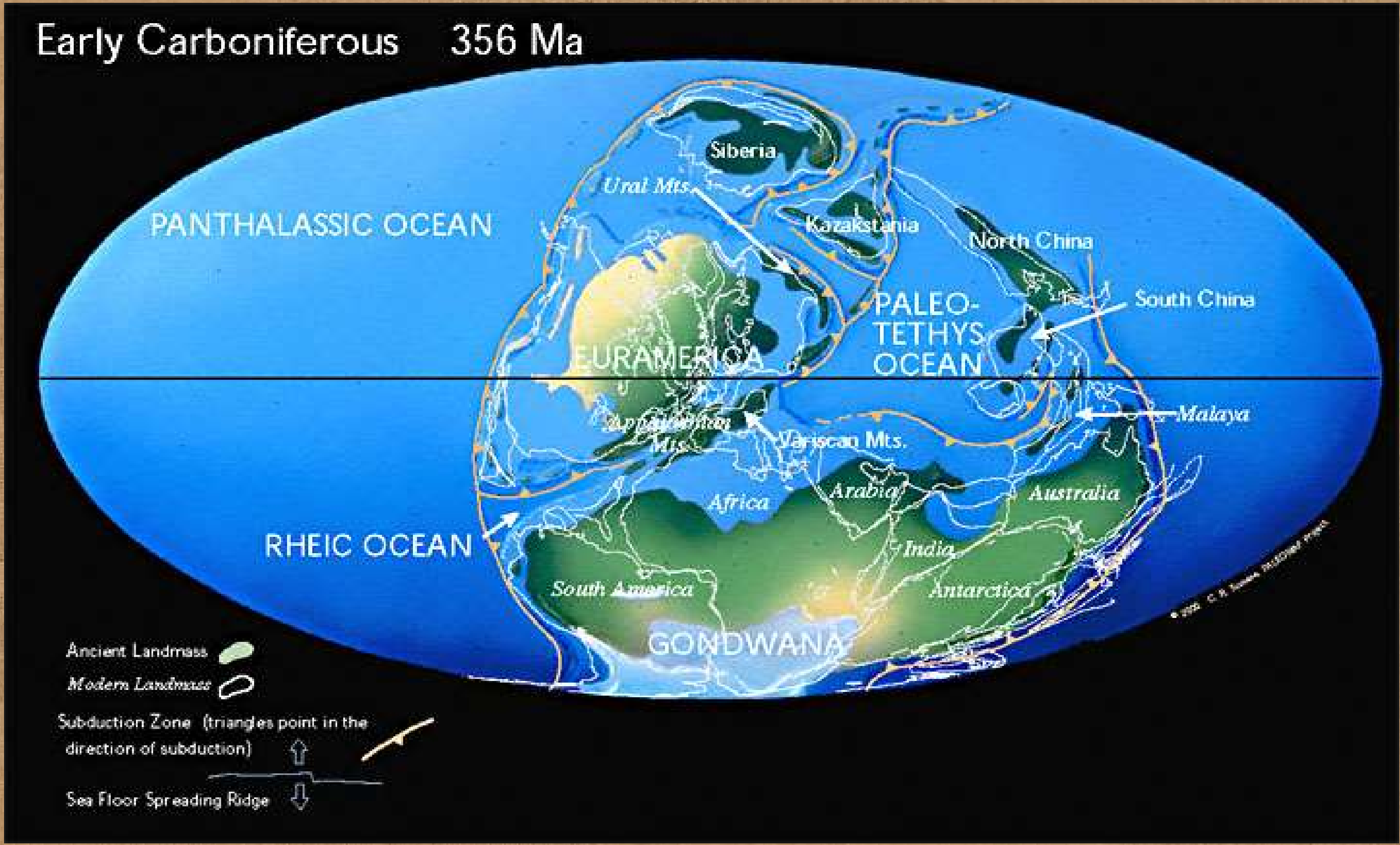




- Ferns are a very ancient family of plants: early fern fossils predate the beginning of the Mesozoic era, 360 million years ago. They are older than land animals and far older than the dinosaurs. They were thriving on Earth for two hundred million years before the flowering plants evolved.

- As we know them now, most ferns are leafy plants that grow in moist areas under forest canopy. They are "vascular plants" with well-developed internal vein structures that promote the flow of water and nutrients. Unlike the other vascular plants, the flowering plants and conifers, where the adult plant grows immediately from the seed, ferns reproduce from spores and an intermediate plant stage called a gametophyte.

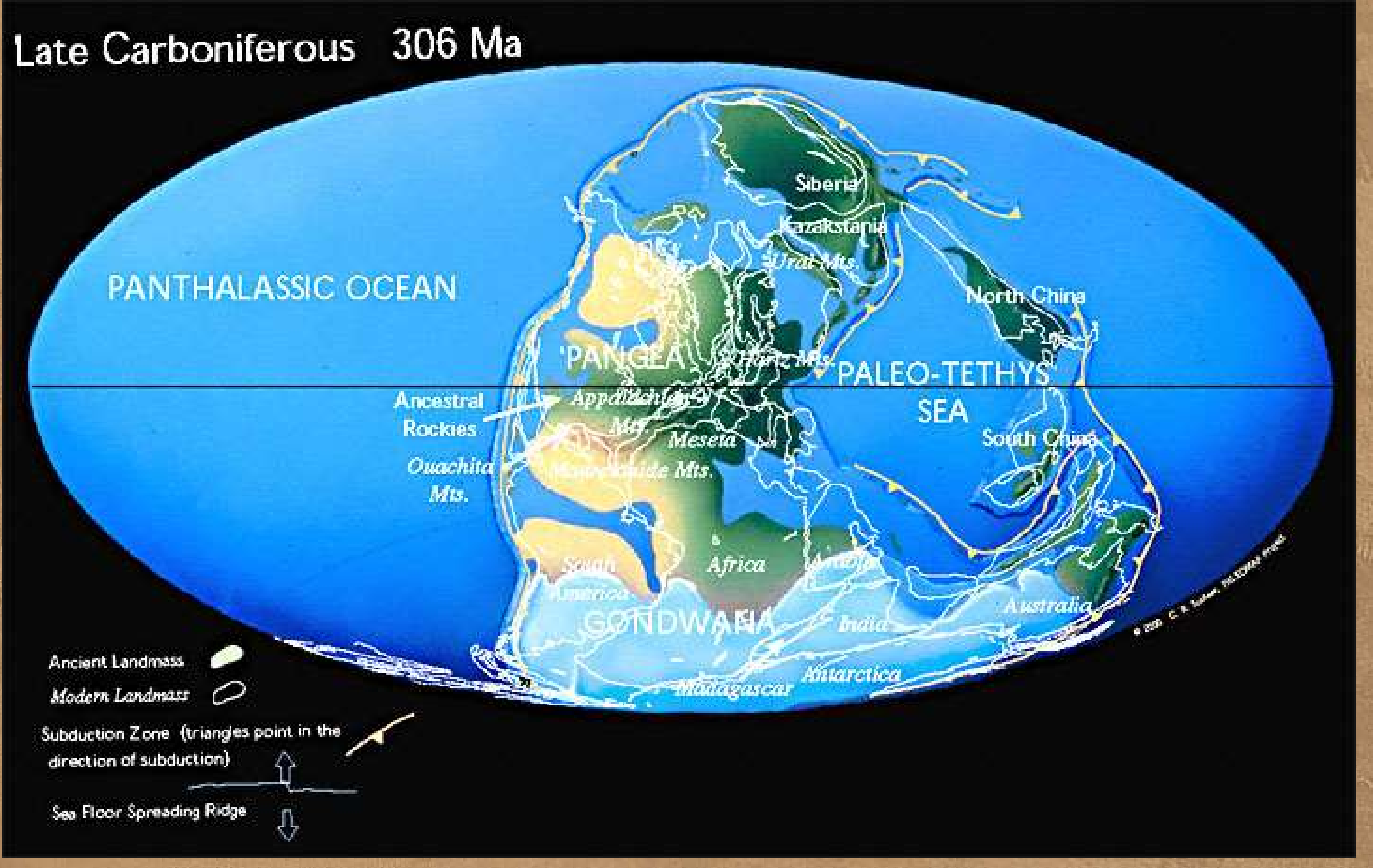
During the Early Carboniferous Pangea Begins to Form.



Early Carboniferous

- During the Early Carboniferous the Paleozoic oceans between Euramerica and Gondwana began to close, forming the Appalachian and Variscan mountains.
- An ice cap grew at the South Pole as four-legged vertebrates evolved in the coal swamps near the Equator.
- By the end of the Paleozoic Era, most of the oceans that had opened during the break-up of Pannotia, were consumed as the continents collided to form the Supercontinent of Pangea. Centred on the Equator, Pangea stretched from the South Pole to the North Pole, and separated the Paleo-Tethys Ocean to the east, from the Panthalassic Ocean to the west.

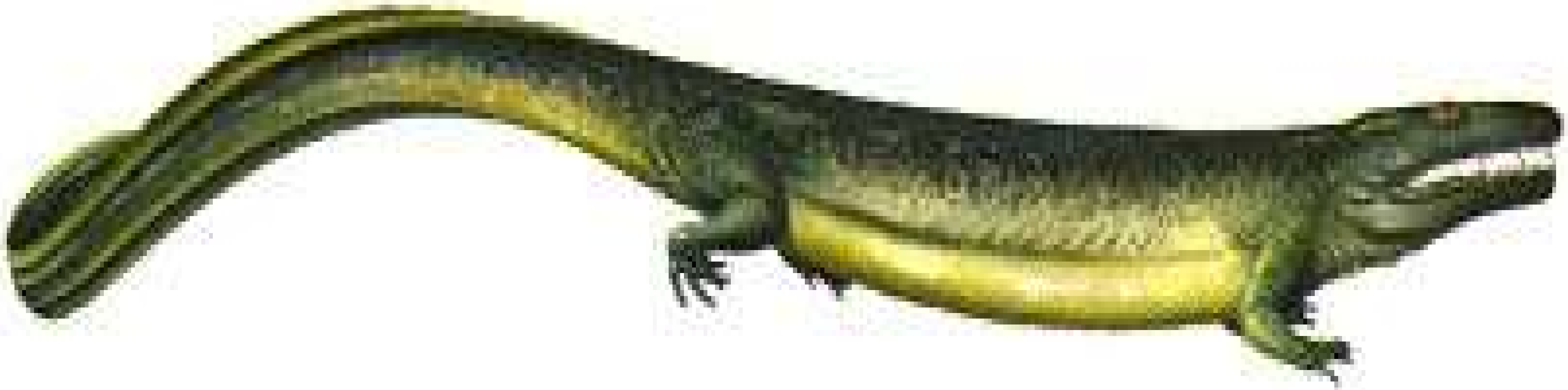
The Late Carboniferous a Time of Great Coal Swamps



Organisms that appeared during Carboniferous

- MAMMAL-LIKE REPTILES BEGIN TO DOMINATE LAND
- FIRST REPTILES DEVELOP AND COLONIZE LAND
- AMPHIBIANS EVOLVE
- TREES DOMINATE,CLUB MOSSES, HORSETAILS, FERNS
- GYMNOSPERMS (SEED-BEARING PLANTS) FIRST APPEAR

- **Carboniferous life**



- **Greererpeton** - a large carnivorous tetrapod that lived an eel-like existence in rivers and swamps (ca 2 m)

More info about the Late Carboniferous

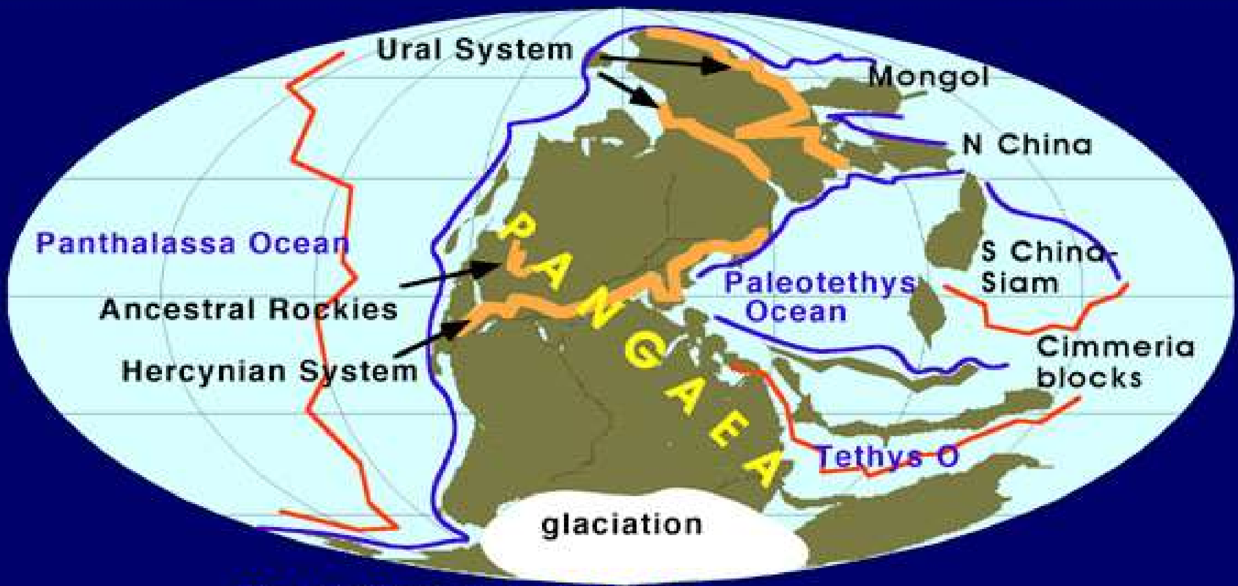
- During the Late Carboniferous and Early Permian the southern regions of Pangea (southern South America and southern Africa, Antarctica, India, southern India, and Australia) were glaciated.

- Evidence of a north polar ice cap in eastern Siberia during the Late Permian. The broad Central Pangean mountain range formed an equatorial highland that during late Carboniferous was the locus of coal production in an equatorial rainy belt. By the mid-Permian, the Central Pangean mountain range had moved northward into drier climates and the interior of North America and Northern Europe became desert-like as the continued uplift of the mountain range blocked moisture-laden equatorial winds.

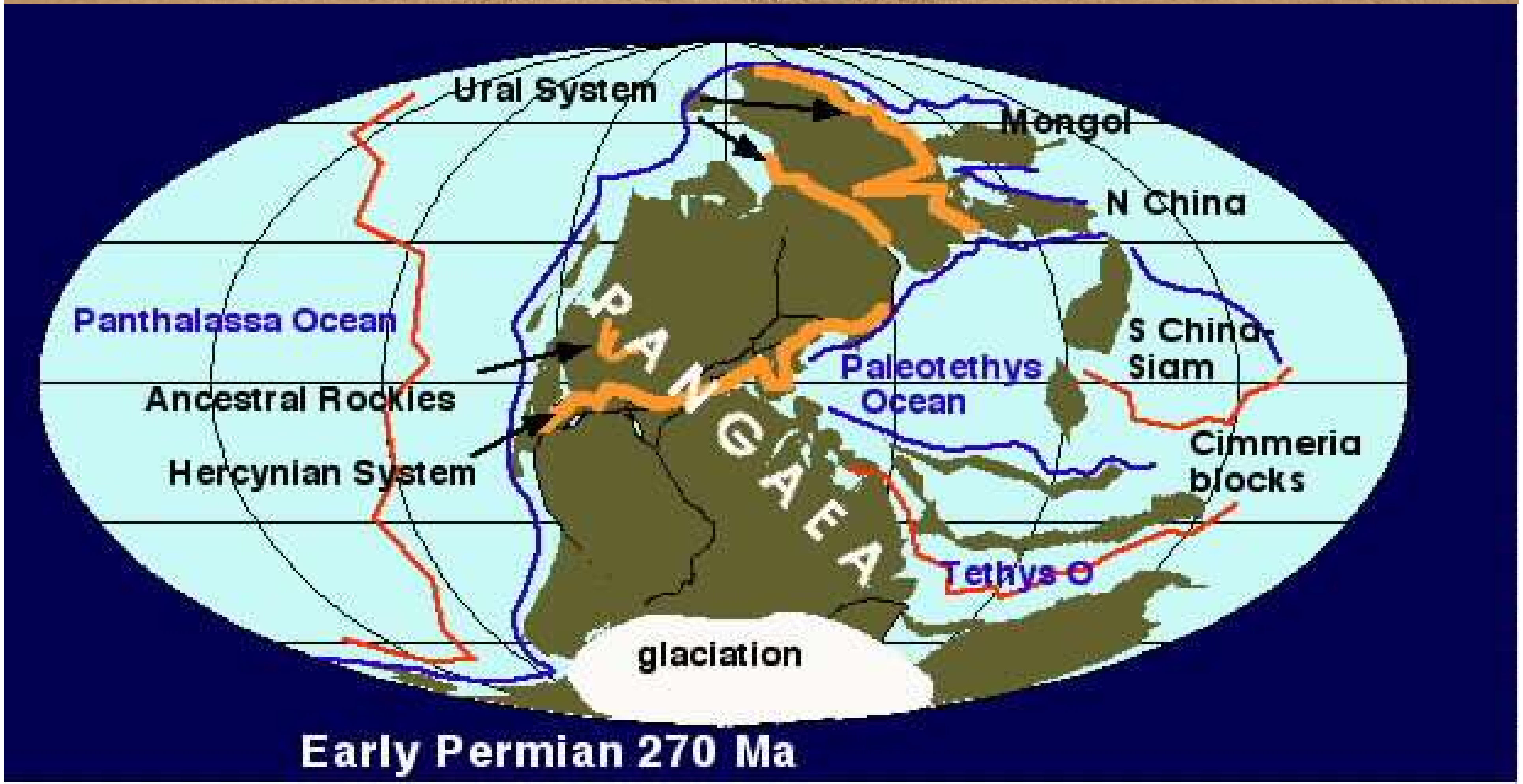
- The term "Pangea" means "all land". Though we call the supercontinent that formed at the end of the Paleozoic Era, "Pangea", this supercontinent probably did not include all the landmasses that existed at that time.

- In the eastern hemisphere, on either side of the Paleo-Tethys Ocean, there were continents that were separated from the supercontinent. These continents were North and South China, and a long "windshield-wiper"-shaped continent known as Cimmeria. Cimmeria consisted of parts of Turkey, Iran, Afghanistan, Tibet, Indochina and Malaya. It appears to have rifted away from the Indo-Australian margin of Gondwana during the Late Carboniferous - Early Permian.
-
- Together with the Chinese continents, Cimmeria moved northwards towards Eurasia, ultimately colliding along the southern margin of Siberia during the late Triassic Period.

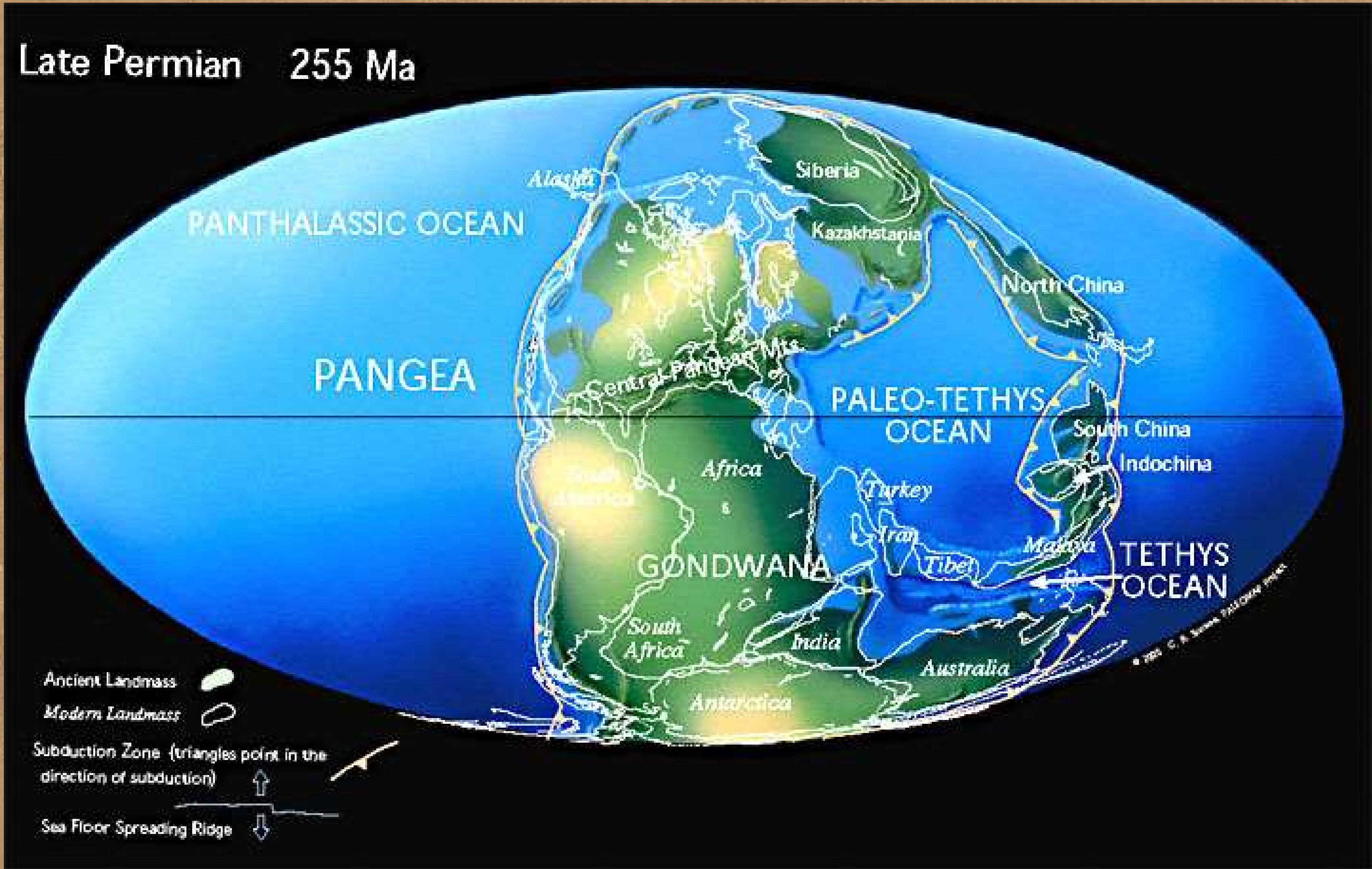
- It was only after the collision of these Asian fragments that all the world's landmasses were joined together in a supercontinent deserving of the name "Pangea".



Early Permian 270 Ma


Ural System
Mongol
N China
Panthalassa Ocean
PANGAEA
S China-
Siam
Paleotethys
Ocean
Ancestral Rockies
Cimmeria
blocks
Hercynian System
Tethys O
glaciation
Early Permian 270 Ma

Permian



Late Permian 255 Ma
PANTHALASSIC OCEAN
PANGEA
Alaska
Siberia
Kazakhstania
North China
Central Pangean Mts.
PALEO-TETHYS OCEAN
South China
Indochina
Africa
Turkey
Iran
Tibet
Malaya
TETHYS OCEAN
GONDWANA
South Africa
India
Australia
Antarctica
Ancient Landmass
Modern Landmass
Subduction Zone (triangles point in the direction of subduction)
Sea Floor Spreading Ridge

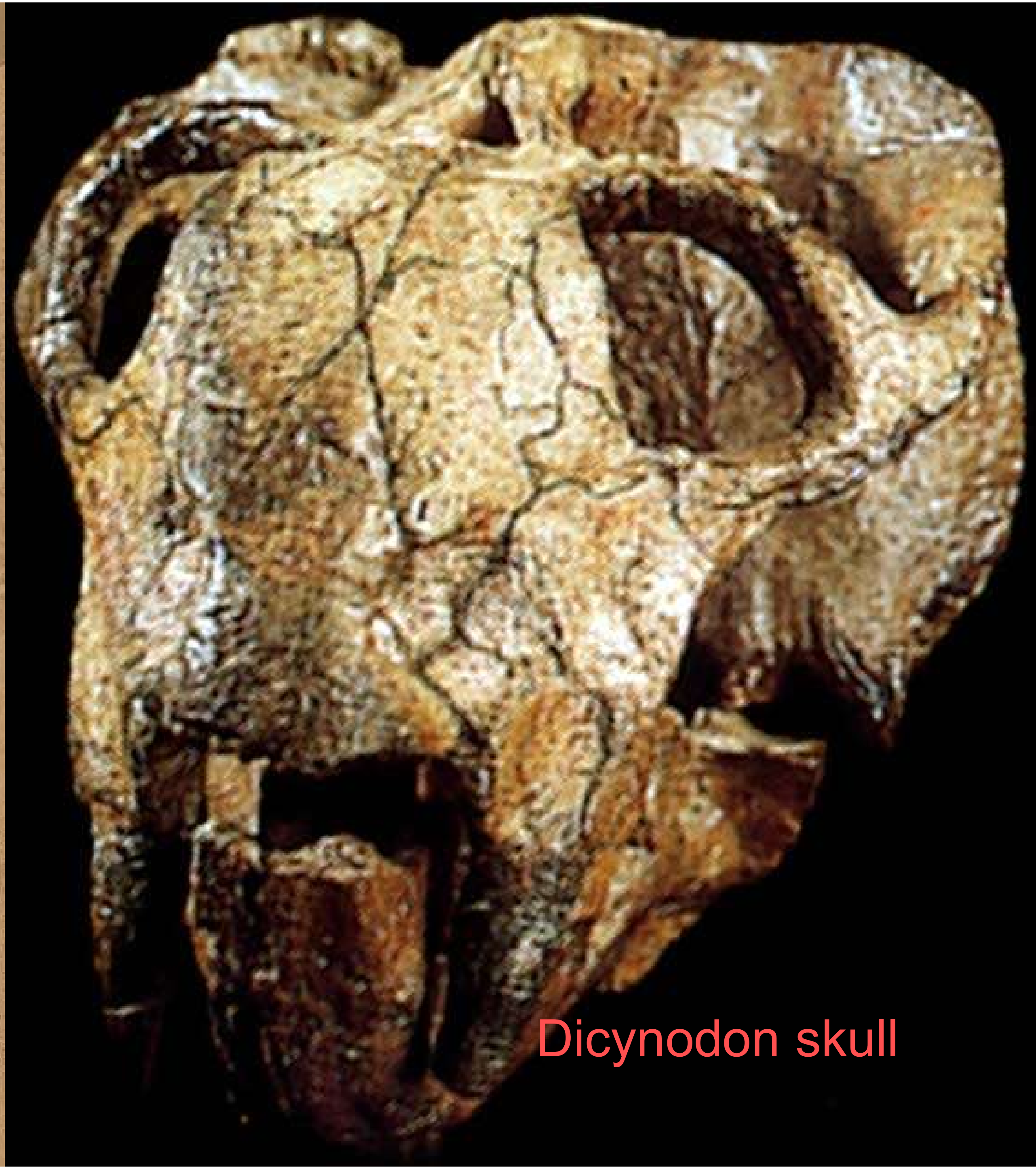
At the end of the Permian was Greatest Extinction of All Time

- Vast deserts covered western Pangea during the Permian as reptiles spread across the face of the supercontinent. 99% of all life perished during the extinction event that marked the end of the Paleozoic Era.
- Trilobites and other types of marine life dissapear
- Mammal-like reptiles and archosaurs dominate land

- The first, the pelycosaur dynasty, included the large finbacks of the early Permian such as *Dimetrodon*, *Edaphosaurus*, *Ctenospondylus*, and *Secodontosaurus* all of which attained a lengths some 3 meters, as well a similar types that lacked a "sail". The large dorsal "sails" were most certainly thermoregulatory devices that would heat up the animal in the cold morning, making it more active and giving it an advantage over it's more sluggish sail-less relatives. These animals were limited to the equatorial tropics.

Deltavjatia

The Synapsids are ancestors of the mammals and became the dominant species in the Permian. By the Mid-Permian the Pelycosaurs were replaced as the dominant species by the Therapsids, known as the mammal-like reptiles. These were more advanced Synapsids which were far more metabolically active, encompassing both herbivorous and carnivorous forms.

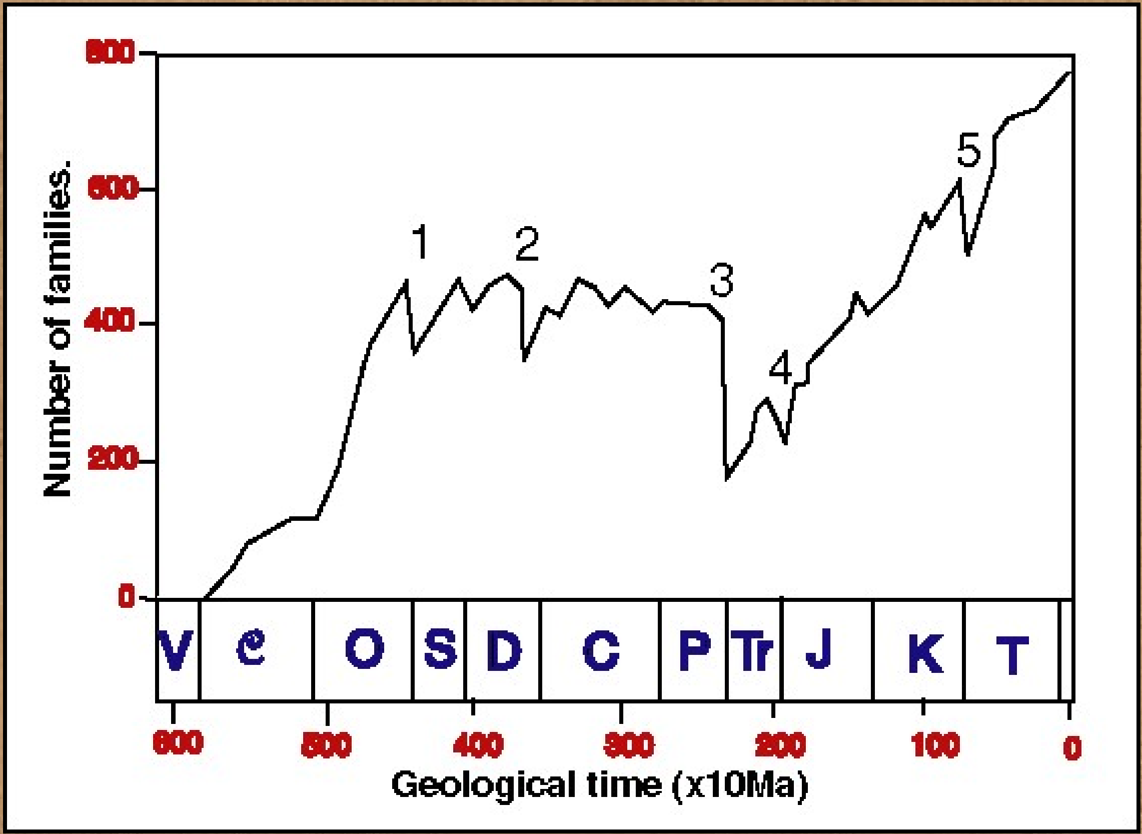


Dicynodon skull

- **The warm shallow oceans swarmed with many kinds of life, basically very similar to Carboniferous forms (*see left*). Sedentary organisms like stromatolites, algae, foraminifers, sponges (*Heliospongea* (yellow) shown here), corals, bryozoa, and brachiopods (including the spiny *Edriosteges*) shown here), built great reefs which in turn provided homes and shelter for active animals like ammonoids, nautiloids, gastropods and fish. Ammonoids differed from their Carboniferous predecessors in that they had far more complex suture lines, frequently with many-pointed lobes and rounded saddles.**
- **There was a major extinction event at end of period, due in part to continental shelf environments being reduced; trilobites and many other groups of organisms became extinct**

THE PERMO-TRIASSIC EXTINCTION

DEVASTATION!



Mass Extinctions: (1) end Ordovician. (2) late Devonian. (3) end Permian. (4) end Triassic. (5) end Cretaceous.

What life was present?

Foraminifera:
- Fusilina
- Non-fusiline Foraminifera

Porifera
Corals:
- Tabulata
- Rugosa

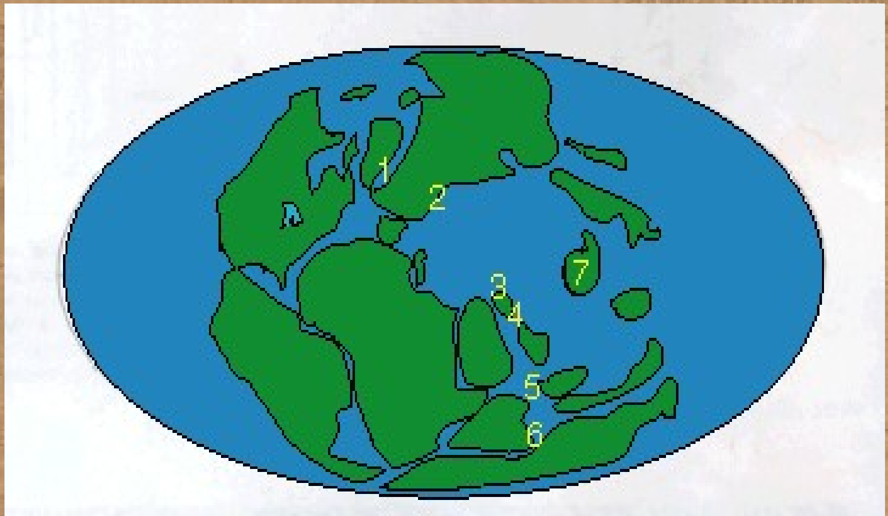
Bryozoa
Brachipods
Mollusca:
- Bivalvia
- Gastropoda
- Orthocerida
- Nautiloidea
- Ammonoidea

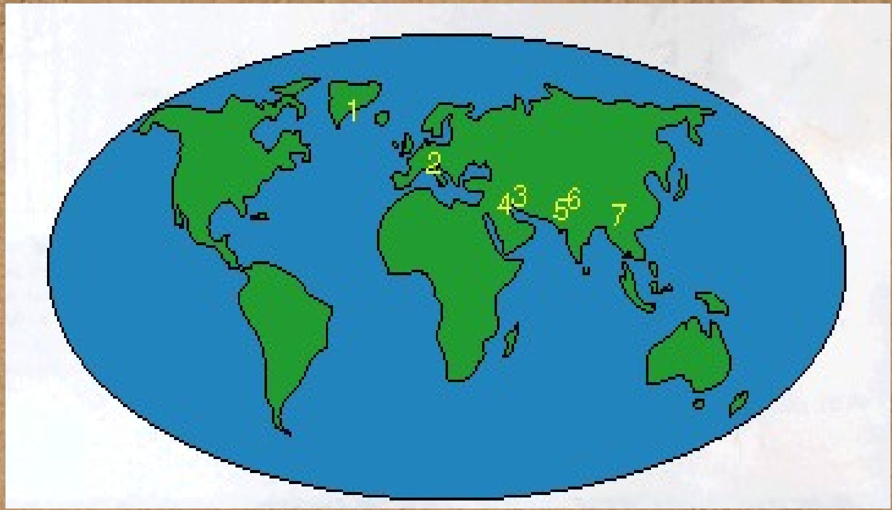
Echinoidermata:
- Echinoidea
- Blastoidea
- Crinoidea

Arthropoda:
- Trilobitae
- Ostracoda

Conodonta
Vertebrates
Vascular plants

EVIDENCE





Localities (1) Greenland. (2) Southern Alps. (3) Iran-Armenia border. (4) Central Iran. (5) Pakistan. (6) Kashmir. (7) Southern China.

What caused the extinction?

- Volcanism
- Meteorite impact
- Climate change
- Formation of a Supercontinent
- Glaciation

The Siberian Traps

The Siberian Traps were the largest volcanic eruption in Earth history and they occurred right at the same time as the largest extinction event in Earth history.

Co-incidence?

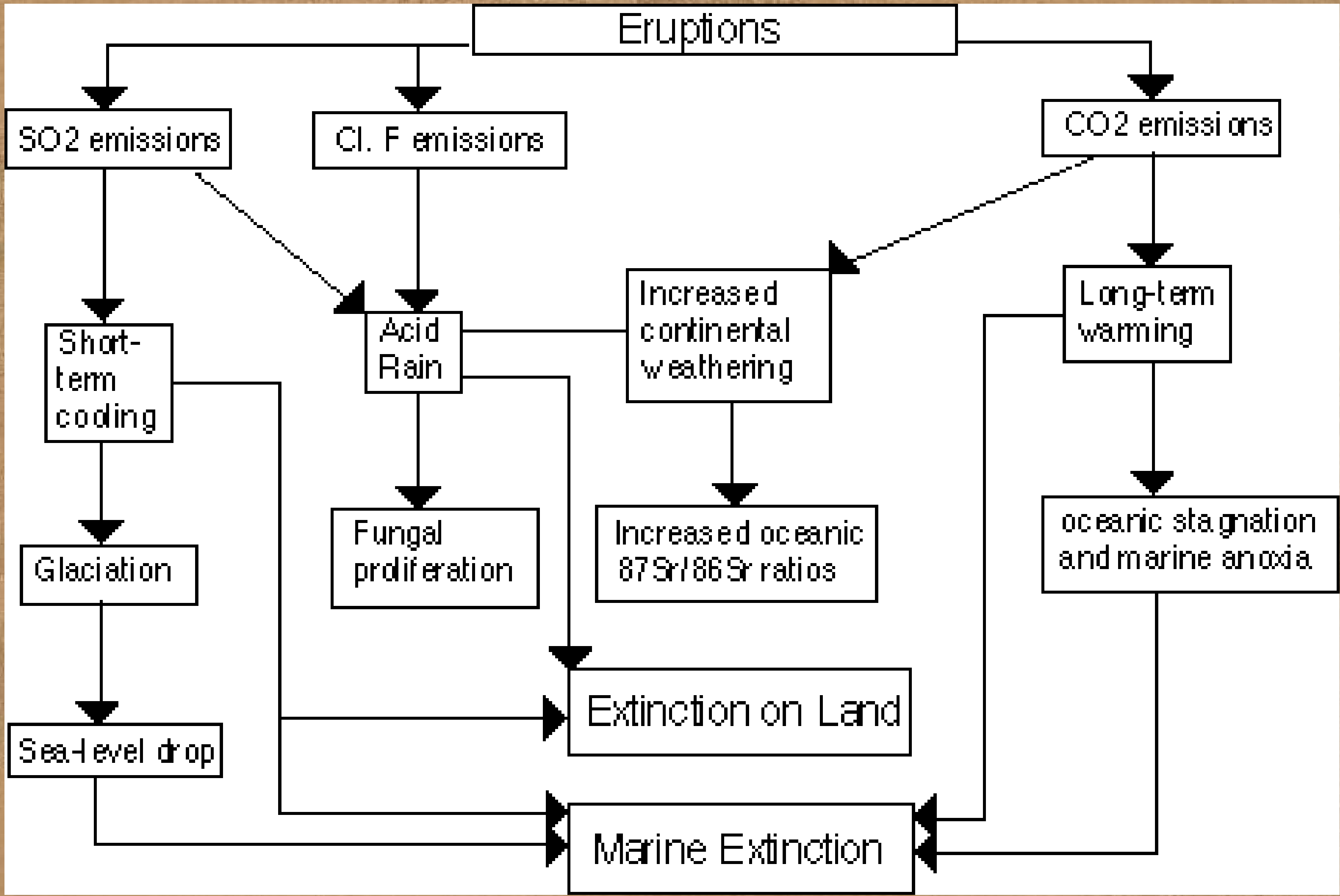
Mantle plume formation

It is engrained in everyone from an early age that volcanic eruptions are dangerous to life so the Siberian Traps could indeed hold the key to explaining the Permo-Triassic Extinction event

Map of the Siberian Traps

Map based on geological map by Zolotukhin and Al'Mukhamedov,1998

Event Flow Chart (P. B. Wignall, 2000)



Extraterrestrial impacts

- Large meteorites with the potential to cause major global environmental change strikes the earth on average every 100000 years, according to NASA. Geologically speaking, 100000 years is a short time interval making it plausible that every so often a "biggie" meteorite could hit the earth and cause a global catastrophe on the Permian type scale .
  - Rare element anomalies (Ir)
  - Shocked quartz (Stishovite)
  - Ejectile beds (rapid deposition near to an impact)
- Debate on the Permian-Triassic boundary
- Xu and Yang, 1993 and Yang et al. 1995 all reported Iridium spikes and Stishovite microspherules in non-marine Permian -Triassic boundary sediments in Australia and Antarctica.
- The presence of the stishovite has been disputed (Holser et al. 1991) which has cast serious doubts on the plausibility of an impact at all.
- Hank Visscher et al. 1996 found fungal cells in P-T boundary terrigenous sediments. These have been interpreted as fungi breaking down massive amounts of vegetation that have been catastrophically killed. These are good evidence of a catastrophic extinction and an impact is the most catastrophic of them all.

Extraterrestrial Impacts

- Very recently a research team led by Dr Luann Becker has published that they have chemical evidence for a meteorite strike 251 millions years ago at the time of the Permian crisis. The evidence is based on complex carbon molecules called fullerenes which have cosmogenic isotopes of helium and argon trapped inside their "football like" structure. The fullerenes show an unusually high concentration at the time of the extinction in three boundary sections in Japan,

China and Hungary.

Climate change

- As well as getting hotter there is evidence that the climate also cooled. Sedimentological evidence for cooling comes from glacial deposits in polar zones, and thick dune sands and evaporites from temperate zones that represent a cool dry environment. Some of the volcanic gasses released from the Siberian trap flood basalts could have the opposite affect to the CO_2, cooling the climate instead of heating it. Why these had this affect is mentioned in volcanism

- Other evidence comes form the reduced presence of carbonate limestones around the end of the Permian. This process would have had the greatest affect in the tropics where most of the Earth's limestone production occurs. Cooling would eliminate the tropical areas and kill tropical species, and if there were less Carbonate producers there would be less Carbonate which is what is seen.

- Another cooling affect comes from Glaciation. Cooling can happen in low latitudes without there being Glaciation and in this way just the cooling of the climate would be the cause of extinction by the method mentioned above. As well as getting hotter there is evidence that the climate also cooled. Sedimentological evidence for cooling comes from glacial deposits in polar zones, and thick dune sands and evaporites from temperate zones that represent a cool dry environment. Some of the volcanic gasses released from the Siberian trap flood basalts could have the opposite affect to the CO_2, cooling the climate instead of heating it. Why these had this affect is mentioned in volcanism

Formation of Pangea

Coastal regions

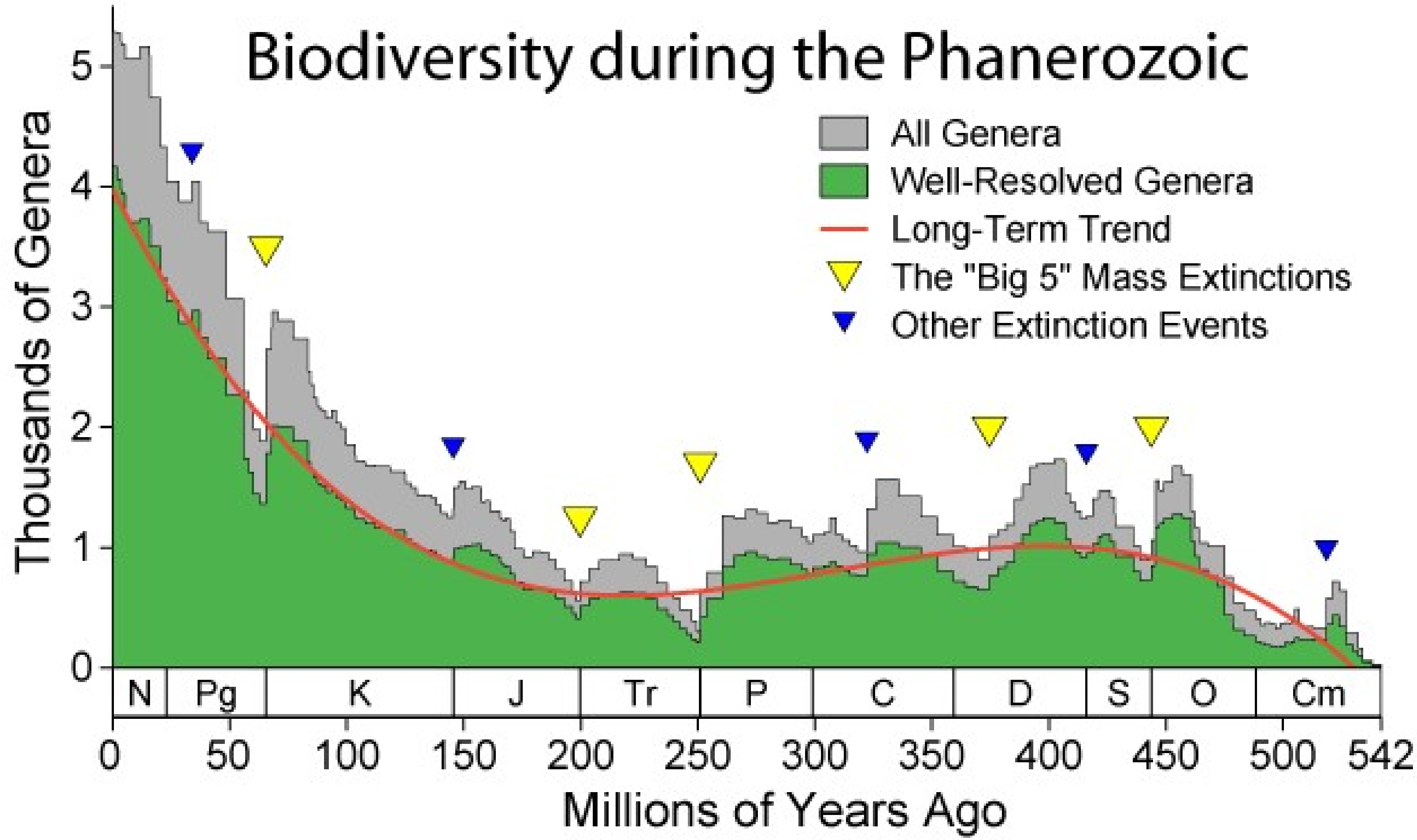
With the land joined together, the area of coastline around the edge of the Supercontinent would have been reduced. Many researchers believe the reduction of shallow marine environments led to less habitat being available to marine organisms. With less habitat, there would have been competition for space and food. Any species that could not adapt to a different environment would be challenged by other species for the remaining shallow marine habitat. This could be one reason why there has been such a loss of marine species recorded for the Permian.

Glaciation

- **Milankovitch cycle**
- **Land over the Poles**

Evidence for glaciation can be seen in abundant glacial deposits of Permian age found in Australia, Siberia and in the North sea.

Sea level change due to ice sheets also lead to layers of Shale, siltstone, Limestone, Sandstone, Marl and Dolomite indicating a regressive period.


Biodiversity during the Phanerozoic
All Genera
Well-Resolved Genera
Long-Term Trend
The "Big 5" Mass Extinctions
Other Extinction Events
Thousands of Genera
0
1
2
3
4
5
N
Pg
K
J
Tr
P
C
D
S
O
Cm
0
50
100
150
200
250
300
350
400
450
500
542
Millions of Years Ago

Permian-Triassic boundary

- On Oceans and continents there is mass extinction at the Permian-Triassic boundary in both plants and animals.
- In oceans and continents extinctions are directly followed by large negative delta 13C shift suggesting sudden and massive disruption of the carbon cycle.
- No “fern spike” has been found at the boundary.
- No Ir anomaly has been found at the boundary.
- No shocked quartz has been found.
- Fullerenes with extraterrestrial He isotopic ratios have been reported.
- There are candidate impact sites.
- But Siberian Traps very close to boundary.
- Effects on the history of marine life massive, but effects less clear for continental life.

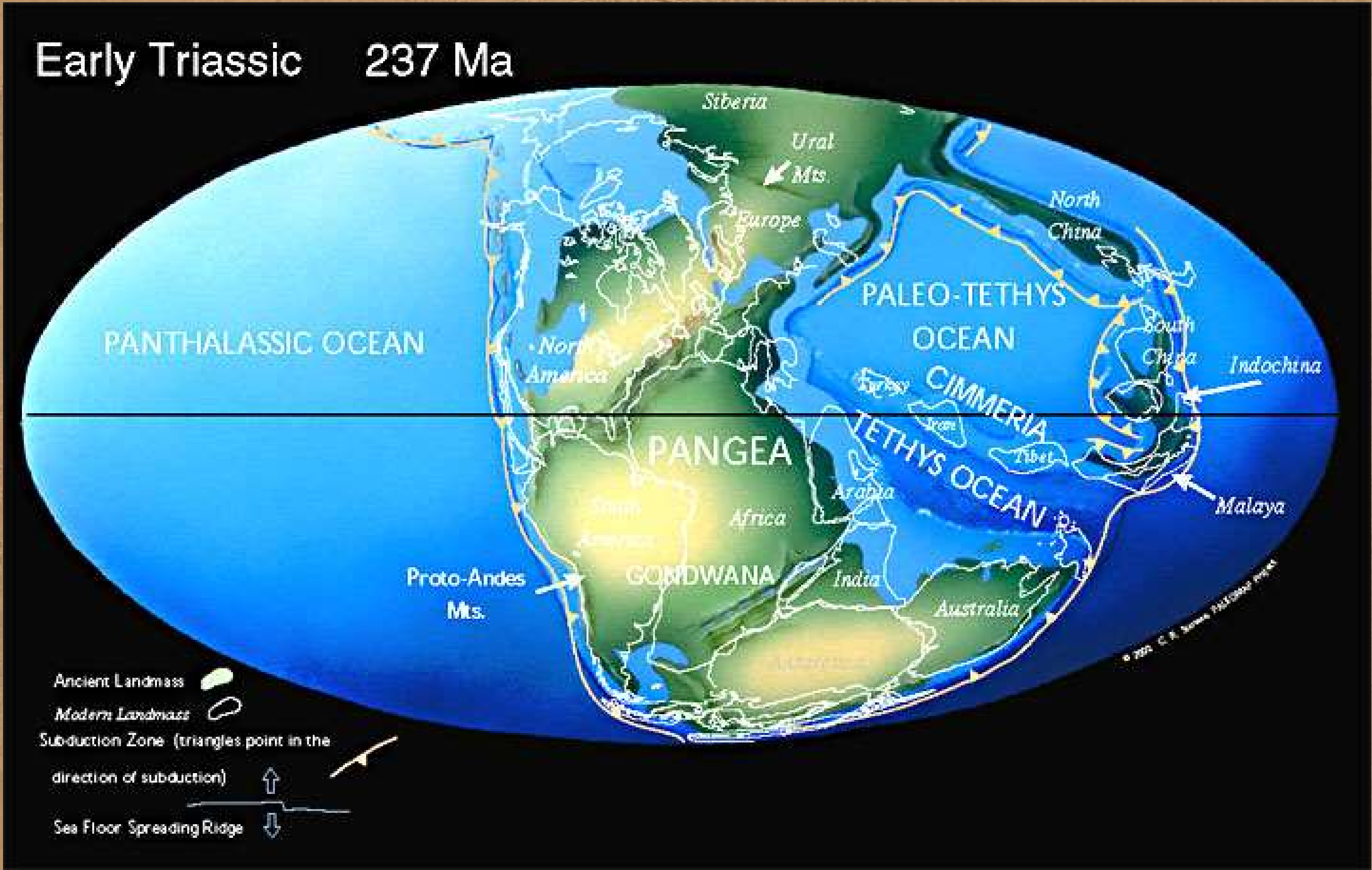
TRIASSIC 251 – 205 Ma

During the latest Paleozoic into the early Mesozoic, Pangaea lay extant, across the equator. Several slices were removed from the north-eastern margin of Gondwana and drifted across the Tethys Ocean to collide with Asia.

Most notable were the Cimmerian blocks that included Turkey, Iran, Afghanistan, Tibet, and Malaysia. The western fringe of Pangaea was adjacent to a long subduction zone that formed the eastern margin of the Pacific "ring of fire".

Arc collision along western N. A. forms the Sonoman orogeny. As the Tethys Ocean expands, Cimmeria (Turkey, Iran, and Afghanistan) move northward towards Laurasia.

Triassic

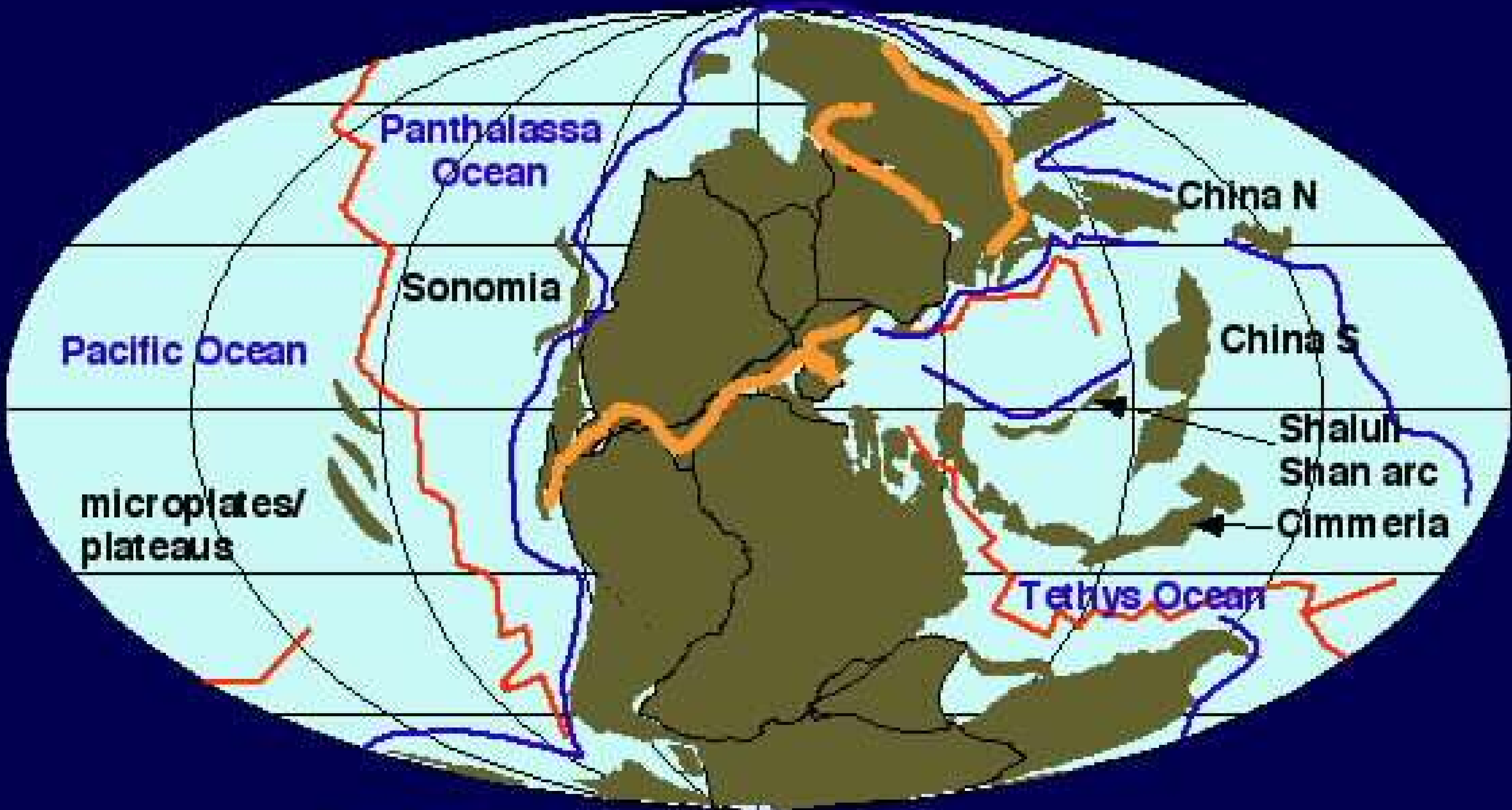

Early Triassic 237 Ma
Siberia
Ural Mts.
Europe
North China
PALEO-TETHYS OCEAN
South China
Indochina
PANTHALASSIC OCEAN
North America
CIMMERIA
Turkey
Iran
Tibet
TETHYS OCEAN
PANGEA
Arabia
Africa
Malaya
South America
Proto-Andes Mts.
GONDWANA
India
Australia
Ancient Landmass
Modern Landmass
Subduction Zone (triangles point in the direction of subduction)
Sea Floor Spreading Ridge

More Info about the Triassic

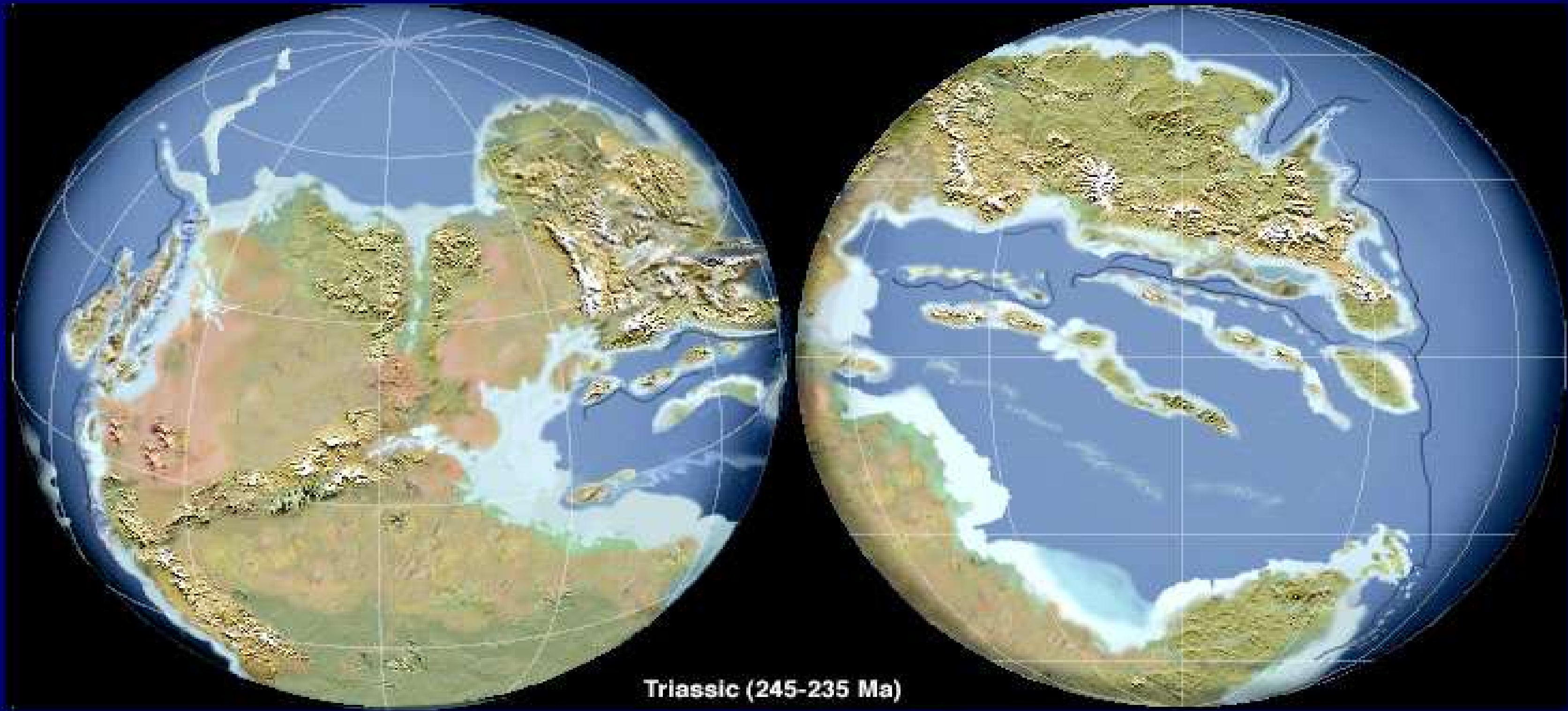
- Pangea was assembled piece-wise. The continental collisions that lead to the formation of the supercontinent began in the Devonian and continued through the Late Triassic.

- In a similar fashion, the supercontinent of Pangea did not rift apart all at once, but rather was subdivided into smaller continental blocks in three main episodes. The first episode of rifting began in the middle Jurassic, about 180 million years ago. After an episode of igneous activity along the east coast of North America and the northwest coast of Africa, the Central Atlantic Ocean opened as North America moved to the northwest (See Jurassic). This movement also gave rise to the Gulf of Mexico as North America moved away from South America. At the same time, on the other side of Africa, extensive volcanic eruptions along the adjacent margins of east Africa, Antarctica, and Madagascar heralded the formation of the western Indian Ocean.

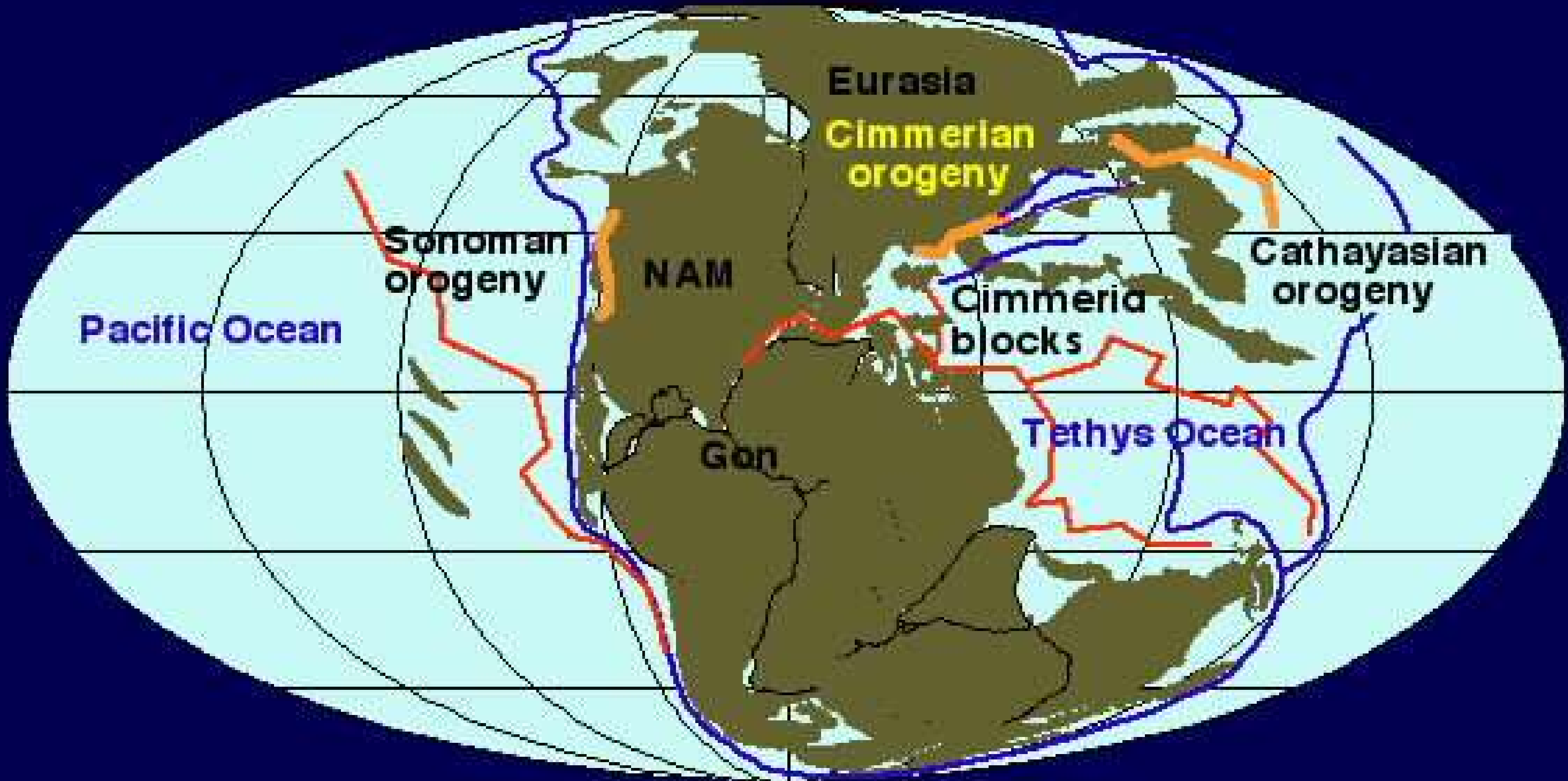
- During the Mesozoic North America and Eurasia were one landmass, sometimes called Laurasia. As the Central Atlantic Ocean opened, Laurasia rotated clockwise, sending North America northward, and Eurasia southward. Coals, which were abundant in eastern Asia during the early Jurassic, were replaced by deserts and salt deposits during the Late Jurassic as Asia moved from the wet temperate belt to the dry subtropics. This clockwise, see-saw motion of Laurasia also lead to the closure of the wide V-shaped ocean, Tethys, that separated Laurasia from the fragmenting southern supercontinent, Gondwana.



Early Triassic 250 Ma


Triassic (245-235 Ma)


Eurasia
Cimmerian orogeny
Sonoman orogeny
NAM
Cathyasian orogeny
Cimmeria blocks
Pacific Ocean
Tethys Ocean
Gon
Late Triassic 220 Ma



Late Triassic 220 Ma

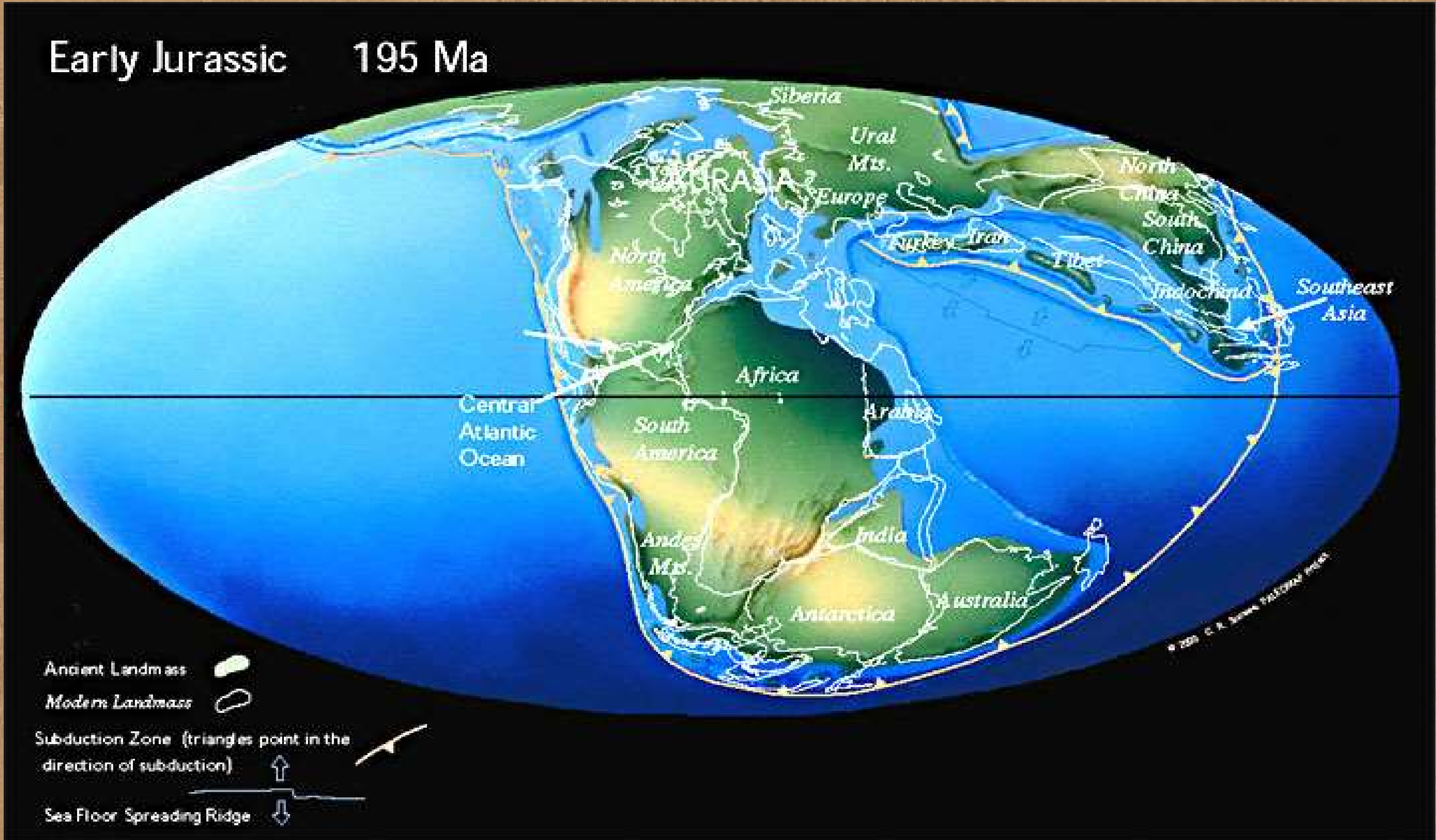
TRIASSIC LIFE

- PRIMITIVE TRUE MAMMALS EVOLVE
- MAMMAL-LIKE REPTILES DISAPPEAR
- DINOSAURS APPEAR
- REPTILES DIVERSIFY AND DOMINATE
- GYMNOSPERMS EVOLVE (SEED-BEARING PLANTS)

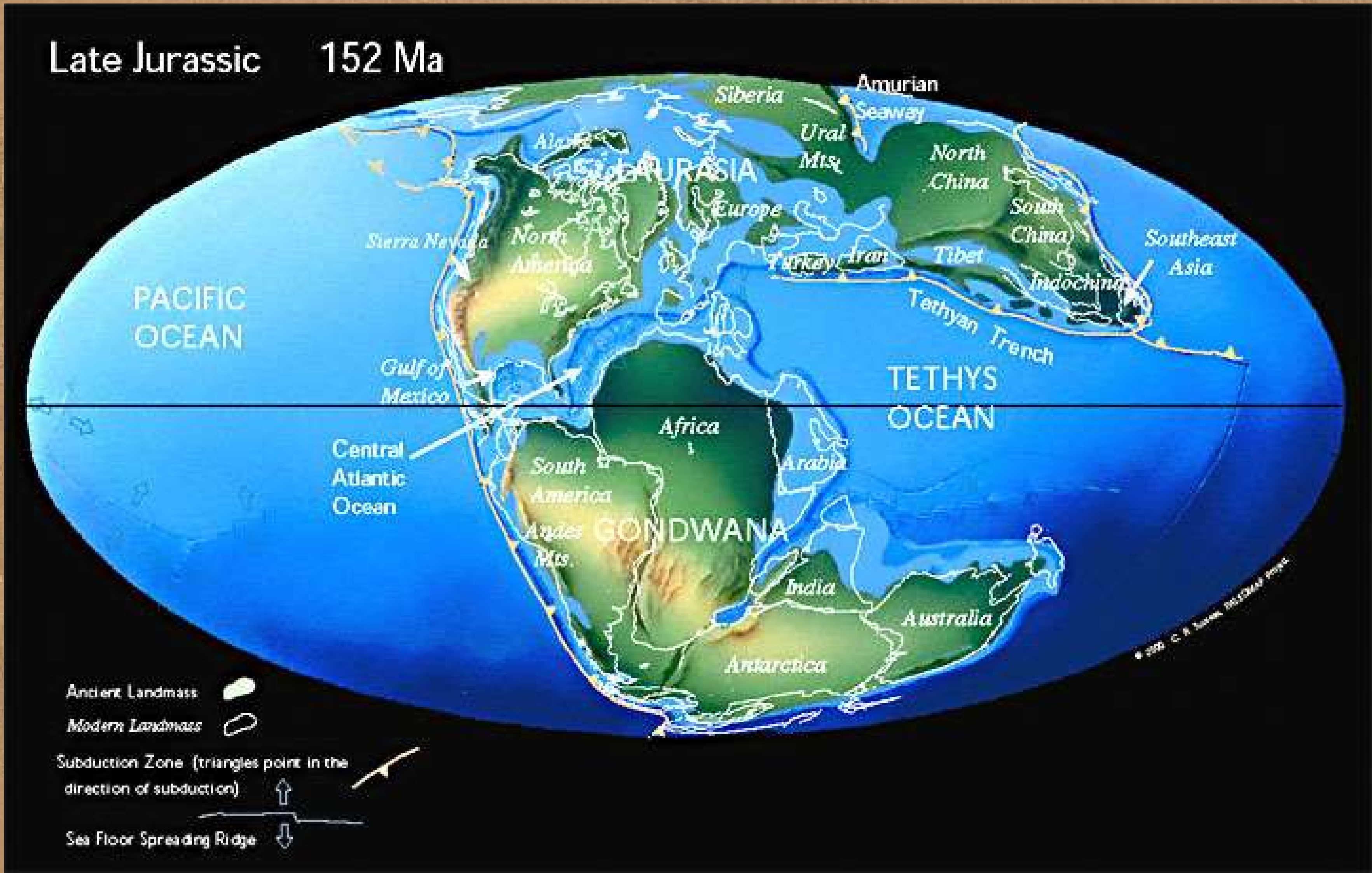
- When dinosaurs first appeared about 230 million years ago the world was very different. There were very few of the animal groups we recognise today - no mammals, no birds and no lizards. But there were some lizard-like reptiles.

- **The Triassic world was unusual for another reason. About 20 million years before the appearance of the first dinosaurs, the biggest extinction the world had ever known had occurred. Over 90% of all plant and animal species then alive on land and in the sea had died out at this time. Even in the Late Triassic the world was still recovering, and there was not the usual variety of life normally found on earth. By the end of the period not only the dinosaurs had appeared but also pterosaurs (flying reptiles), various kinds of marine reptiles, the first crocodiles and turtles, and the earliest true mammals.**

Early Jurassic, the Dinosaurs spread across Pangea

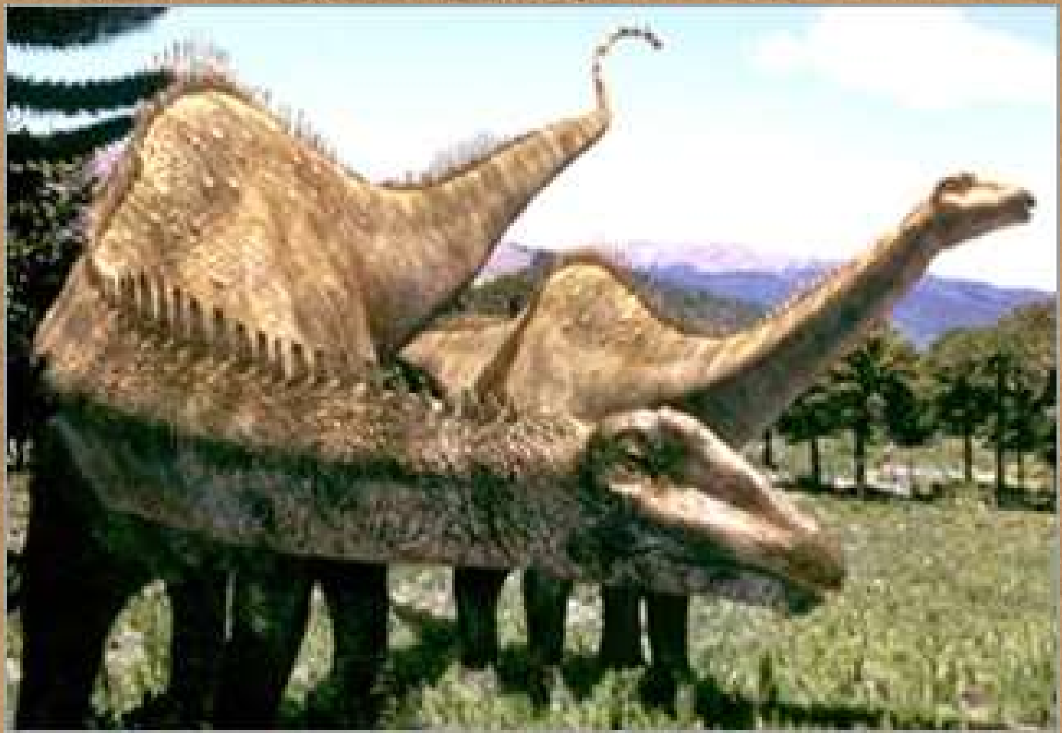


Late Jurassic: Pangea Begins to Rift Apart



JURASSIC LIFE

- FIRST BIRDS EVOLVE
- DINOSAURS REACH GIGANTIC FORMS
- DINOSAURS ARE THE DOMINATING ANIMALS
- CYCADS, CONIFERS,



- At the beginning of the Jurassic, dinosaurs started getting bigger. As vegetarians grew in size, so did the creatures that hunted them.

Possibly the oldest bird

- A particularly important and still contentious discovery is *Archaeopteryx lithographica*, found in the *Jurassic Solnhofen Limestone* of southern Germany, which is marked by rare but exceptionally well preserved fossils. *Archaeopteryx* is considered by many to be the first bird, being of about 150 million years of age. It is actually intermediate between the birds that we see flying around in our backyards and the predatory dinosaurs like *Deinonychus*. In fact, one skeleton of *Archaeopteryx* that had poorly preserved feathers was originally described as a skeleton of a small bipedal dinosaur, *Compsognathus*. A total of seven specimens of the bird are known at this time.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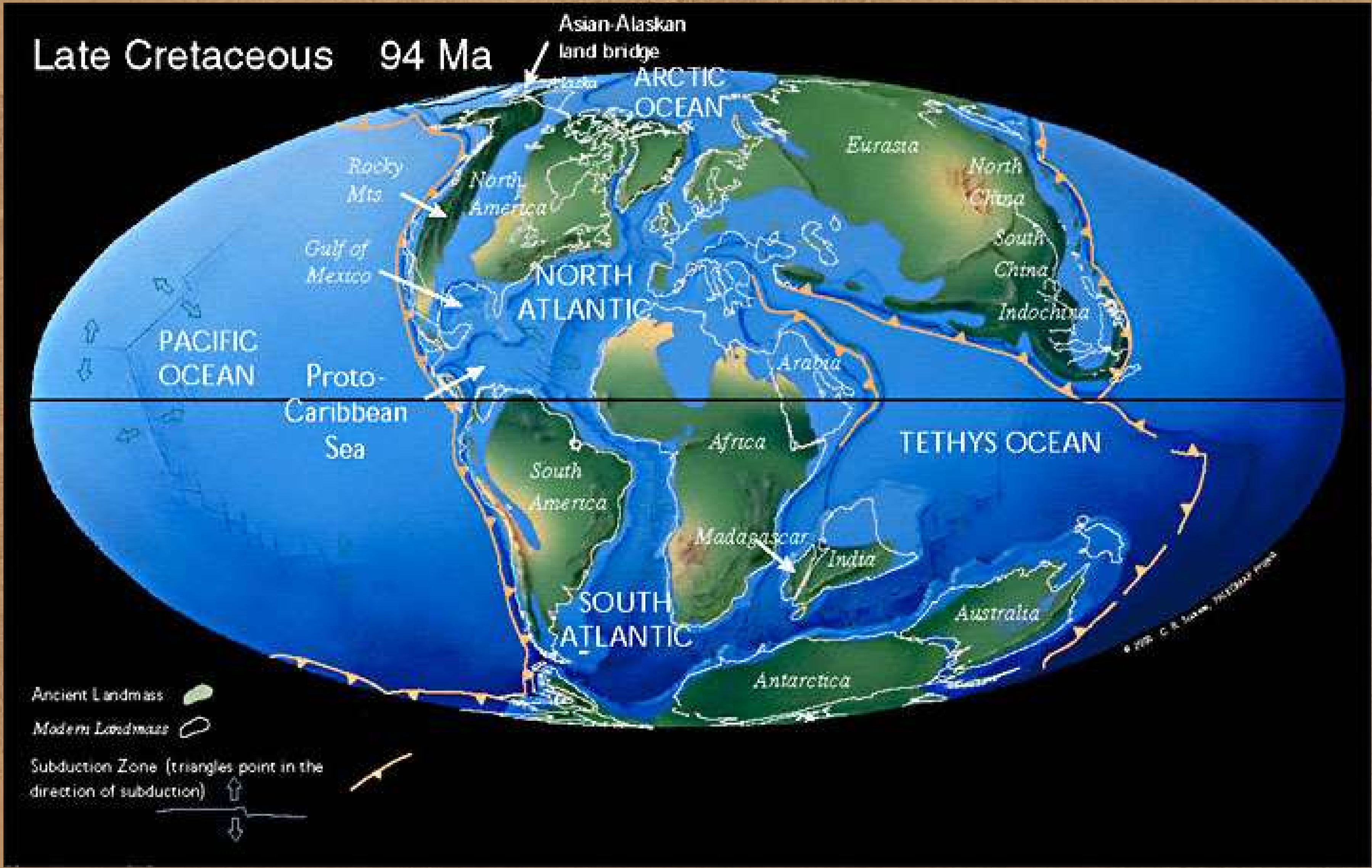
Late Cretaceous: New Oceans Begin to Open



More info about Cretaceous 144 to 65 Ma

- The second phase in the break-up of Pangea began in the early Cretaceous, about 140 million years ago. Gondwana continued to fragment as South America separated from Africa opening the South Atlantic, and India together with Madagascar rifted away from Antarctica and the western margin of Australia opening the Eastern Indian Ocean. The South Atlantic did not open all at once, but rather progressively "unzipped" from south to north. That is why the South Atlantic is wider to the south.

- Other important plate tectonic events occurred during the Cretaceous Period. These include: the initiation of rifting between North America and Europe, the counter-clockwise rotation of Iberia from France, The separation of India from Madagascar, the derivation of Cuba and Hispaniola from the Pacific, the uplift of the Rocky mountains, and the arrival of exotic terraines (Wrangellia, Stikinia) along the western margin of North America.

- Globally, the climate during the Cretaceous Period, like the Jurassic and Triassic, was much warmer than today. Dinosaurs and palm trees were present north of the Arctic Circle and in Antarctica and southern Australia. Though there may have been some at the poles during the Early Cretaceous, there were no large ice caps at anytime during the Mesozoic Era.

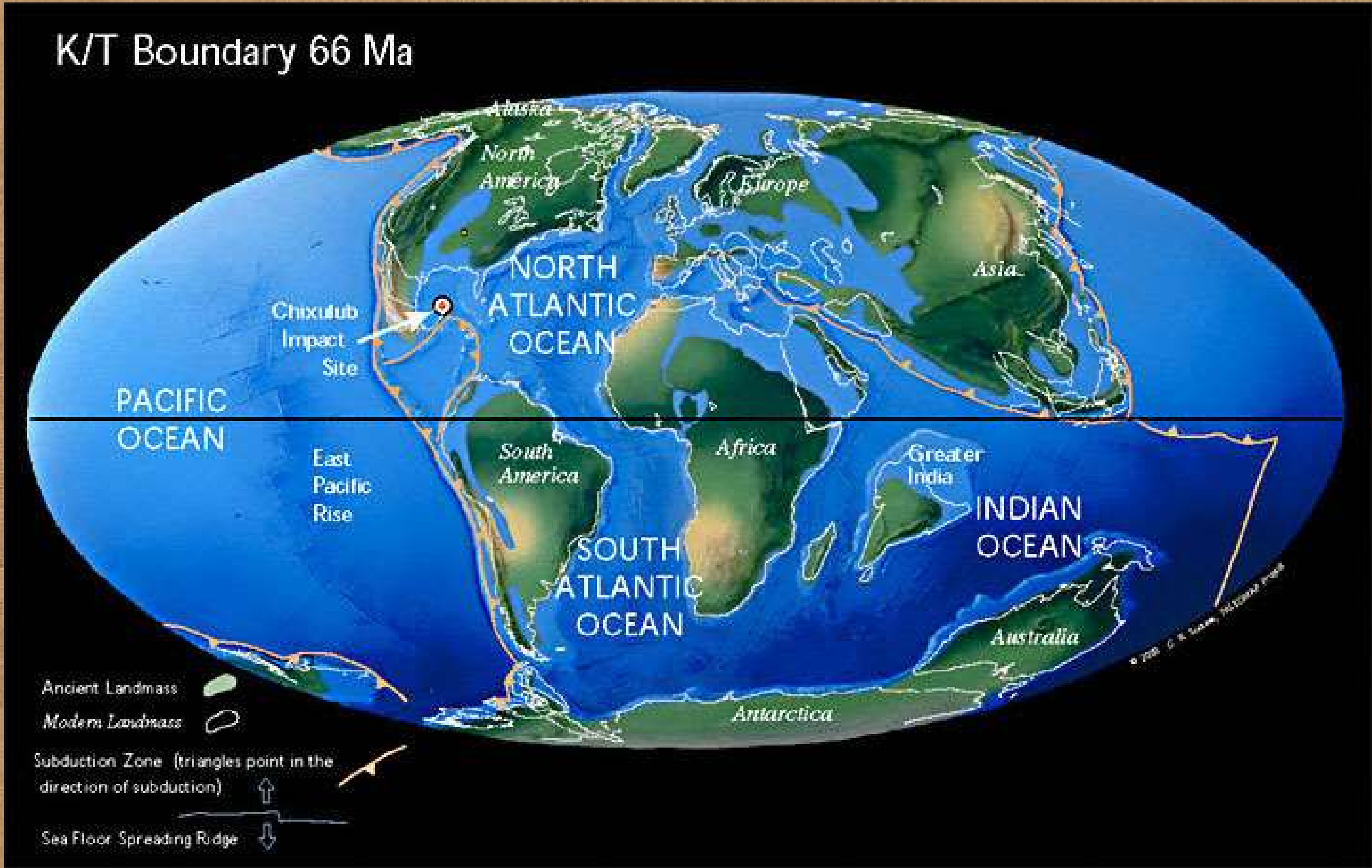
- These mild climatic conditions were in part due to the fact shallow seaways covered the continents during the Cretaceous. Warm water from the equatorial regions was also transported northward, warming the polar regions. These seaways also tended to make local climates milder, much like the modern Mediterranean Sea, which has an ameliorating effect on the climate of Europe.

- Shallow seaways covered the continents because sea level was 100 - 200 meters higher than today. Higher sea level was due, in part, to the creation of new rifts in the ocean basins that, as discussed previously in this article, displaced water onto the continents. The Cretaceous was also a time of rapid sea-floor spreading. Because of their broad profile, rapidly spreading mid-ocean ridges displace more water than do slow spreading mid-ocean ridges. Consequently, during times of rapid sea-floor spreading, sea level will tend to rise.

CRETACEOUS LIFE

- EXTINCTION OF DINOSAURS AND MARINE REPTILES
- ANGIOSPERMS EVOLVE (FLOWERING PLANTS) MODERN PLANT TYPE BEGIN TO APPEAR
- MODERN MAMMALS BEGIN TO EVOLVE
- DINOSAURS CONTINUE TO DIVERSIFY
- BIRDS GROUPS CONTINUE TO EVOLVE

The End of the Dinosaurs



The Tertiary Period 65-1.8 Ma

- UPRIGHT HOMINIDS APPEAR
- FIRST APES APPEAR
- BIRD GROUPS CONTINUE TO EVOLVE
- MAMMAL GROUPS EVOLVE AND BECOME THE DOMINATE LIFE ON EARTH

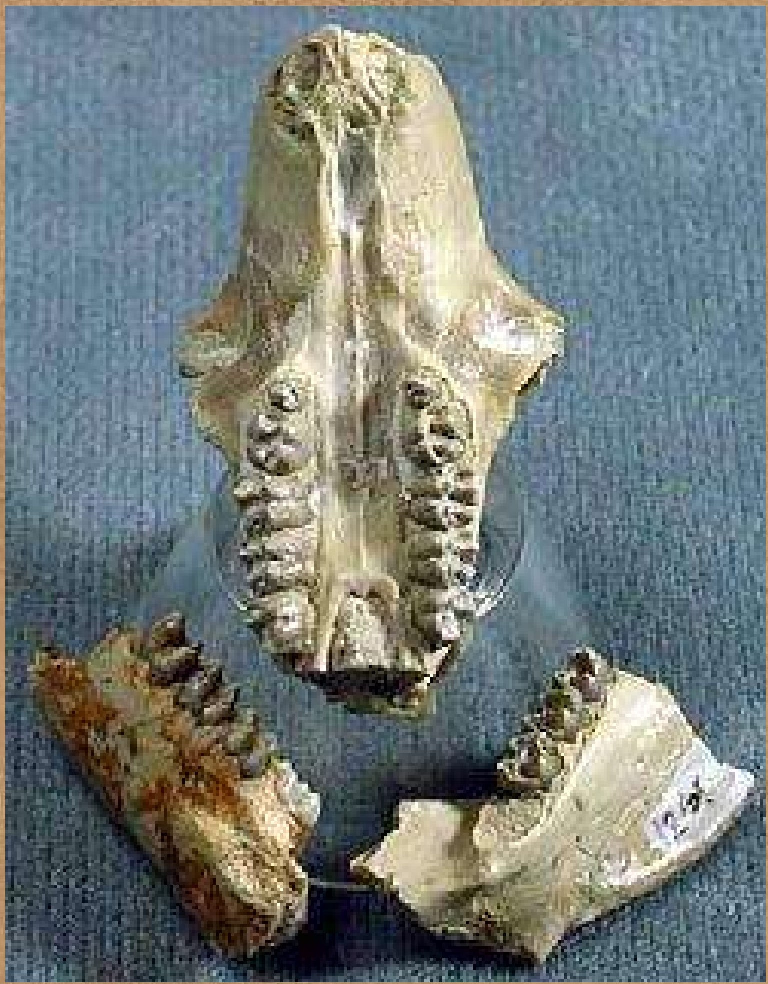
Some vertebrates of the Tertiary

Priscacara liops From the Tertiary in Wyoming

Some vertebrates of the Tertiary

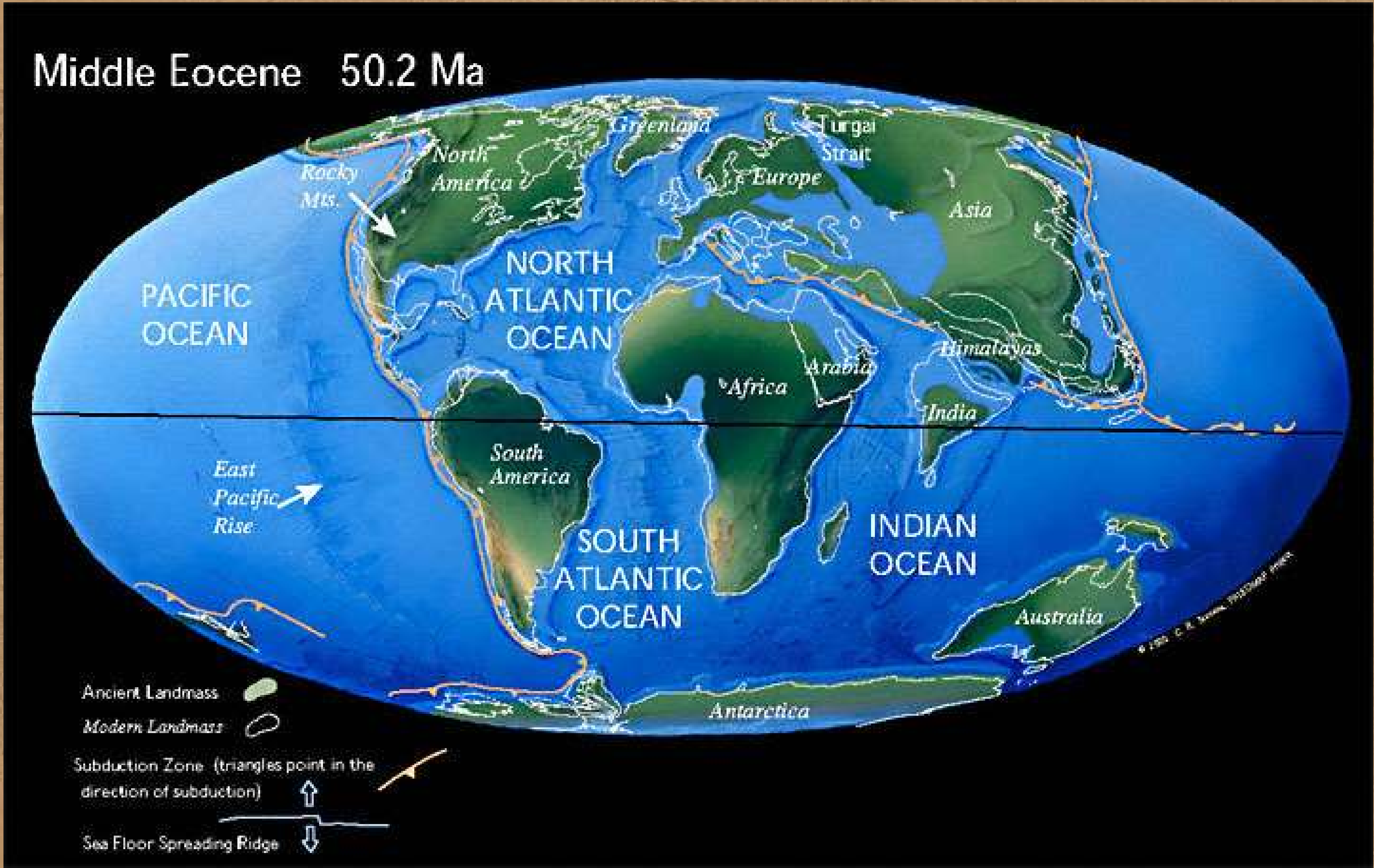
Turtle: *Baptemys garmanni* from the Tertiary in Wyoming

Some vertebrates of the Tertiary



Ischyromys (fossil rodent)

During the Early Cenozoic India began to Collide with Asia.



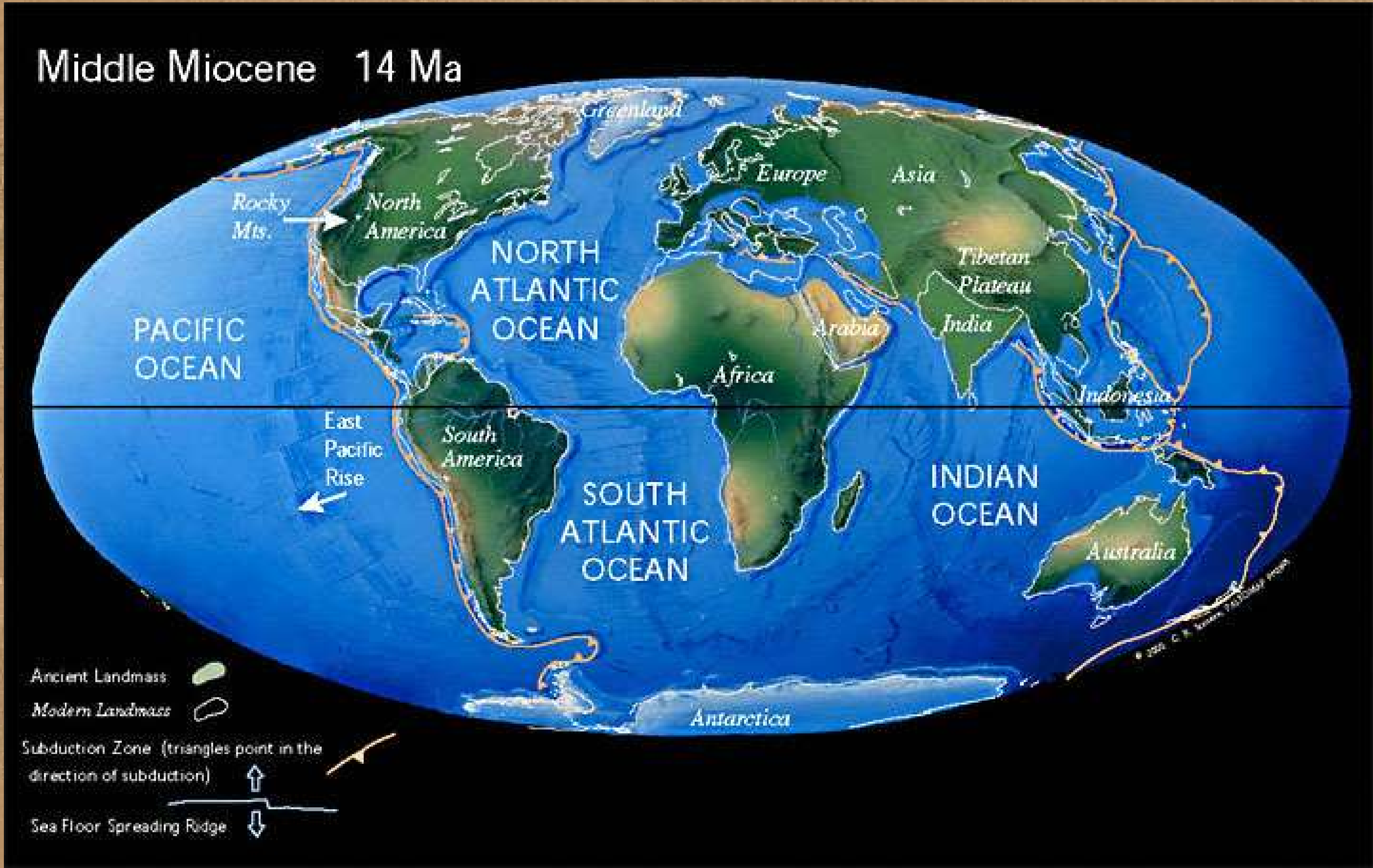
50 - 55 million years ago India began to collide with Asia forming the Tibetan plateau and Himalayas. Australia, which was attached to Antarctica, began to move rapidly northward.

- The third, and final phase in the breakup of Pangea took place during the early Cenozoic. North America and Greenland split away from Europe, and Antarctica released Australia which like India 50 million years earlier, moved rapidly northward on a collision course with southeast Asia. The most recent rifting events, all taking place within the last 20 million years include: the rifting a Arabia away from Africa opening the Red Sea, the creation of the east African Rift System, the opening of the Sea of Japan as Japan moved eastward into the Pacific, and the northward motion of California and northern Mexico, opening of the Gulf of California.

- Though several new oceans have opened during the Cenozoic, the last 66 million years of Earth history are better characterized as a time of intense continental collision. The most significant of these collisions has been the collision between India and Eurasia, which began about 50 million years ago. During the Late Cretaceous, India approached Eurasia at rates of 15 - 20 cm/yr - a plate tectonic speed record. After colliding with marginal island arcs in the Late Cretaceous, the northern part of India, Greater India, began to be subducted beneath Eurasia raising the Tibetan Plateau. Interesting, Asia, rather than India, has sustained most of the deformation associated with this collision. This is because India is a solid piece of continental lithosphere riding on a plate that is primarily made up of stronger oceanic lithosphere. Asia on the other hand, is a loosely knit collage of continental fragments. The collision zones, or sutures, between these fragments are still warm, and hence, can be easily reactivated. As India collided with Asia, these fragments were squeezed northwards and eastwards out of the way, along strike-slip faults that followed older sutures. Earthquakes along these faults continue to the present-day.

- The collision of India with Asia is just one of a series of continental collisions that has all but closed the ocean great Tethys Ocean. From east to west these continent-continent collisions are: Spain with France forming the Pyrenees mountains, Italy with France and Switzerland forming the Alps, Greece and Turkey with the Balkan States forming the Hellenide and Dinaride mountains, Arabia with Iran forming the Zagros mountains, India with Asia, and finally the youngest collision, Australia with Indonesia.

The World Assumes a Modern Configuration



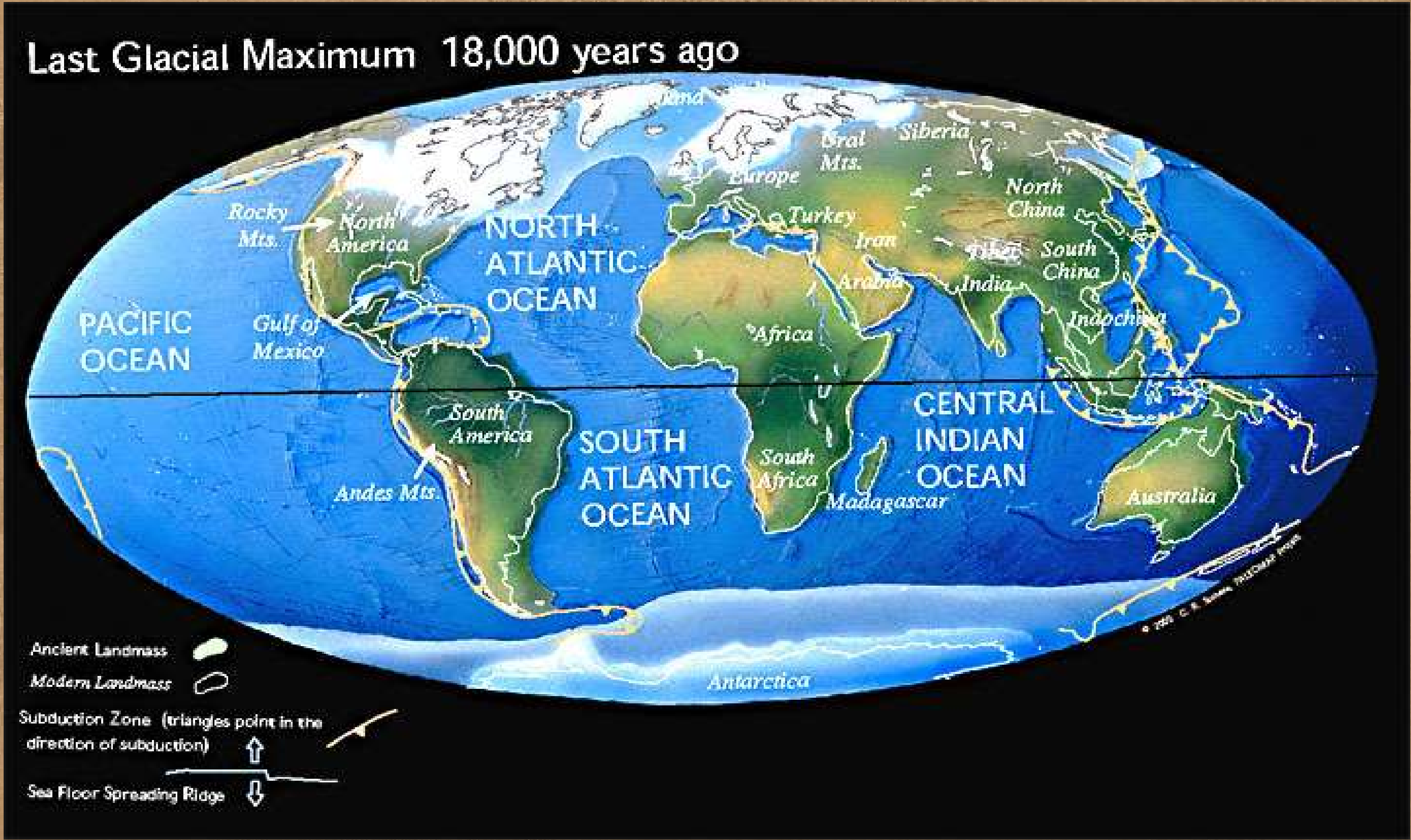
More information about the Cenozoic

- The collision of India with Asia is just one of a series of continental collisions that has all but closed the ocean great Tethys Ocean. From east to west these continent-continent collisions are: Spain with France forming the Pyrenees mountains, Italy with France and Switzerland forming the Alps, Greece and Turkey with the Balkan States forming the Hellenide and Dinaride mountains, Arabia with Iran forming the Zagros mountains, India with Asia, and finally the youngest collision, Australia with Indonesia.

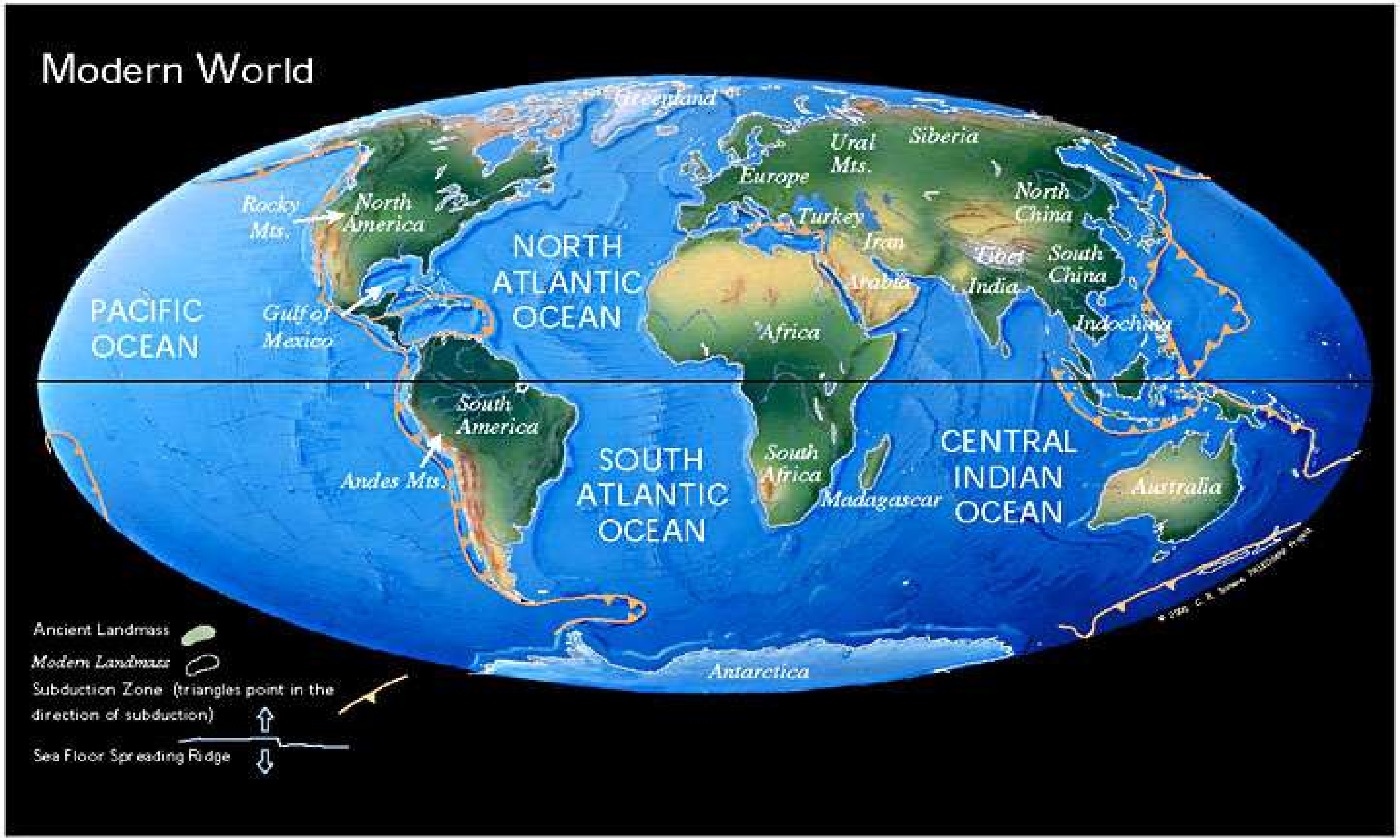
- This phase of continental collision has raised high mountains by horizontally compressing the continental lithosphere. Though the continents occupy the same volume, their area has decreased slightly. Consequently, on a global scale, the area of the ocean basins has increased slightly during the Cenozoic, at the expense of the continents. Because the ocean basins are larger, they can hold more water. As a result, sea level has fallen during the last 66 million years. In general, sea level is lower during times of continental collision (early Devonian, Late Carboniferous, Permian,Triassic).

- During times of low sea level the continents are emergent, land faunas flourish, migration routes between continents open up, the climate becomes more seasonal, and probably most importantly, the global climate tends to cool off. This is largely because land tends to reflect the Sun's energy back to space, while the oceans absorb the Sun's energy. Also, land masses permit the growth of permanent ice sheets, which because they are white reflect even more energy back to space. The formation of ice on the continents, of course, lowers sea level even further, which results in more land, which cools the Earth, forming more ice, and so on, and so on. The lesson here is: once the Earth begins to cool (or warm-up) positive feed-back mechanisms push the Earth's climate system to greater and greater cooling (or heating). During the last half of the Cenozoic the Earth began to cool off. Ice sheets formed first on Antarctica and then spread to the northern hemisphere. For the last 5 million years the Earth has been in a major Ice Age. There have been only a few times in Earth's history when it has been as cold as it has been during the last 5 million years.

The Last Ice Age



The Present-day world has well defined climatic zones.



Now – more about fossils…

According to the size of the fossil, we distinguish:

•Microfossils and

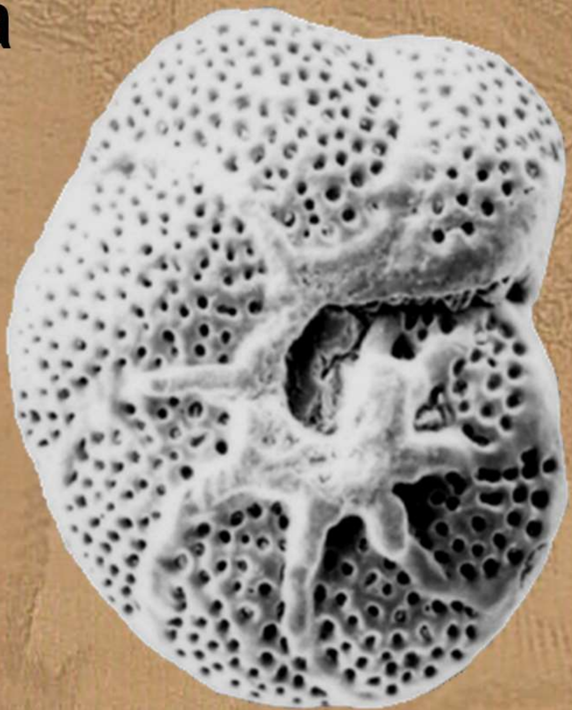
•Macrofossils

Marine Microfossils

- Calcareous microfossils:
  - Foraminifera
  - Calcareous nannoplankton
  - Ostracods
- Siliceous microfossils:
  - Diatoma
  - Radiolaria
- Conodonts

Foraminifera have a geological range from the earliest Cambrian to the present day.

- Foraminifera

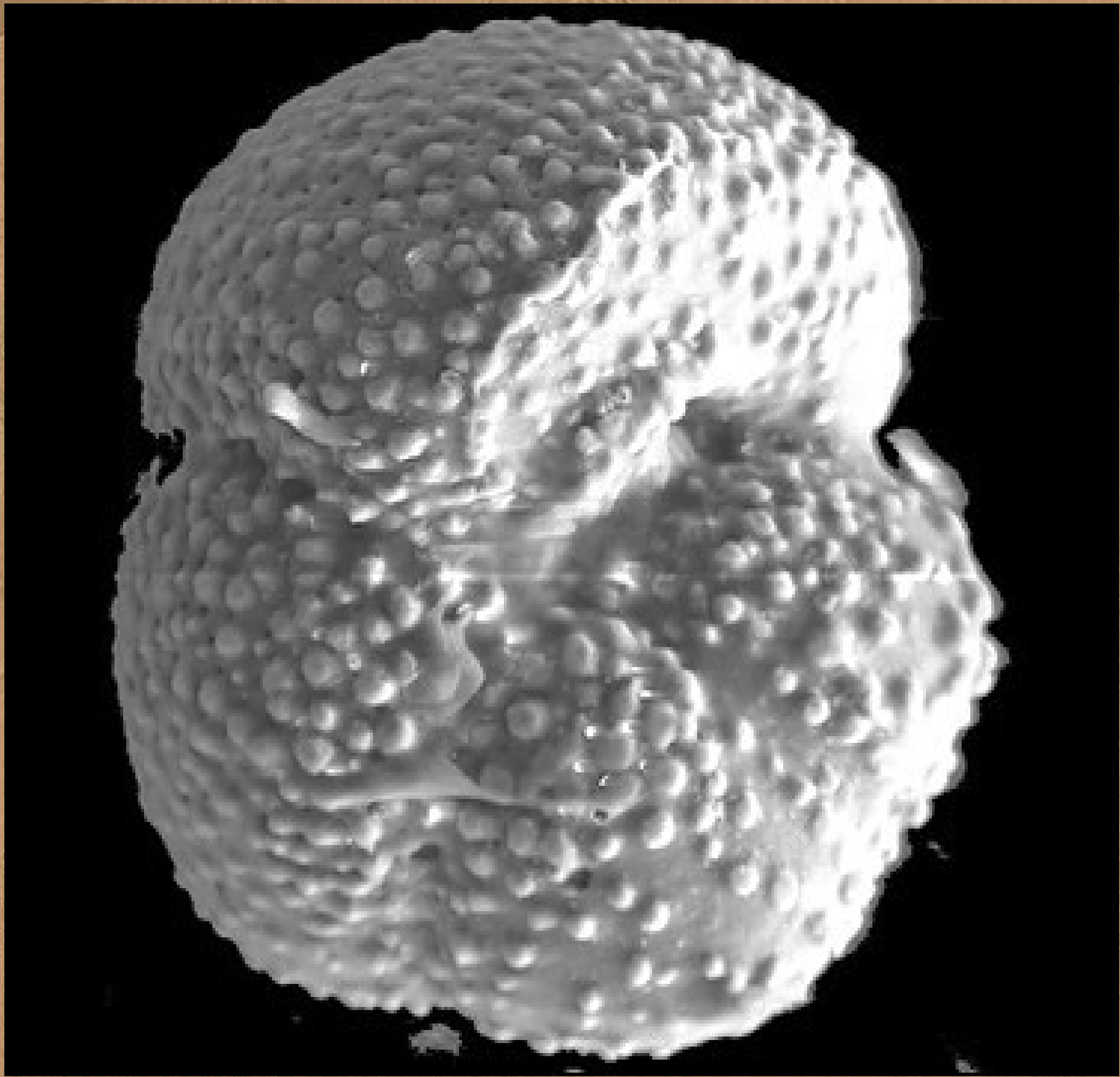


FORAMINIFERA

Planulinoides bioconcavus

- Foraminifera, or forams, belong to a group of single-celled animals (protozoans) that form calcareous shells. These shells are mostly microscopic, ranging from 0.5 to 1.0 millimetre, although some grow to several centimetres in size.
- Foraminifera are found in all depths of brackish and marine water today. They include benthic (bottom-living) forms living on or in the sediment and planktic forms floating near the surface of the water.
- Benthic forams have a long fossil record extending back to the Cambrian (about 545 to 490 million years ago). They are particularly useful in determining ancient depositional environments and for dating rocks.
- Planktic forams evolved in the Mesozoic Era (251 to 65 million years ago). They were almost wiped out in the mass extinctions at the end of that era (65 million years ago), but recovered in an adaptive radiation early in the Cainozoic (65 million years ago to present). They are very important for the correlation and dating of rocks in the Cainozoic because of their rapid evolution and worldwide distribution.

Benthic foram *Elphidium crispum* from Bass Strait.



Planktic foram *Turborotalia inflata* from Bass Strait

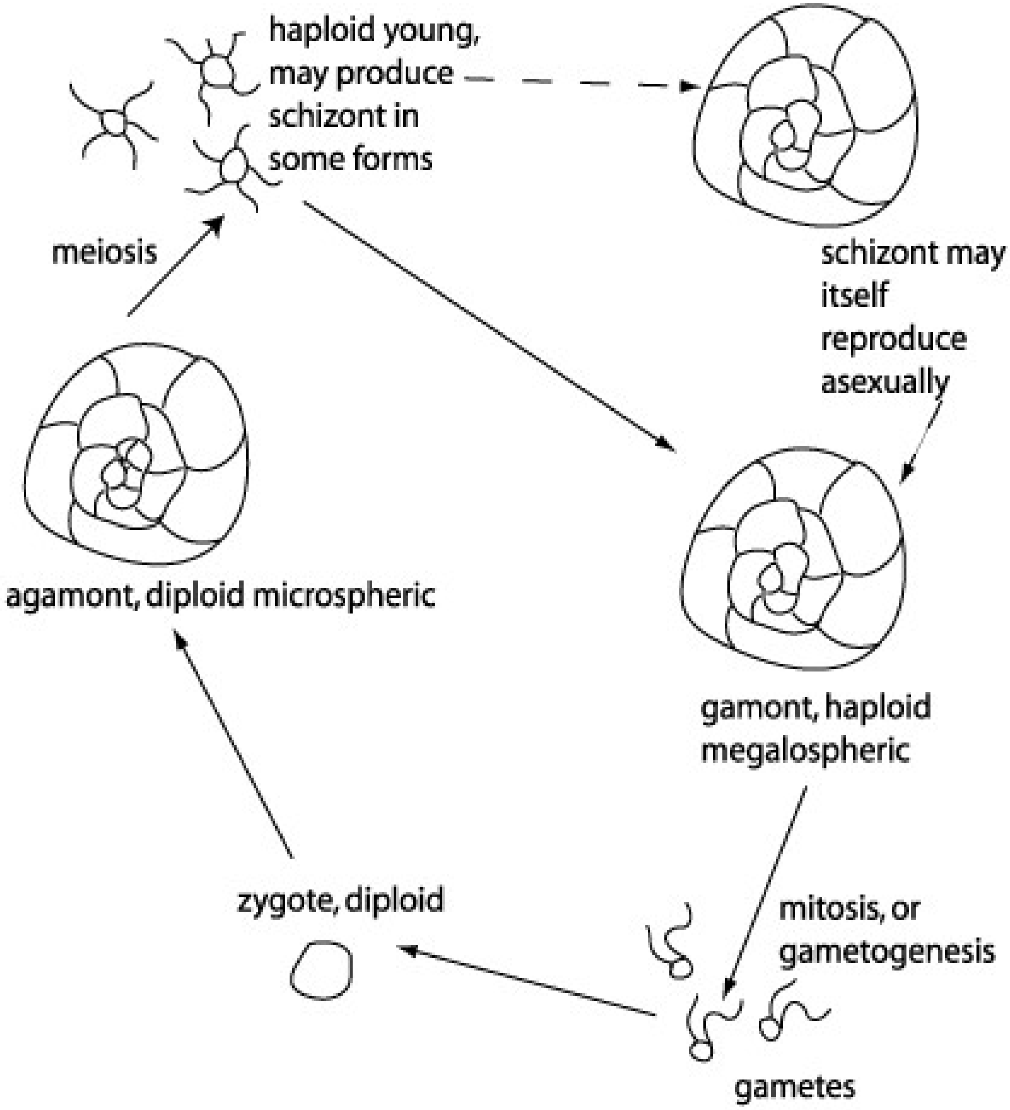


Diagram showing a generalised foraminifera life cycle note alternation between a haploid megalospheric from and a diploid microspheric form.

Redrawn from Goldstein 1999.

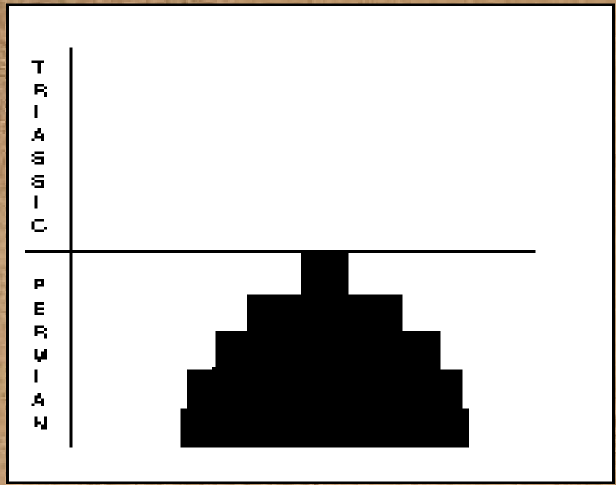
Life Cycle of forams

Of the approximately 4000 living species of foraminifera the life cycles of only 20 or so are known. There are a great variety of reproductive, growth and feeding strategies, however the alternation of sexual and asexual generations is common throughout the group and this feature differentiates the foraminifera from other members of the Granuloreticulosea. An asexually produced haploid generation commonly form a large proloculus (initial chamber) and are therefore termed megalospheric. Sexually produced diploid generations tend to produce a smaller proloculus and are therefore termed microspheric. Importantly in terms of the fossil record, many foraminiferal tests are either partially dissolved or partially disintegrate during the reproductive process.The planktonic foraminifera *Hastigerina pelagica* reproduces by gametogenesis at depth, the spines, septa and apertural region are resorbed leaving a tell-tale test. *Globigerinoides sacculifer* produces a sac-like final chamber and additional calcification of later chambers before dissolution of spines occurs, this again produces a distinctive test, which once gametogenesis is complete sinks to the sea bed.

Classification of Foraminifera

- Foraminifera are classified primarily on the composition and morphology of the test. Three basic wall compositions are recognised, organic (protinaceous mucopolysaccharide i.e. the allogromina), agglutinated and secreted calcium carbonate (or more rarely silica).
- Agglutinated forms, i.e the Textulariina, may be composed of randomly accumulated grains or grains selected on the basis of specific gravity, shape or size; some forms arrange particular grains in specific parts of the test.
- Secreted test foraminifera are again subdivided into three major groups, microgranular (i.e. Fusulinina), porcelaneous (i.e. Miliolina) and hyaline (i.e. Globigerinina).
  - Microgranular walled forms (commonly found in the late Palaeozoic) are composed of equidimensional subspherical grains of crystalline calcite.
  - Porcelaneous forms have a wall composed of thin inner and outer veneers enclosing a thick middle layer of crystal laths, they are imperforate and made from high magnesium calcite.
  - The hyaline foraminifera add a new lamella to the entire test each time a new chamber is formed; various types of lamellar wall structure have been recognised, the wall is penetrated by fine pores and hence termed perforate.
- A few "oddities" are also worth mentioning, the Suborder Spirillinina has a test constructed of an optically single crystal of calcite, the Suborder Silicoloculinina as the name suggests has a test composed of silica. Another group (the Suborder Involutina) have a two chambered test composed of aragonite. The Robertinina also have a test composed of aragonite and the Suborder Carterina is believed to secrete spicules of calcite which are then weakly cemented together to form the test.

Foraminifera: Fusilina

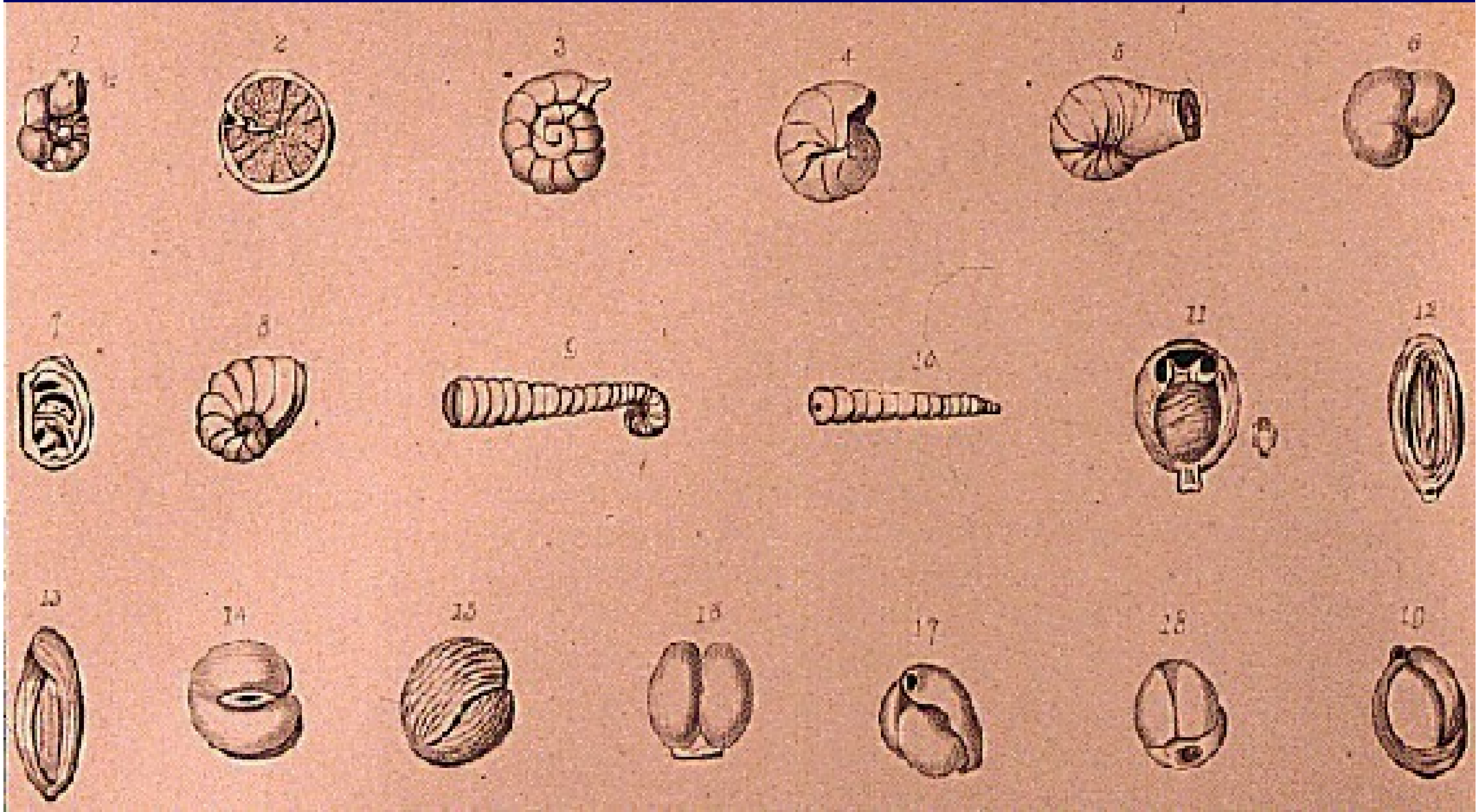


•Peaked in number in Early Carboniferous, already in prolonged decline throughout Permian.
•Already 90% extinct by P-T boundary, but last 10% was finished off by extinction event.
•Only fossils found in Triassic beds are derived from underlying beds.

• Extinct sub-order of the Foraminifera group. Unicellular animal ranging in size from 0.1-8mm.

• Benthonic or planktonic forms with a considerable disparity in morphology within the suborder.

Fusilinid foraminifera



Non-Fusiline Foraminifera

•Different suborders were affected differently by the extinction.

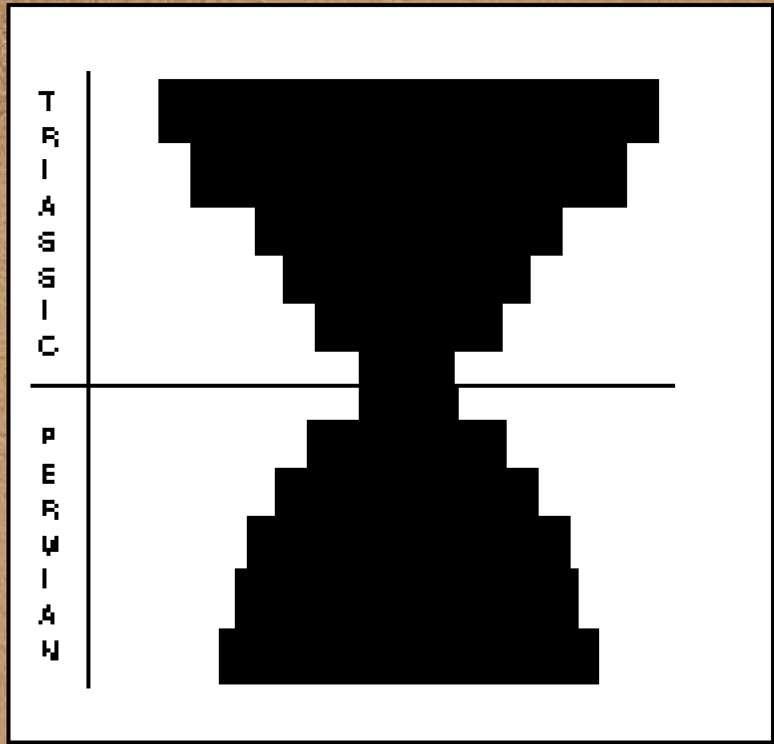
•Allogromiina has a very poor fossil record.

•Textulariina lost a third of all its genera.

•Miololina lost half of its genera.

•Lagenina and Involutina showed dramatic increase in post extinction radiation.

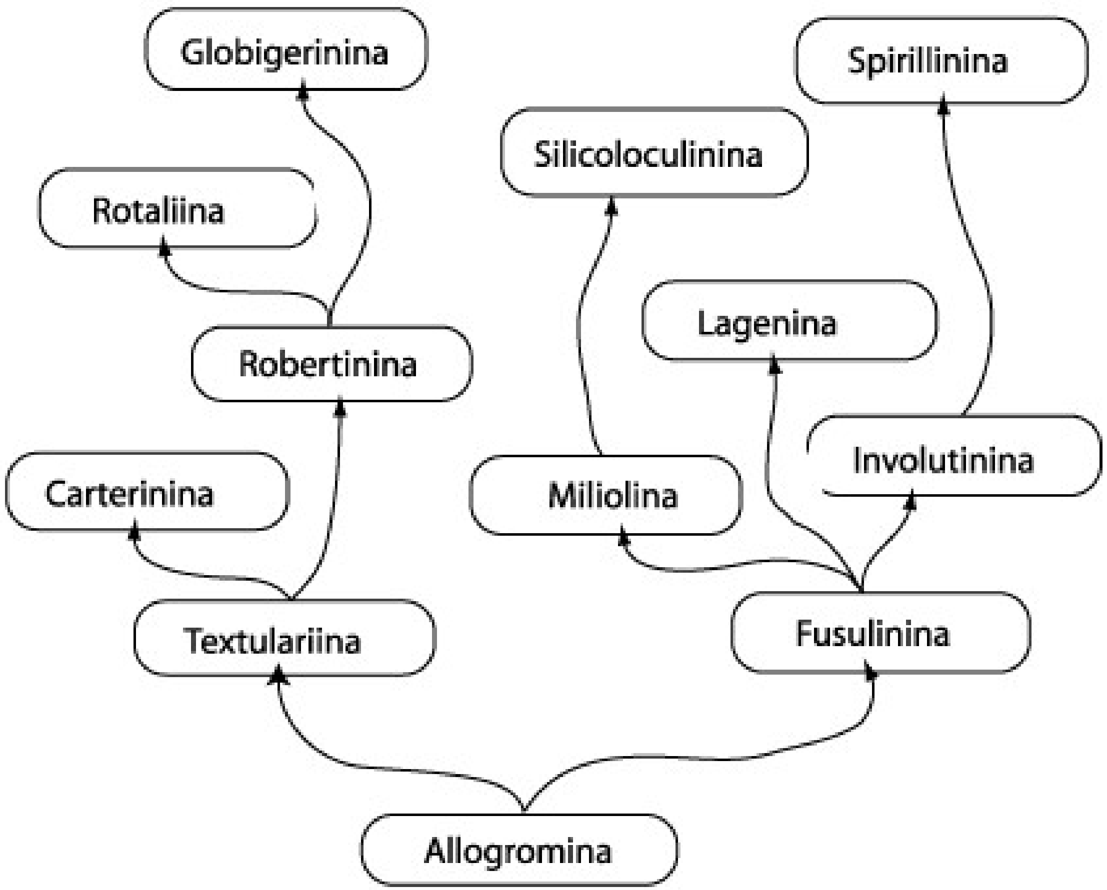
•-he order on the whole has a very good, widespread fossil record.



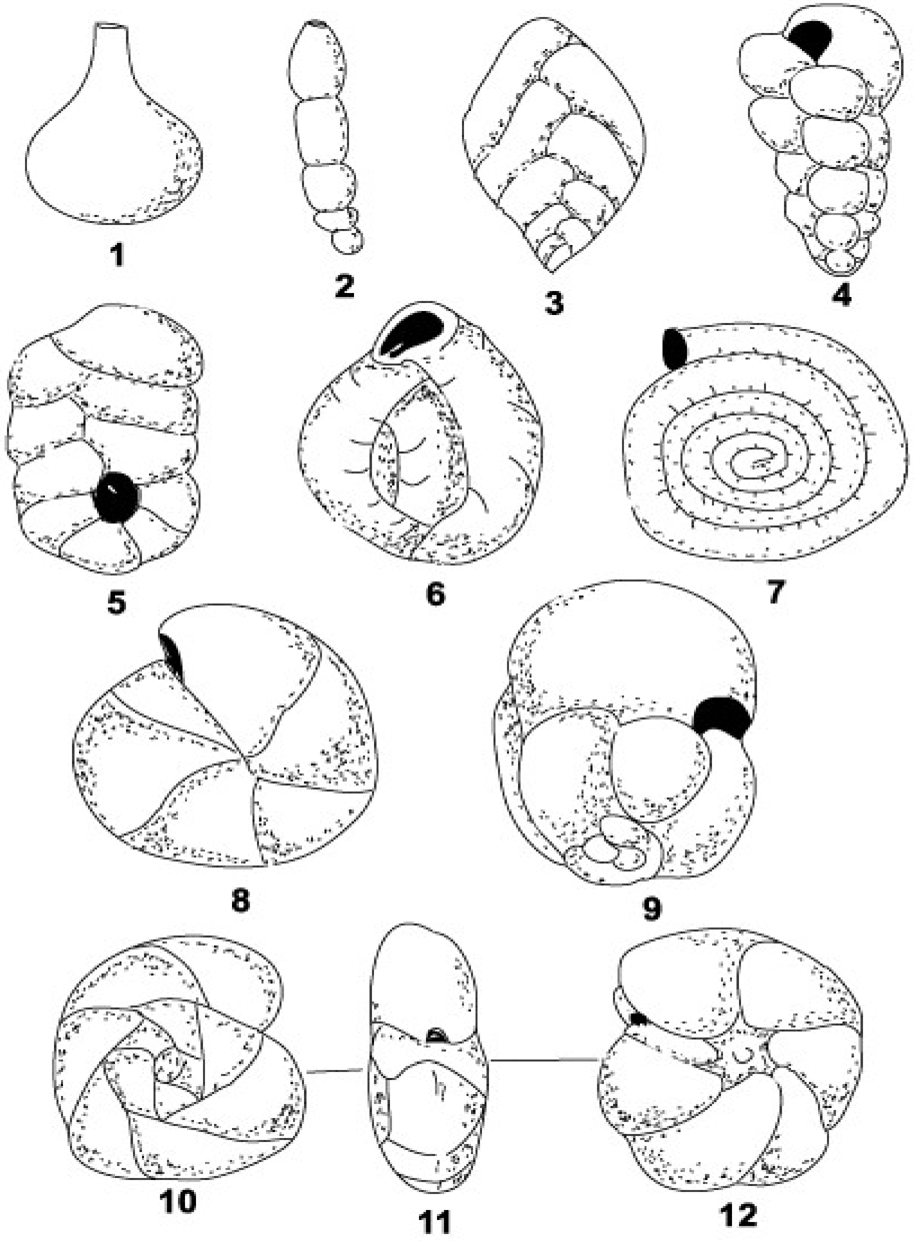
-5 non-fusiline foraminifera:- Allogromiina, Textulariina, Miliolina, Layenina and Involutina.

-Unicellular animal ranging in size from 0.1-8mm.

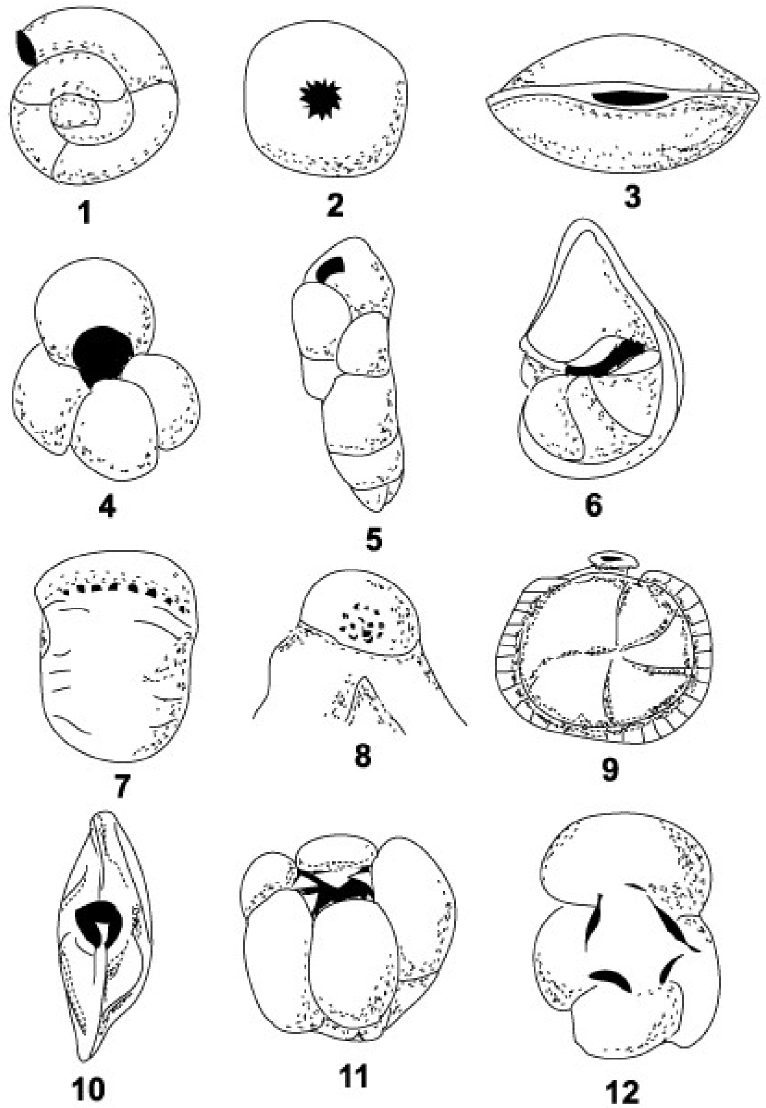
-Benthonic or planktonic forms with a considerable disparity in morphology within the suborders.



Foraminiferal suborders and their envisaged phylogeny. Redrawn from Tappan and Loeblich (1988). Among the suborders shown only the Fusulinina are extinct.



Principle types of chamber arrangement. 1, single chambered; 2, uniserial; 3,biserial; 4, triserial; 5, planispiral to biserial; 6, milioline; 7, planispiral evolute; 8, planispiral involute; 9, streptospiral; 10-11-12, trochospiral (10, dorsal view; 11, edge view; 12, ventral view). Redrawn from Loeblich and Tappan 1964.



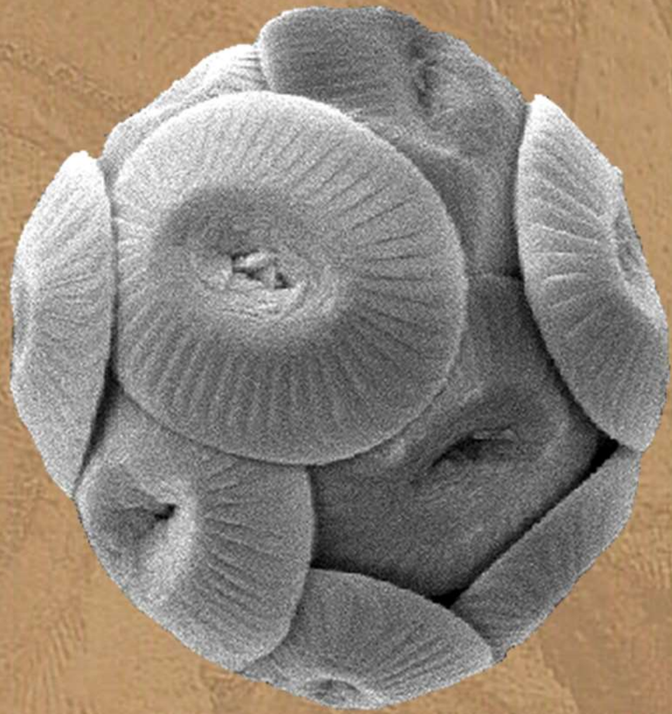
Principle types of aperture. 1, open end of tube; 2, terminal radiate; 3, terminal slit; 4, umbilical; 5, loop shaped; 6, interiomarginal; 7, interiomarginal multiple; 8, areal crbrate; 9, with phialine lip; 10, with bifid tooth; 11, with umbilical teeth; 12, with umbilical bulla. Redrawn from Loeblich and Tappan 1964.

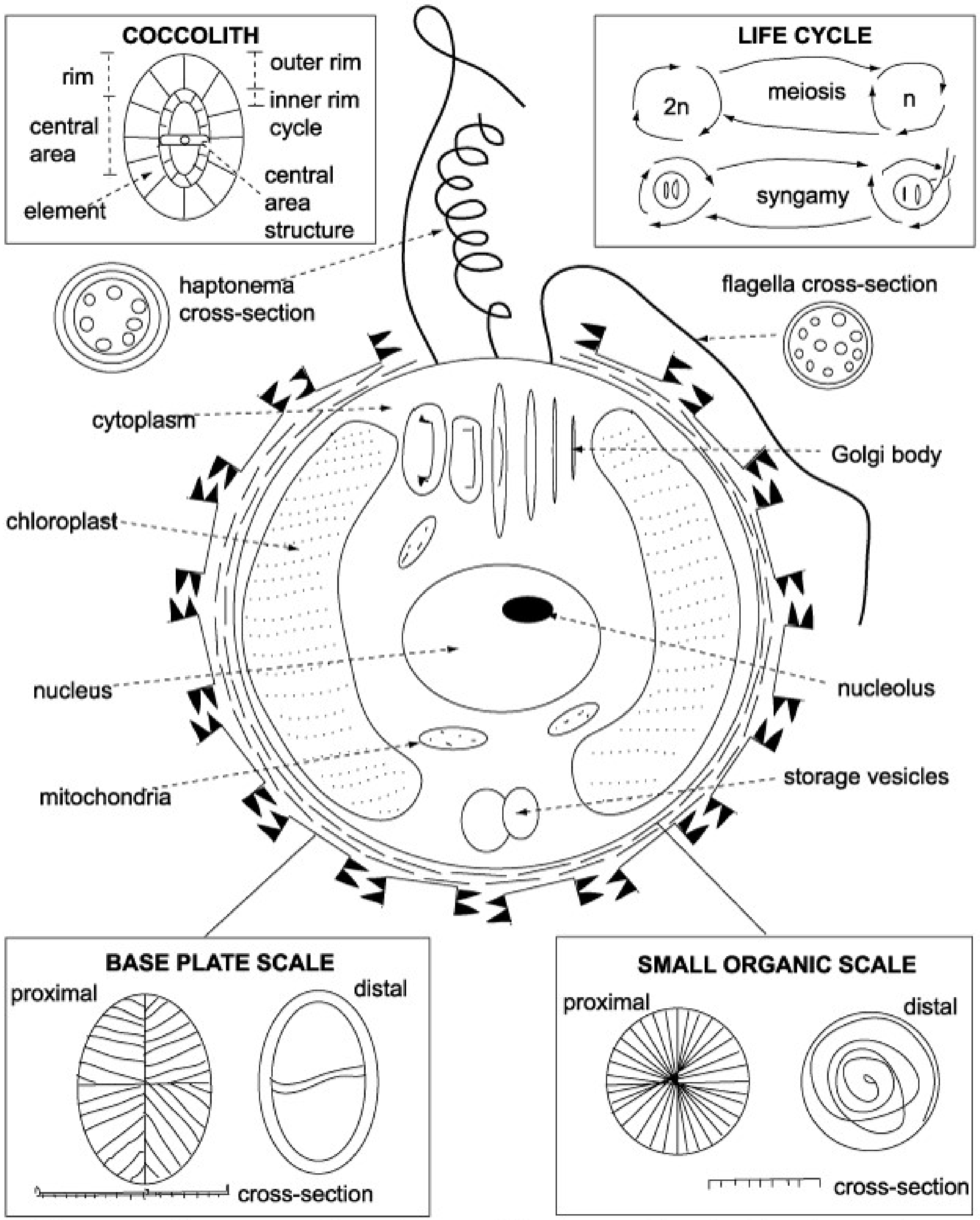
Applications

- Foraminifera have been utilised for biostratigraphy for many years, and they have also proven invaluable in palaeoenvironmental reconstructions most recently for palaeoceanographical and palaeoclimatological purposes.
- For example palaeobathymetry, where assemblage composition is used and palaeotemperature where isotope analysis of foraminifera tests is a standard procedure.
- n terms of biostratigraphy, foraminifera have become extremely useful, different forms have shown evolutionary bursts at different periods and generally if one form is not available to be utilised for biostratigraphy another is.
- For example preservation of calcareous walled foraminifera is dependent on the depth of the water column and Carbonate Compensation Depth (the depth below which dissolution of calcium carbonate exceeds the rate of its deposition), if calcareous walled foraminifera are therefore not preserved agglutinated forms may be.
- The oldest rocks for which foraminifera have been biostratigraphically useful are Upper Carboniferous to Permian strata, which have been zoned using the larger benthic fusulinids.
- Planktic foraminifera have become increasingly important biostratigraphic tools, especially as petroleum exploration has extended to offshore environments of increasing depths.
- The first and last occurrence of distinctive "marker species" from the Cretaceous to Recent (particularly during the Upper Cretaceous) has allowed the development of a well established fine scale biozonation.

Calcareous Nannofossils

Calcareous nannofossils include the coccoliths and coccospheres of haptophyte algae and the associated nannoliths which are of unknown provenance. The organism which creates the coccosphere is called a coccolithophore, they are phytoplankton (autotrophs that contain chloroplasts and photosynthesise). Their calcareous skeletons are found in marine deposits often in vast numbers, sometimes making up the major component of a particular rock, such as the chalk of England. One freshwater species has been reported. Formally coccolithophores are separated from other phytoplankton such as diatoms by the presence of a third flagella-like appendage called a haptonema, although the flagella bearing stage is often only one of a multi-stage life cycle.





Diagrammatic cross-section of a coccolithophore cell and cell-wall coverings

Classification

- The classification of calcareous nannoplankton is carried out under the International Code of Botanical Nomenclature.
- They are formally classified in the Kingdom Protoctista, Phylum (or Division) Haptophyta, Class Prymnesiophyceae.
- Classification is complicated by the fact that some species are dimorphic, that is they possess more than one coccolith on a single coccosphere.
- This may lead to the belief that two species exist where in fact there is only one.
- Also, pleomorphism (where a holococcolith phase alternates with a heterococcolith phase) may also result in coccoliths being placed in different species or even genera when in fact they are simply different stages in the life cycle of the same species.

Applications

- As the groups name suggests calcareous nannofossils are small, generally less than 30 microns across and usually between 5 and 10 microns (individual coccoliths).

- This has advantages and disadvantages. Advantages include:

  - Good preservation, their small size makes mechanical damage unlikely.

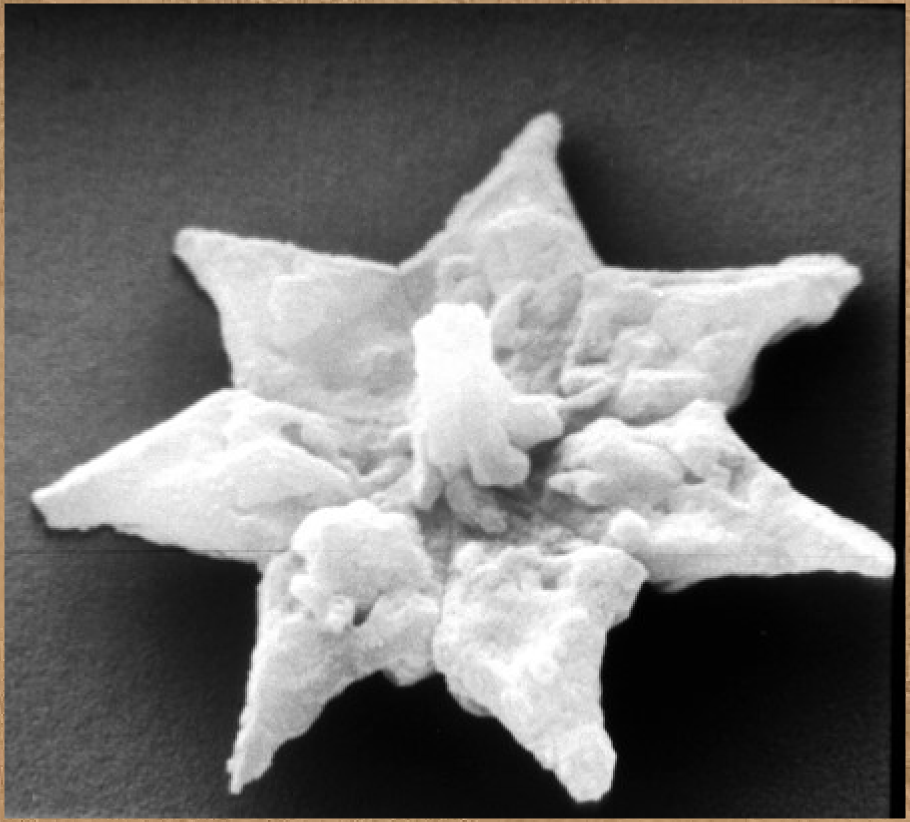
  - Widespread distribution, as part of the phytoplankton coccolithophores are distributed throughout the photic zone (predominantly the upper 50m of the water column) across almost all marine habitats.

  - A very large number of individual coccoliths may be preserved in a tiny amount of sediment hence only very small quantities of sample are needed to produce statistically valid results.

- **Disadvantages include:**
  - **Because of dissolution of calcium carbonate at depth in sea water (called the carbonate compensation depth (CCD)), preservation is compromised in deep water sediments.**
  - **Because of their small size and resistance to mechanical breakdown nannofossils can be reworked, great care is therefore needed especially when utilising nannofossils for biostratigraphic studies.**
  - **Again, because of the small size the opportunities for contamination are high, although careful and thorough preparation and collection techniques should significantly reduce this risk.**

Lotharingius haufii Grun and Zweili in Grun et al, 1974 Upper Pliensbachian-Upper Bathonian Untersturmig, GermanySEM (collapsed coccosphere)

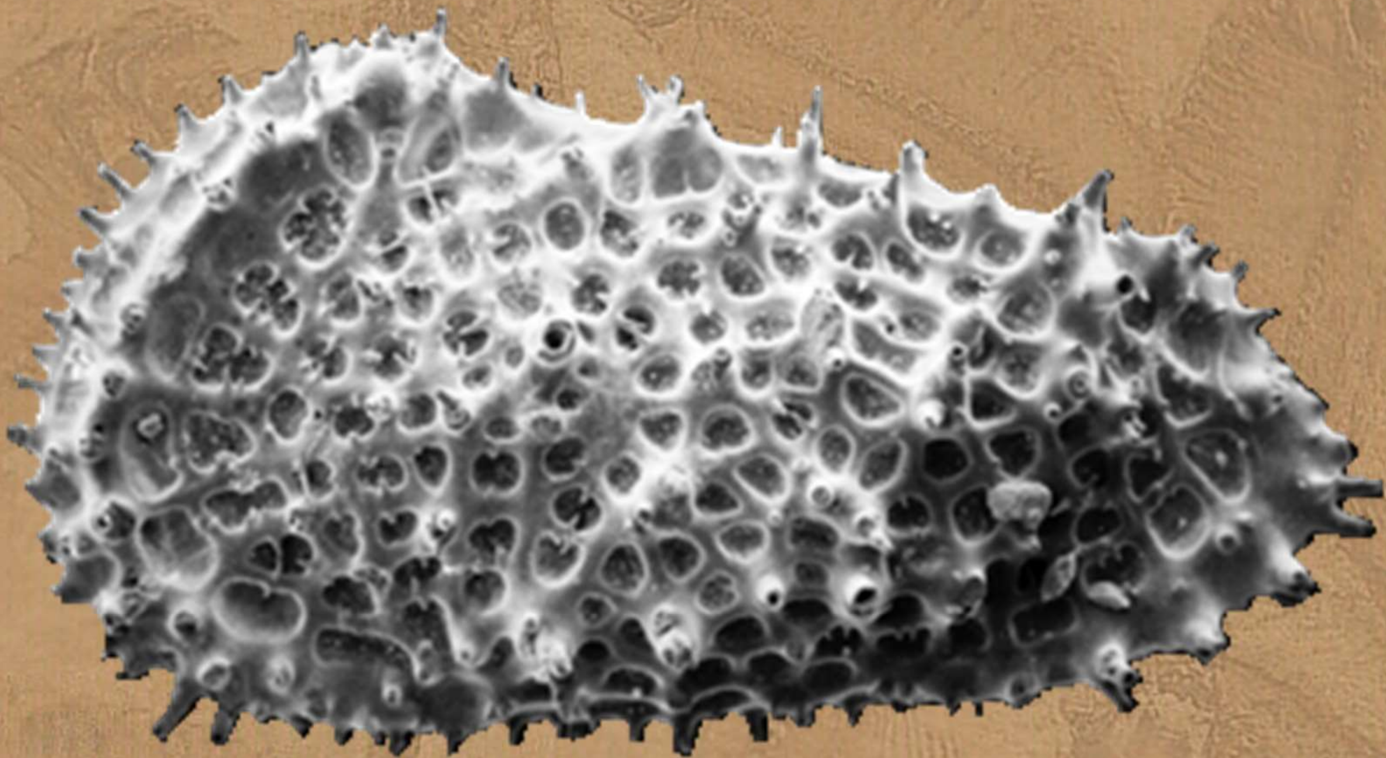
Discoasters

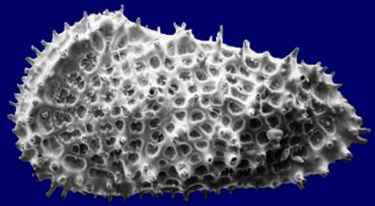


Discoaster saipanensis

- Discoasters are distinguished by their 6-pointed star shape.
- They are best seen in plane-polarized light.
- Discoasters are common in Tertiary sediments and died out at the end of the Pliocene.
- Presence or lack of discoasters (in post-Cretaceous calcareous sediments) is a good indicator of Tertiary or Quaternary sediments, respectively.

Ostracods





Ostracods

- Ostracods are by far the most complex organisms studied within the field of micropalaeontology. They are Metazoa and belong to the Phylum Arthropoda (as trilobites), Class Crustacea (as lobsters and crabs).
- An important distinguishing feature Ostracods share with other arthropods is the bilateral symmetry of their body form.
- The paired body parts are enclosed in a dorsally hinged carapace composed of low magnesium calcite, which is what is commonly preserved in the fossil record.
- They are found today in almost all aquatic environments including hot springs, caves, within the water table, semi-terrestrial environments, in both fresh and marine waters, within the water column as well as on (and in) the substrate.

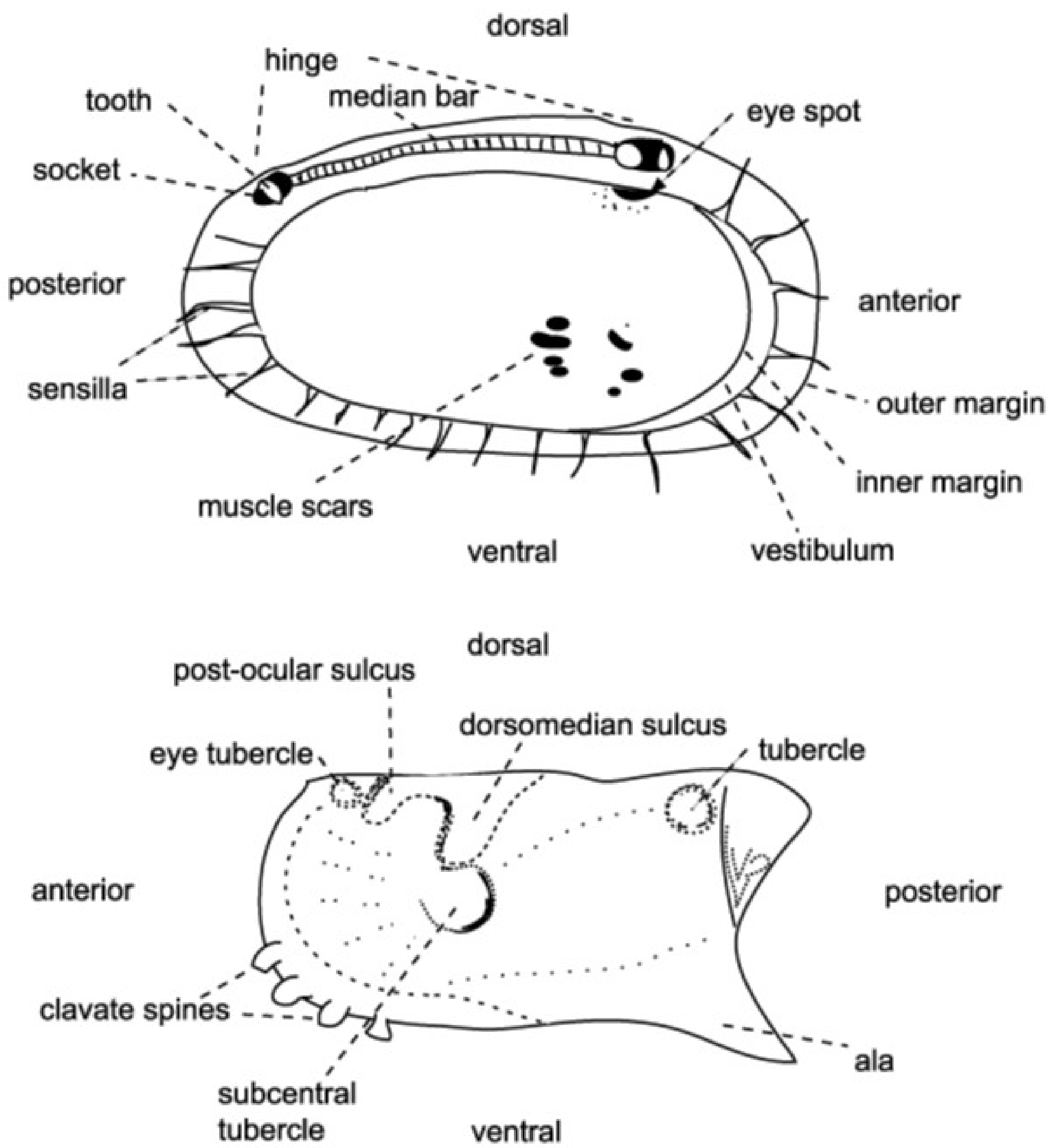


Diagram of two different idealised ostracods to show common ostracod valve features. Top internal view of a left valve, bottom external view of left valve.

After Horne et al. 1989

- **Range of Ostracods**

- **Ostracod-like organisms (bivalved arthropods) are recorded from the Cambrian, but it is uncertain whether these can be classified as true ostracods.**

- **Myodocopid and podocopid forms are recorded from the Ordovician.**

- **All these early forms are marine, the first freshwater forms (Darwinulacea and Carbonita) occur in the Carboniferous and by the Jurassic ostracods are common in freshwater environments.**

- **Between the Silurian/Devonian and the present there are big gaps in the fossil record of planktonic marine forms, which is thought to reflect weak calcification of the carapace.**

Classification 1.

- The Class Ostracoda is separated from other Crustacea by their laterally compressed body, undifferentiated head, seven or less thoracic limbs and the bivalved, perforate carapace lacking growth lines.

- The living ostracods are further classified in many cases by variations in their appendages and other soft parts.

- Although exceptionally well preserved fossil ostracods with the soft parts intact have been found these are very rare and therefore the morphological features (see below) of the carapace have become vital in fossil ostracod classification.

- The Ostracoda have been divided into five Orders:

  – the extant Podocopida and Myodocopida

  – and the extinct Phosphatocopida, Leperditicopida and Palaeocopida (however, the latter groups may well not be ostracods in the strict biological sense).

Classification 2.

- Several morphological features of ostracods are at times preserved in the fossil forms and have been utilised in their classification. The ostracod carapace is usually ovate, kidney-shaped or bean-shaped, it is divided into a right and left valve, one being, commonly slightly larger than the other partially overlapping it, and hinged at the dorsal margin. The hinge is an important feature in terms of taxonomy and classification. Four basic types of hinge are recognised:

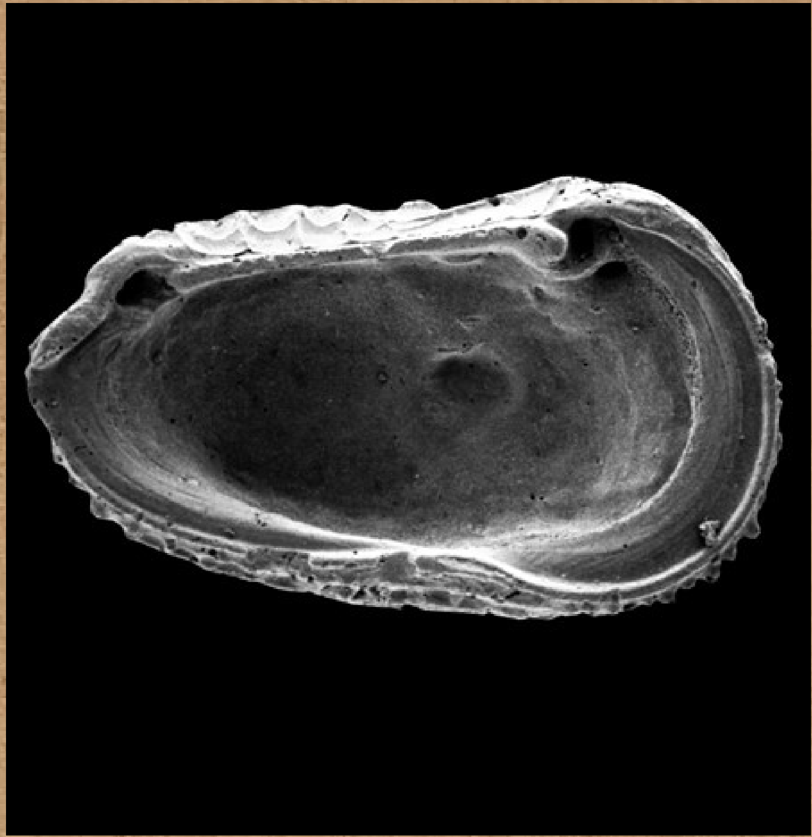
- The adont hinge is the simplest, without teeth or sockets, often forms part of a contact groove on the larger valve and a corresponding ridge on the smaller valve.

- The merodont hinge is composed of a tooth and socket at each end of a groove or ridge structure (complementary negative and positive structures in left and right valves).

- The entomodont hinge differs from the merodont hinge style by having a coarsely crenulated anterior portion of the median groove/ ridge element.

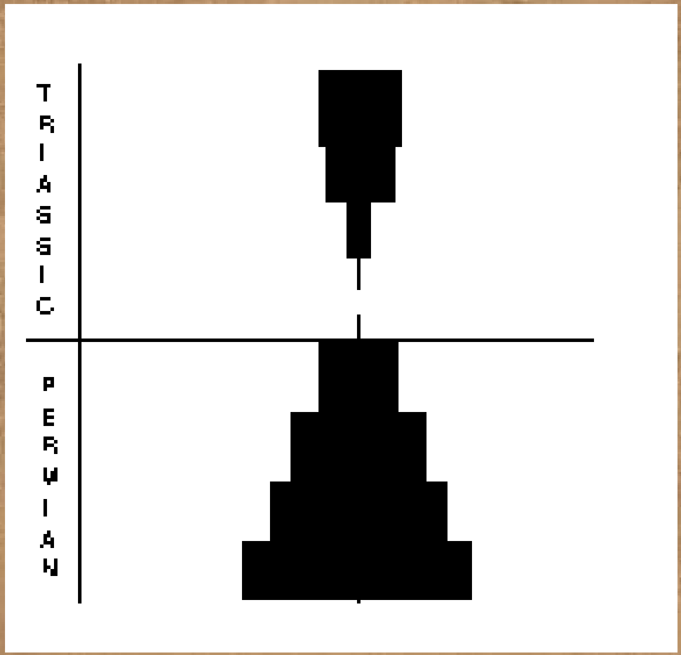
- The amphidont hinge has a more complex median structure with an anterior tooth and socket.

Heterocyprideis sorbyana Recent



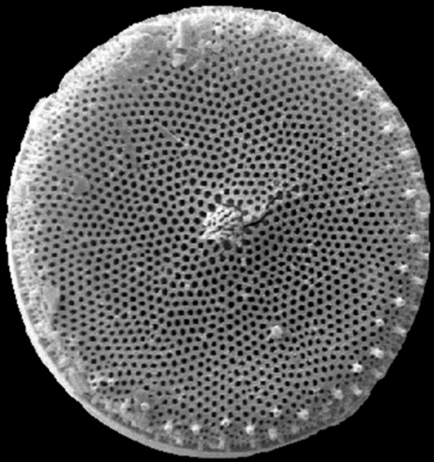
Actinocythereis asanmamoi Reyment, Late Palaeocene

Arthropoda: Ostracoda

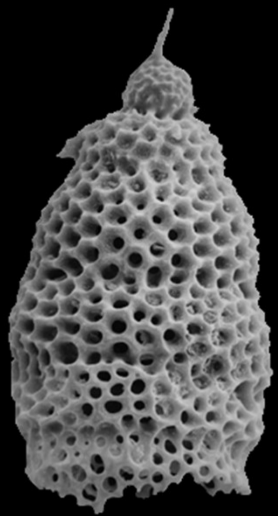


- Fairly poor global fossil record with fossils only found in sporadic, localised beds. Permian beds have upto 35 genera, with 87 species of Ostracoda.
- Beds of Triassic age contain 88 genera which are different from those in the Permian, with no evidence of the Permian genera.
- Suggests that there was mass extinction of Ostracoda, with only a few genera surviving through to Triassic. These rapidly diversified to form the Triassic generas.
- Segmented animals with carapace consisting of chitin or calcium carbonate. -Range in size from 0.5-10mm in size.
- Anterior portion of carapace consists of two valves, inside which the rest of the animal resides.
- Classification according to the bivalved section which is moulted at regular intervals to allow growth as with other arthopods.

Siliceous microfossils



1. Diatoma
   (siliceous algae)



2. Radiolaria
   (Siliceous
   zooplankton)

Diatoma

- Diatoms are photosynthesising algae, they have a siliceous skeleton (frustule) and are found in almost every aquatic environment including fresh and marine waters, soils, in fact almost anywhere moist.

- They are non-motile, or capable of only limited movement along a substrate by secretion of mucilaginous material along a slit-like groove or channel called a raphe.
- Being autotrophic they are restricted to the photic zone (water depths down to about 200m depending on clarity).

- Both benthic and planktic forms exist. Diatoms are formally classified as belonging to the Division Chrysophyta, Class Bacillariophyceae. The Chrysophyta are algae which form endoplasmic cysts, store oils rather than starch, possess a bipartite cell wall and secrete silica at some stage of their life cycle.

- Diatoms are commonly between 20-200 microns in diameter or length, although sometimes they can be up to 2 millimeters long. The cell may be solitary or colonial (attached by mucous filaments or by bands into long chains).

- Diatoms may occur in such large numbers and be well preserved enough to form sediments composed almost entirely of diatom frustules (diatomites), these deposits are of economic benefit being used in filters, paints, toothpaste, and many other applications.

Biology

- Diatoms have been well studied both in their natural habitat and in cultures by biologists and there is therefore a wealth of knowledge on their biology and ecology.
- The protoplast of diatoms consists of a cytoplasmic layer that lines the interior of the frustule and surrounds a large central vacuole, within the cytoplasmic layer there is a diploid nucleus and two to several pigment-bearing plastids (the site of photosyntheseis).

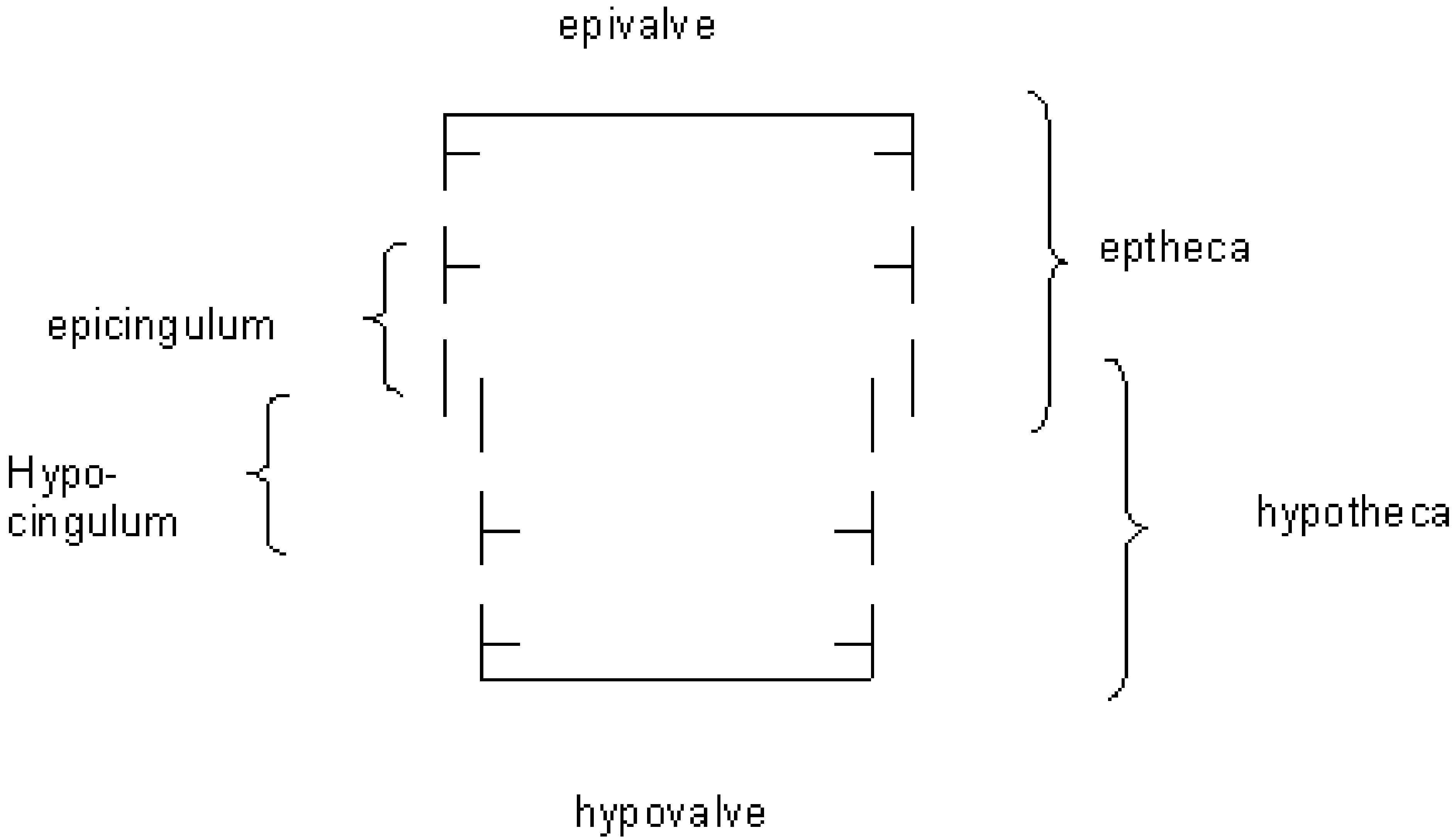
- The diatom frustule is often likened to a pill-box or agar dish with an epitheca (larger upper valve), and a hypotheca (smaller lower valve). The vertical lip or rim of the epitheca is called the epicingulum, and the epicingulum fits over (slightly overlaps) the hypocingulum of the hypotheca.

- The epicingulum and hypocingulum with one or several connective bands make up the girdle. Many diatoms are heterovalvate, i.e., the two valves of the frustule are dissimilar.

- This is most obvious within the family Achnanthaceae where one valve has a raphe and the other does not, and the Cymatosiraceae where one valve has a tubular process and the other does not.

- Chain-forming species with cells linked together by siliceous structures may, in addition, have separation valves. These valves are morphologically different from the valves within the chain. Therefore, one species may have four morphologically distinct types of valves.

Diagrammatic section showing
frustule terminology



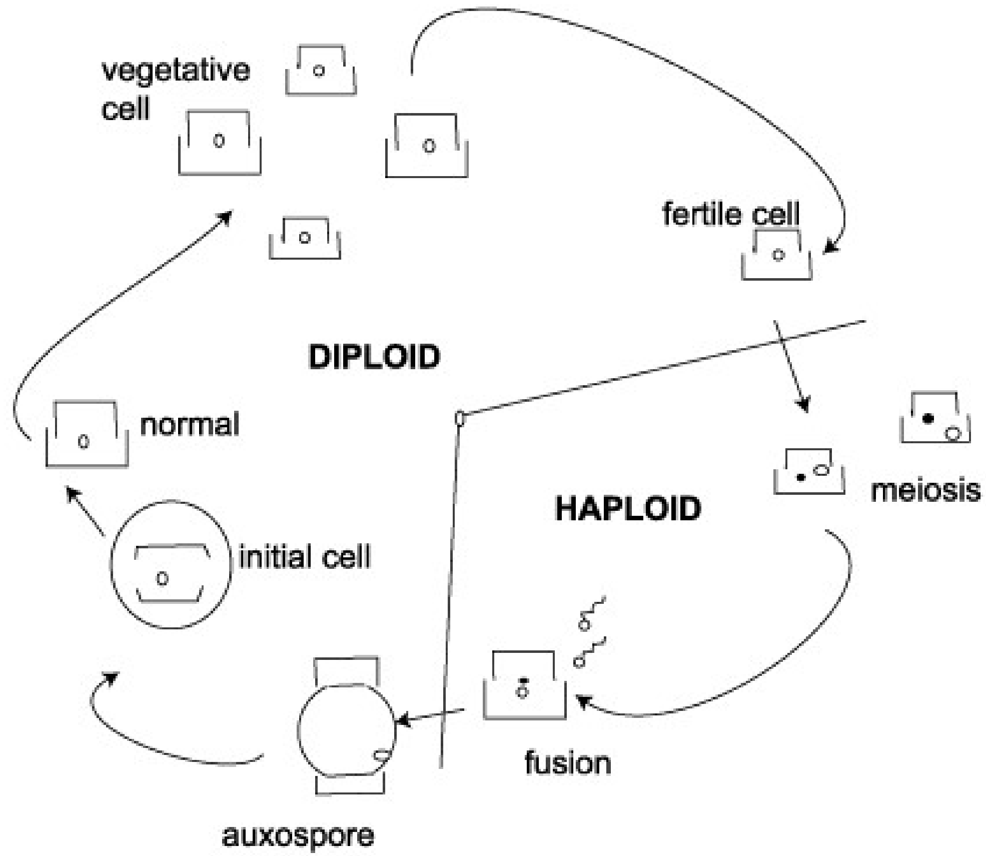


Diagram showing simplified life cycle of a typical diatom. The decrease in the average cell size of a diatom population requires at a certain point the restoration of cell size by the production of an auxospore in which the cell sheds its siliceous frustule. The resulting organic walled cell then produces a new maximal sized frustule within itself. The new first cell may differ from the normal vegetative cell in girdle straucture, valve outline and process pattern.

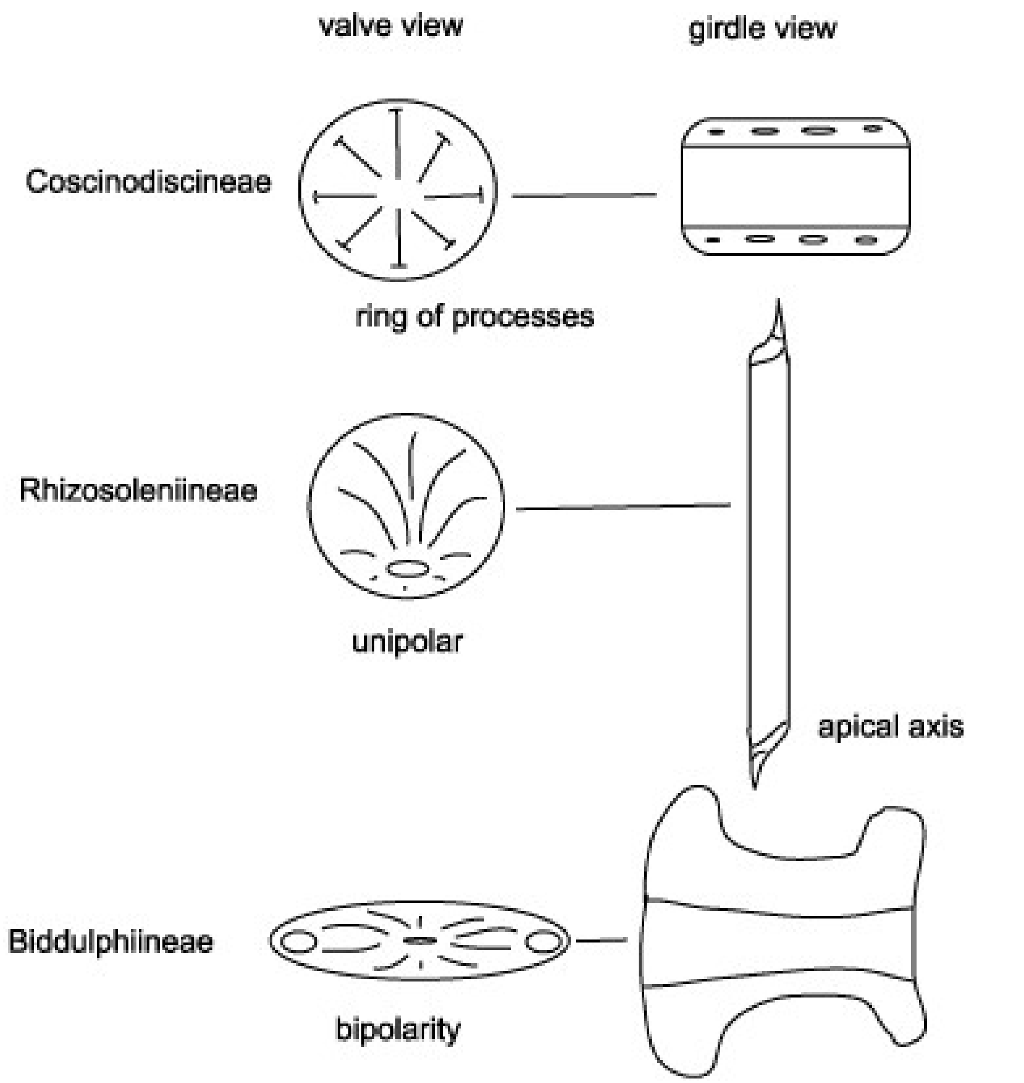
Range of diatoms

- First recorded occurrences of diatoms are from the Jurassic, however, these are uncertain and the earliest recorded well preserved diatoms are centric forms from the Aptian-Albian stages of the Cretaceous.
- Since these are quite diverse assemblages it is assumed diatoms have an earlier evolutionary history, perhaps lacking a relatively robust silica frustule.
- As with coccoliths, the earliest forms in the fossil record may reflect a biomineralization event rather than an evolutionary appearance.
- The earliest araphid (lacking a raphe) pennate diatoms appear in the Late Cretaceous, and raphid pennates in the Middle Eocene.
- The earliest freshwater diatoms appear in the Palaeocene in Russia and the Late Eocene in North America.
- In a similar manner to Radiolaria, it has been noticed that there has been a gradual progression towards less heavily silicified frustules, probably as a result of increasing competition for a limited resource (silica).

Classification

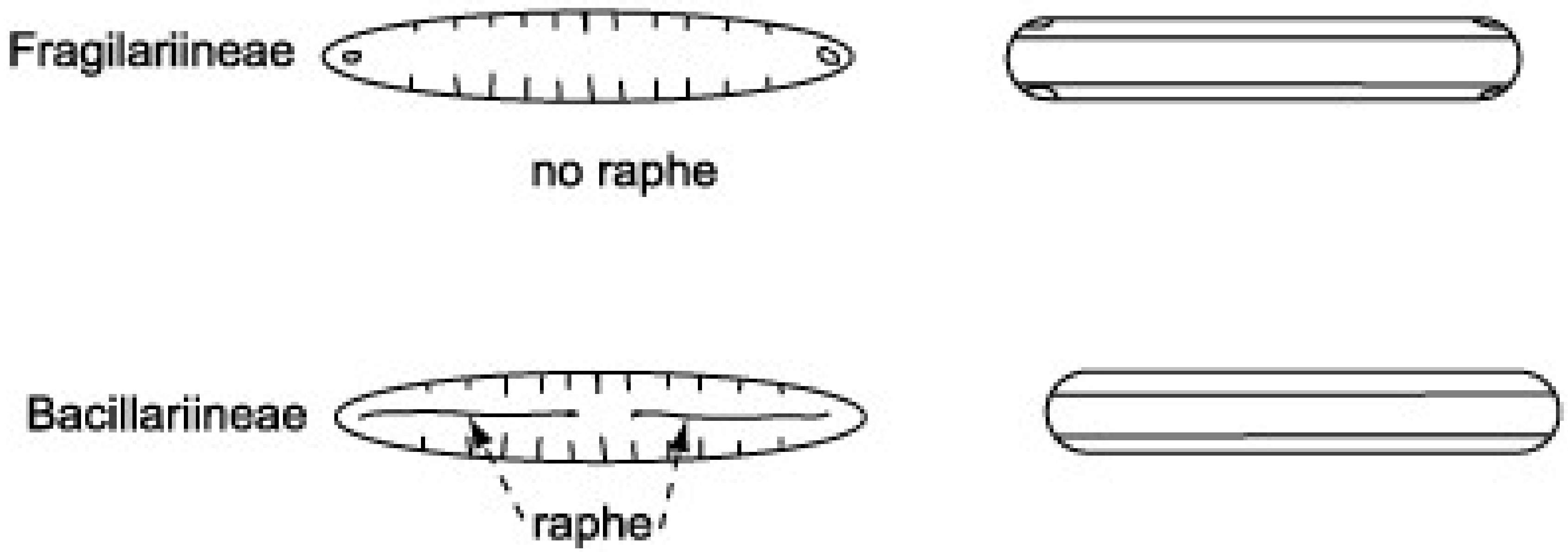
- **Diatoms are divided into two Orders:**
- **The Centrales (now called the Biddulphiales) which have valve striae arranged basically in relation to a point, an annulus or a central areola and tend to appear radially symmetrical, and the**
- **Pennales (now called Bacillariales) which have valve striae arranged in relation to a line and tend to appear bilaterally symmetrical.**
- **The valve face of the diatom frustule is ornamented with pores (areolae), processes, spines, hyaline areas and other distinguishing features. It is these skeletal features which are used to classify and describe diatoms, which is an advantage in terms of palaeontology since the same features are used to define extant species as extinct ones.**
- **The classification system developed by Simonsen (1979) and further developed by Round et al. (1990) is currently the most commonly accepted.**
- **Diatoms commonly found in the marine plankton may be divided into the centric diatoms including three sub-orders based primarily on the shape of the cells, the polarity and the arrangement of the processes.**
- **These are the Coscinodiscineae, with a marginal ring of processes and no polarity to the symmetry, the Rhizosoleniineae with no marginal ring of processes and unipolar symmetry, and the Biddulphiineae with no marginal ring of processes and bipolar symmetry.**
- **The pennate diatoms are divided into two sub-orders, the Fragilariineae which do not posses a raphe (araphid) and the Bacillariineae which posses a raphe.**

CENTRIC DIATOMS



Schematic diagram of centric diatom suborders redrawn from Hasle and Syvertsen 1997.

PENNATE DIATOMS



Schematic diagram of pennate diatom suborders. Redrawn from Hasle and Syvertsen 1997.

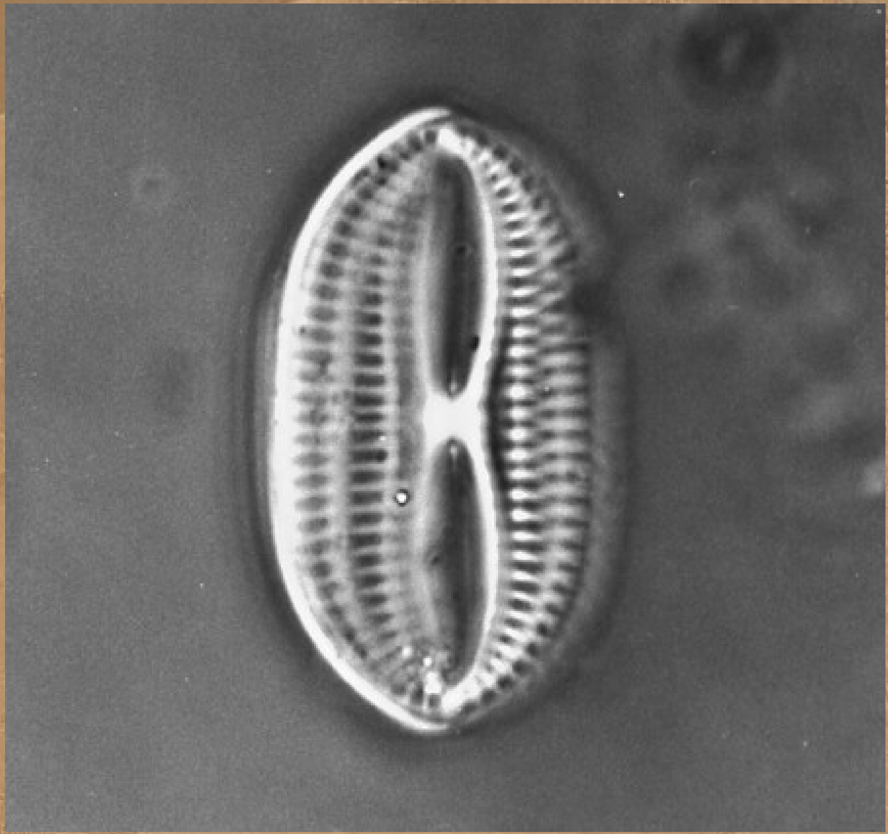
Applications

- The evolutionary history of diatoms has been punctuated by several floristic turnovers, these have been utilised to allow basin wide biostratigraphic correlations.

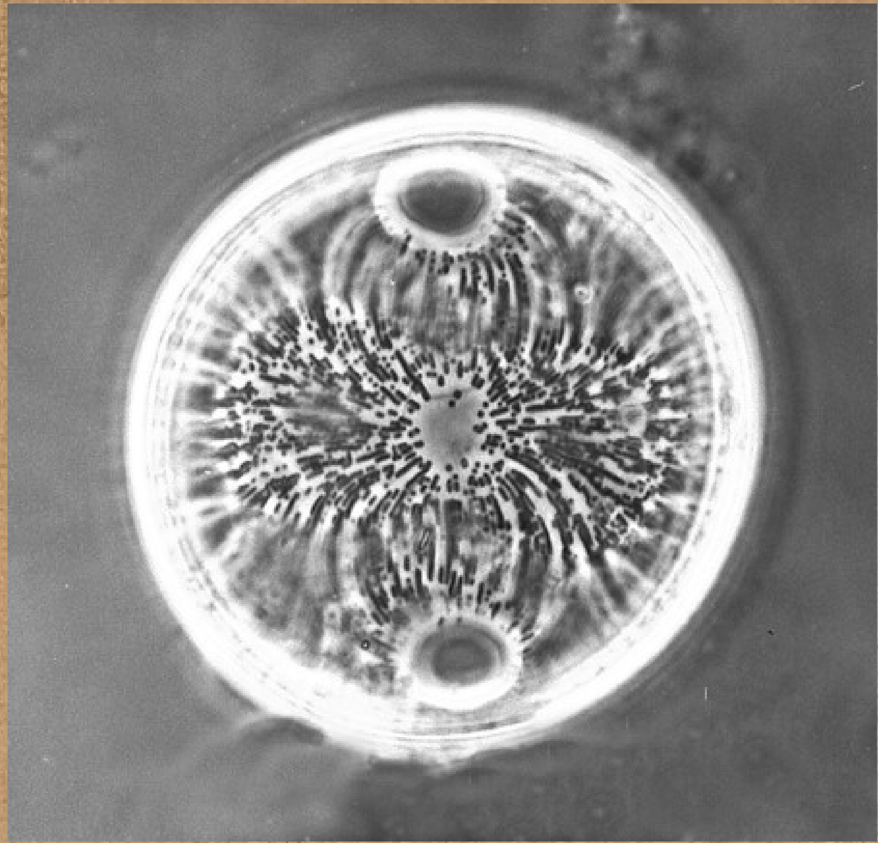
- Diatoms are also used extensively in palaeoenvironmental studies particularly in palaeoceanography.

- Dissolution of diatom frustules during descent through the water column, on the sediment surface and during diagenesis may seriously alter the preserved assemblage by preferentially dissolving more lightly silicified forms.
-
- High alkalinity of pore waters and burial temperatures in excess of 50 degrees centigrade are also known to increase dissolution of silica. Incorporation into faecal pellets or muciligenous aggregations, rapid burial and the formation of heavily silicified resting spores tend to counteract these problems, however, in marine samples it is thought that only 1% to 5% of the living assemblage in surface plankton is represented in the death assemblage found on the sediment surface.

- Despite these problems diatoms are still a useful and to a certain extent under-utilised group in terms of biostratigraphy.

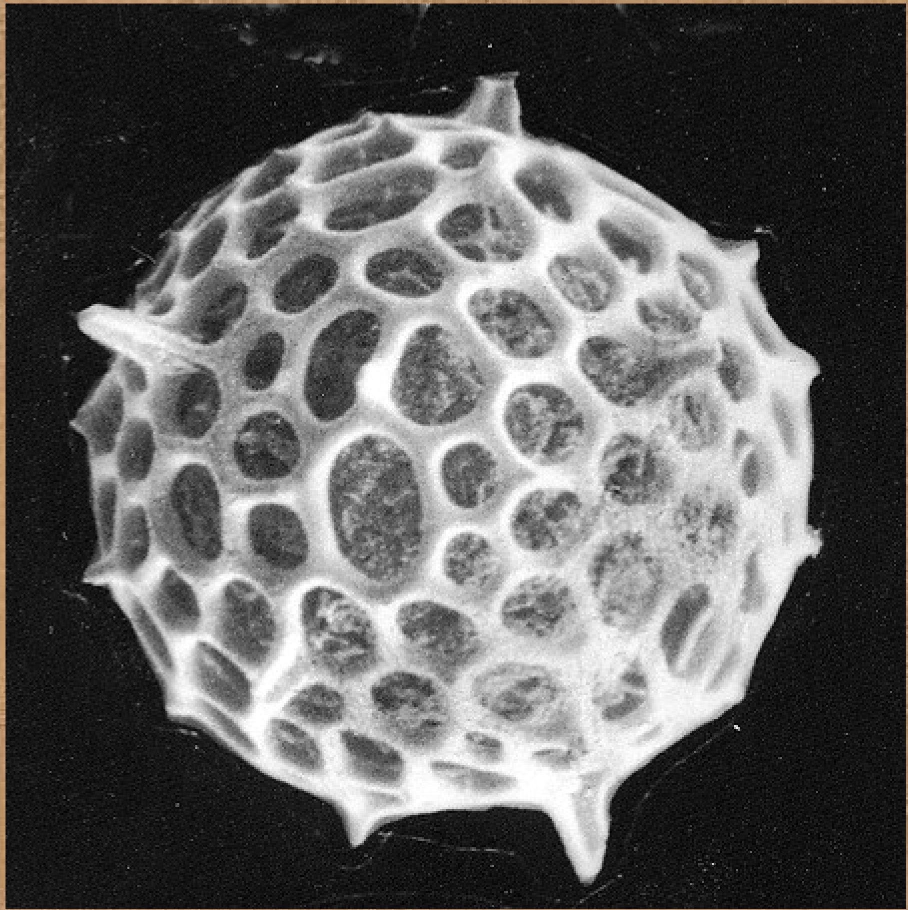


Diploneis suborbicularis



Auliscus sculptus

Radiolaria



- **Radiolaria are holoplanktonic protozoa and form part of the zooplankton, they are non-motile (except when flagella-bearing reproductive swarmers are produced) but contain buoyancy enhancing structures; they may be solitary or colonial.**

- **Formally they belong to the Phyllum Protista, Subphylum Sarcodina, Class Actinopoda, Subclass Radiolaria.**

- **The sister Subclass Acantharia have skeletons composed of strontium sulphate which is easily dissolved in seawater and are not preserved in the fossil record.**

- **Within the Subclass Radiolaria there are two important super-orders.**

- **The Tripylea which includes the Phaedaria which have skeletons composed of hollow silica bars joined by organic material, which are not commonly preserved, and the**

- **Polycystina which form skeletons of pure opal and are therefore more resistant to dissolution in seawater and hence more commonly preserved in the fossil record.**

- **The Polycystina may be divided into two suborders the Spumellaria and the Nassellaria. They are wholly marine, the most relatively commonly preserved and therefore studied members of the formal Subclass Radiolaria.**

- **t must be remembered, however, that seawater is under saturated with respect to silica and the degree of preservation of Radiolaria depends on the robustness of the skeleton, depositional and burial conditions and diagenesis.**

Range

- **First recorded occurrences of Radiolaria are from the latest Pre-Cambrian, they are generally thought to have been restricted to shallow water habitats.**

- **By the Silurian deep water forms are believed to have evolved. All early Radiolaria are *spumellarians*, the first possible *nassellarians* appear in the Carboniferous and definite true nassellarians do not appear until the Triassic.**

- **During the late Palaeozoic Radiolaria show a gradual decline until the end of the Jurassic when there is a rapid diversification, this coincides with the diversification of the dinoflagellates which may have represented an increased source of food for the Radiolaria.**

- **It is thought that the evolution of diatoms in the Cretaceous may have had a significant effect on radiolarian evolution due to competition for silica (diatoms also use silica to build their skeleton); it is commonly accepted that radiolarian skeletons have become finer and less robust from this time.**

Classification

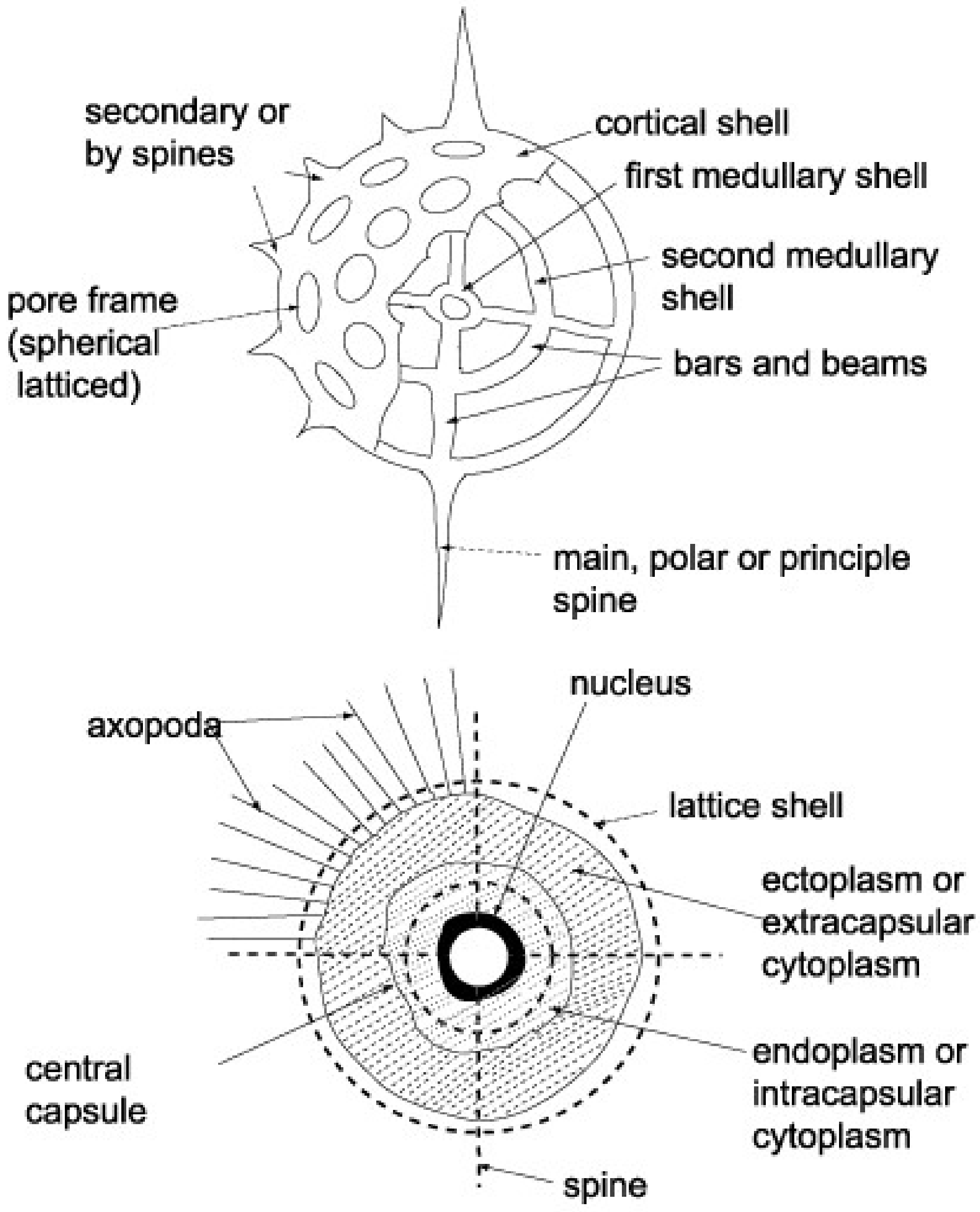
- Extant radiolaria are classified using features of both the preservable skeleton and the soft parts, which makes the classificaiton of fossil forms extremely difficult.

- Most workers in this field today use classification schemes based on Nigrini and Moore's and Nigrini and Lombari's works on modern and Miocene radiolarians.

- A major problem with radiolarian classification is that separate classifications have been established for the Palaeozoic, Mesozoic and Cenozoic, and little has been done to integrate them.

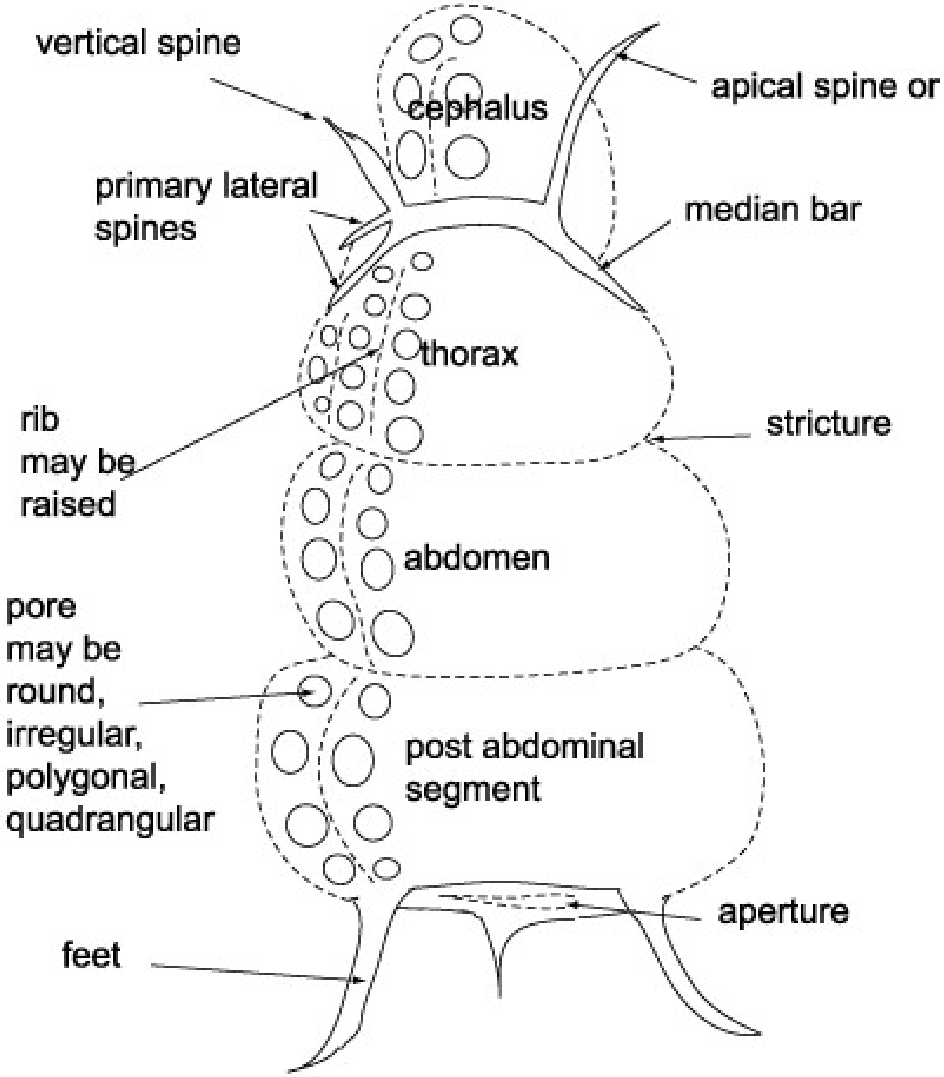
- The two suborders, the spumellarians and the nassellarians are subdivided into informal groups which equate to family level.

SPUMULLARIAN



Diagrammatic cross-sections of spumullarian radiolaria.

NASSELLARIAN



Diagrammatic idealised nassellarian radiolaria showing basic morphological features

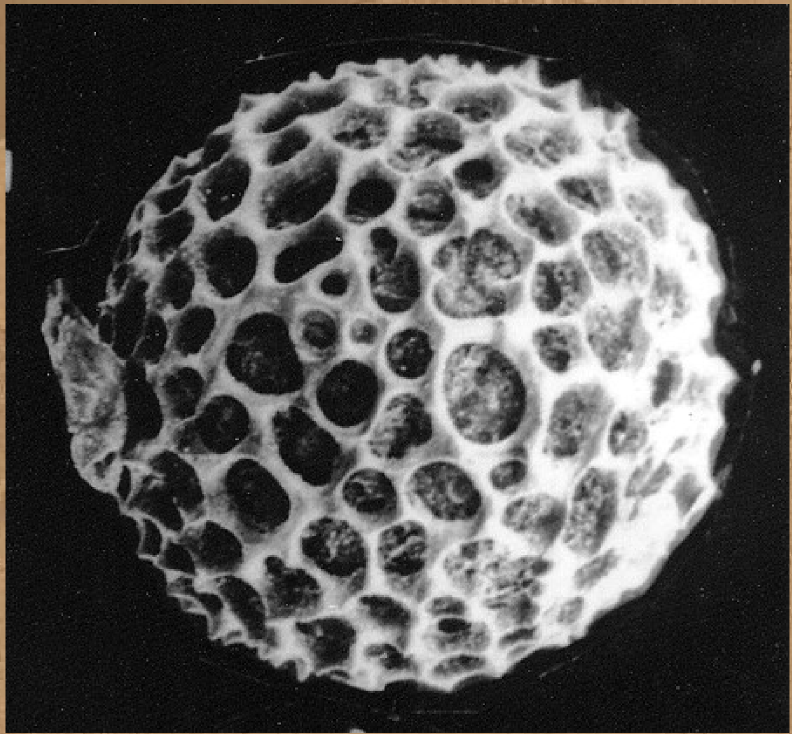
Applications

- Radiolarian assemblages often contain 200-400 species so they can potentially be very useful biostratigraphic and palaeoenvironmental tools.

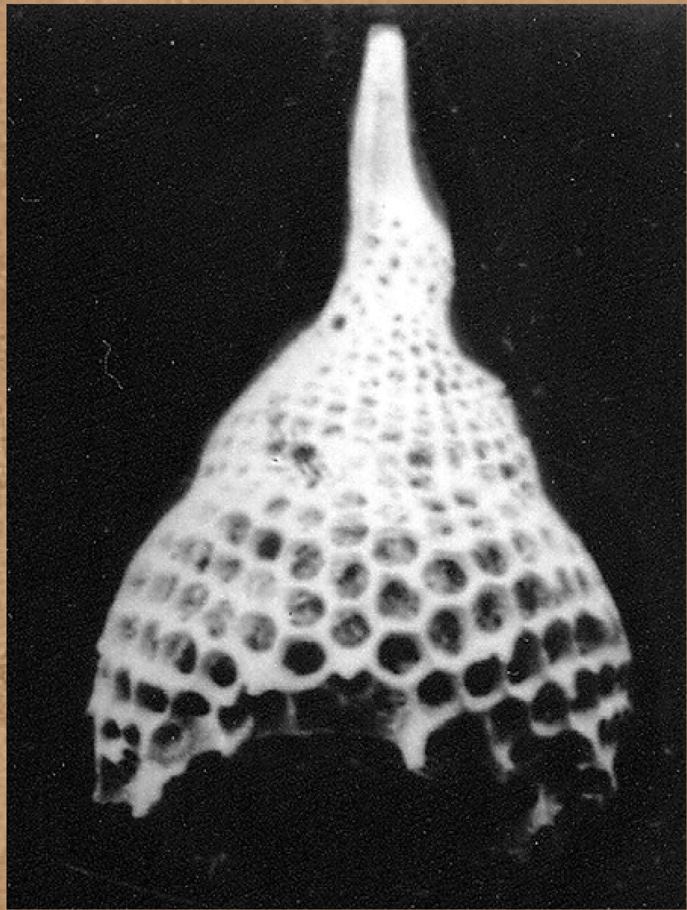
- They have an unusually long geological range, from latest Pre-Cambrian to Recent. Because Radiolaria have a skeleton composed of silica and have an extremely long geological range they have become useful in the study of sediments which lack calcareous fossils, either because of deposition below the CCD (Carbonate Compensation Depth) or because the strata being examined are too old.

- Cherts and particularly nodules within chert bands are often good sources for Radiolaria.

- Ophiolites and accretionary terrains often include chert bands and Radiolaria may be the only palaeontological aid available in these situations and as such have proved invaluable in the study of these geological settings.

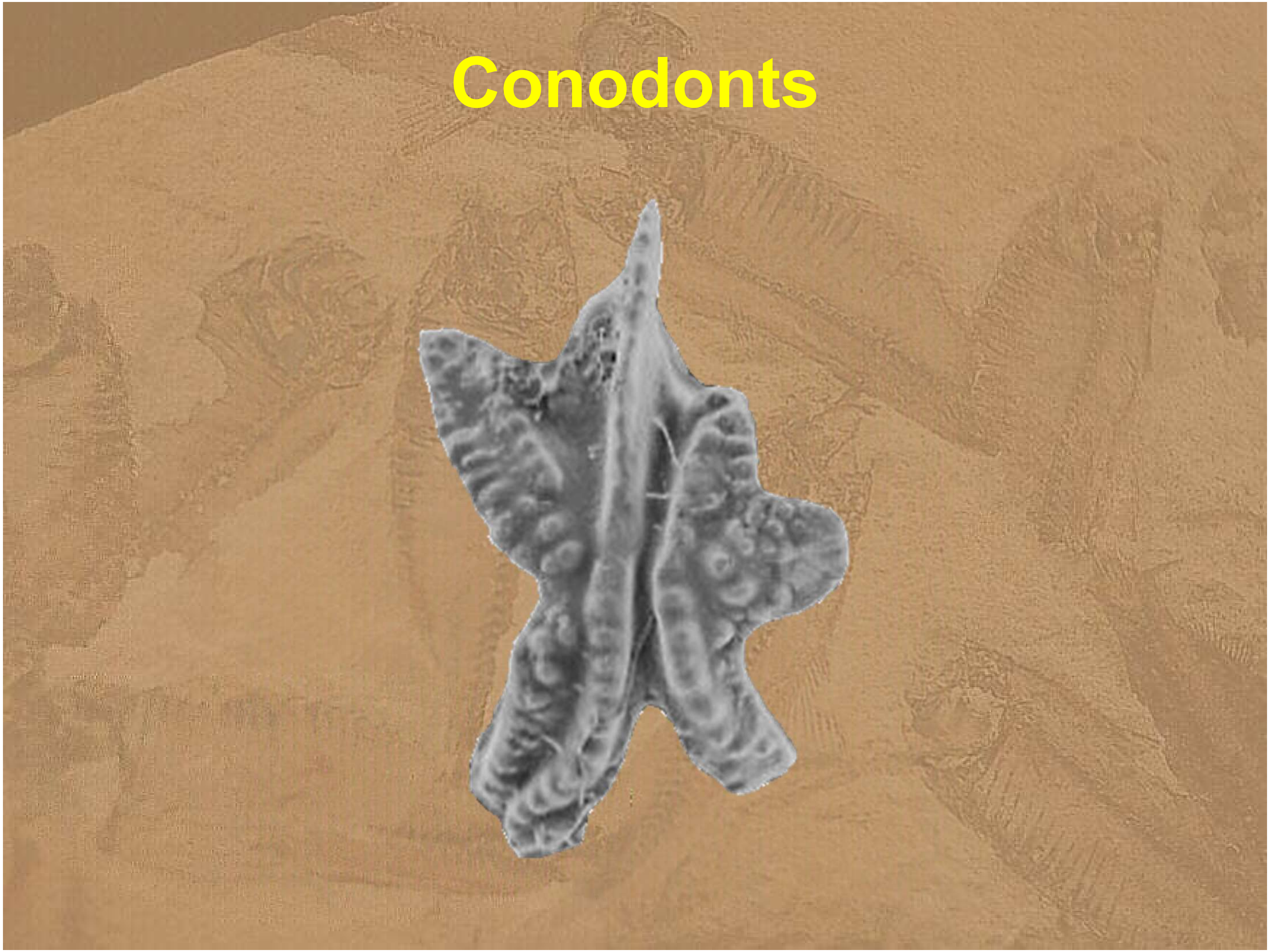


Cenosphaera cristata Haeckel



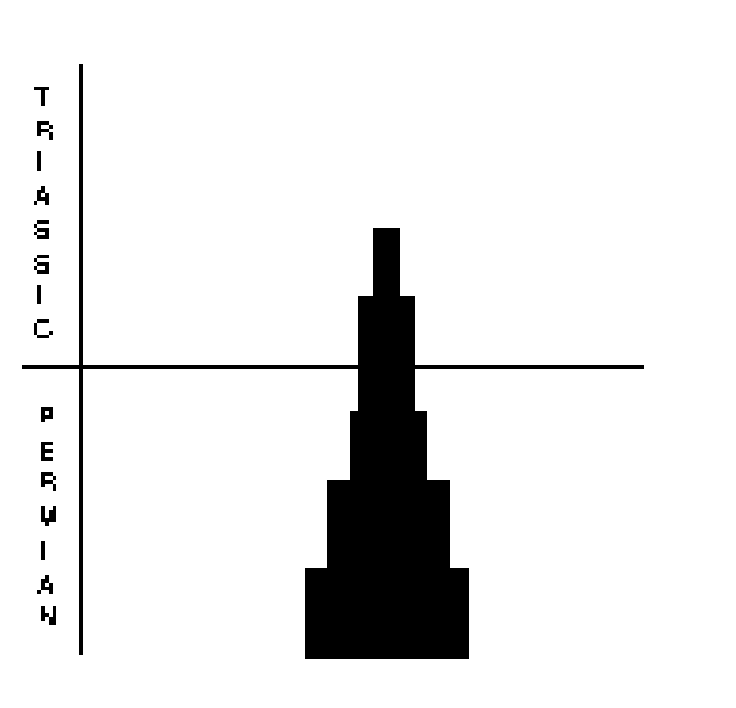
Lamprocyclus maritalus Haeckel

Conodonts



Conodonts

- Conodont elements are phosphatic tooth-like structures whose affinity and function is now believed to be part of the feeding apparatus of an extinct early vertebrate.
- Early ideas concluded that the conodontophorid was a soft bodied, bilaterally symmetrical nektonic organism, although there is still much debate concerning possible benthic, nektonic or combined mode of life.
- Conodont elements are composed of calcium carbonate fluorapatite with additional organic matter.
- They are found in marine deposits, commonly in black shales associated with graptolites, radiolarians, fish remains, brachiopods, cephalopods, trilobites and palaeocopid ostracods.



Conodonta

- Had suffered a near extinction in the Early Permian, but had managed to survive and modestly diversify during Permian. Didn't ever become major order, becoming fully extinct in Late Triassic/Early Jurassic.
- "Most Late Permian [Conodont] species passed the notorious Permian-Triassic filter with seeming indifference" (Sweet,1973).
- Seemingly only ?invertebrate? (Clark, 1986) to cross boundary with no noticeable negative effect.
- Microscopic, 0.05-2 mm phosphatic structures. - Specific mode of life not fully understood.
- Some believe could be vertebrates due to phosphatic nature, but opinion is divided.
- Not known to which group of animals they belong.

Range

- The very earliest conodonts are known from rocks of probable Precambrian age in Siberia, they are found more commonly in Cambrian deposits, diversity increased in the Ordovician and again during the Devonian.

- The conodont-bearing organism clearly survived the Permo-Triassic boundary extinctions but became extinct during the late Triassic.

- It has been noted that the extinction of the conodonts coincides with the diversification of dinoflagellates and first appearance of calcareous nannofosils.

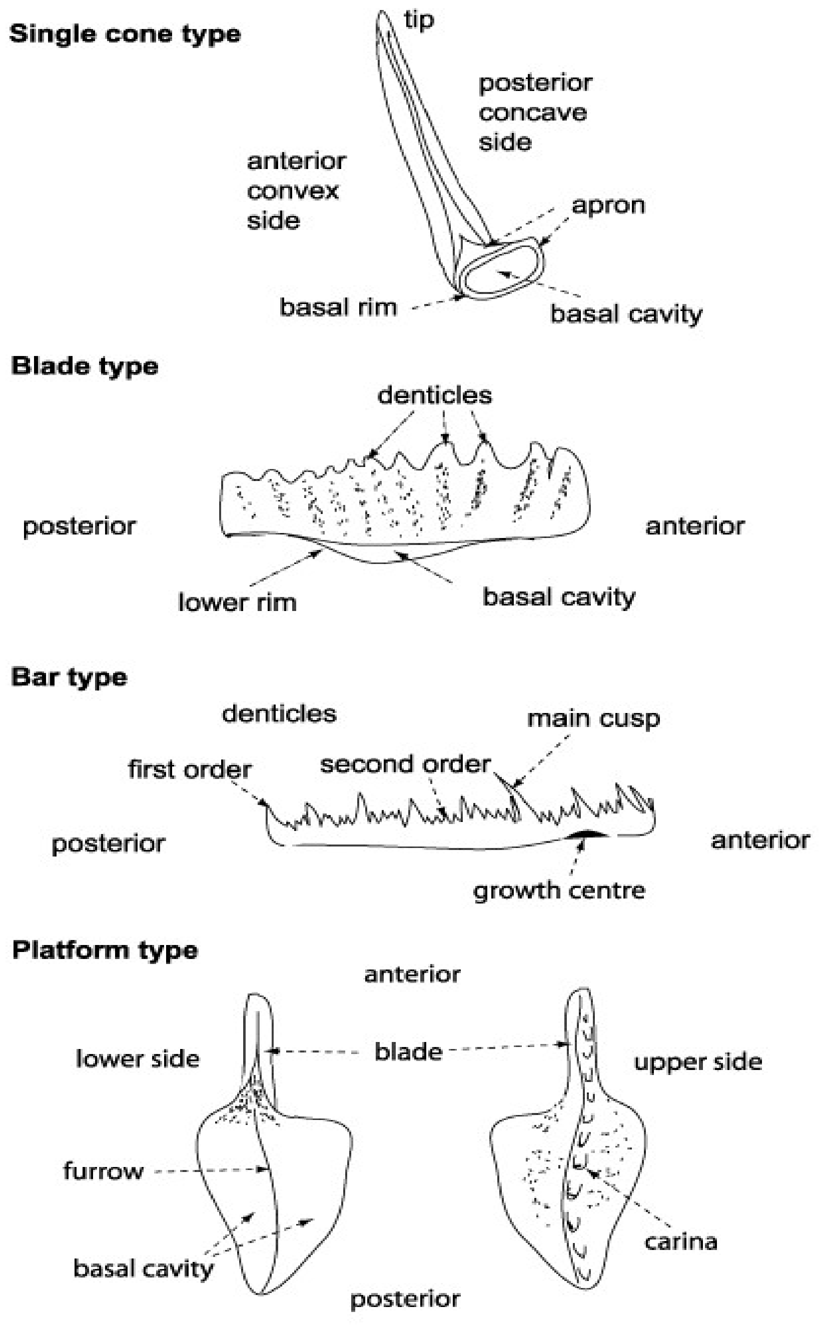
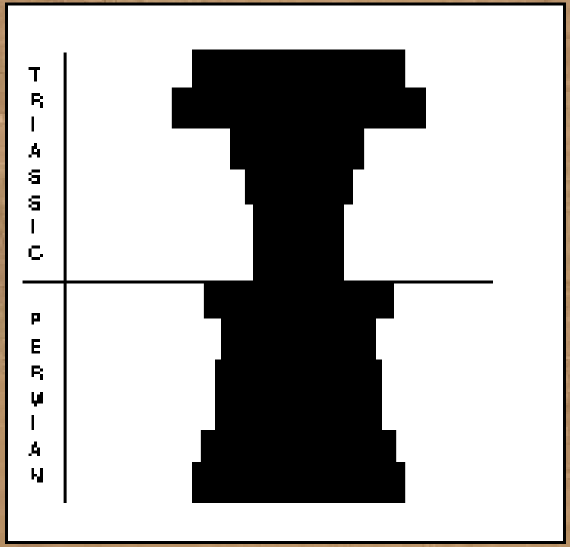


Diagram showing morphological terminology redrawn from Muller 1978



Porifera

•Reef related, found particularly in localised zones within China.

•13 genera, of which 4 survived into Triassic.

•Surviving Palaeozoic forms dominated sponge faunas through Triassic. Didn't radiate quickly however.

•Doesn't have abundant fossil record, not being found at many locations.

•Sponges thought to be the most primitive of metazoans. Believed to have been formed by the uniting of protozoa to a colonial organism.

•Benthonic, with an internal skeleton of spicules of calcite or silica.

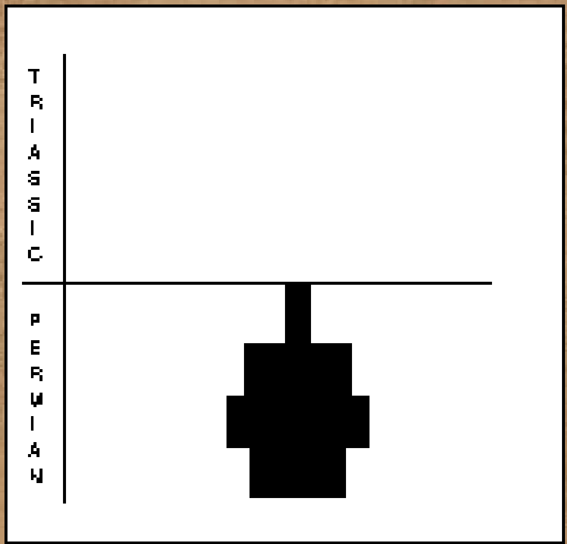
•Classified on the nature of these spicules and way in which they unite.

Corals

- Two extinct types of corals which are frequently preserved in limestones are the **rugose** and the **tabulate** corals, both of which arose in the Ordovician Period (434 to 490 million years ago) and became extinct at the end of the Permian Period (251 million years ago).

- Scleractinian ("hard-rayed") corals first appeared in the **Middle Triassic** and refilled the ecological niche once held by **tabulate** and **rugose** corals. They are probably not closely related to the extinct tabulate or rugose corals, and probably arose independently from a sea anemone-like ancestor. Their *pattern of septa* differs markedly from that of the Rugosa, being basically six-rayed. For this reason, scleractinians are sometimes referred to as hexacorals.

Corals: Tabulata



•Became fully extinct at the Permo-Triassic boundary.

•7 species lost.

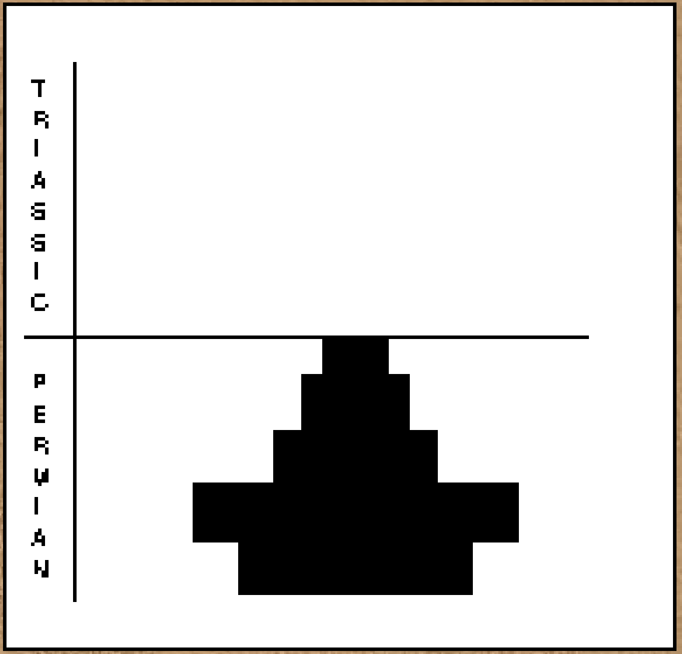
•Radially symmetrical coral consisting

•of two layers of cells united by acellular layer of jelly.

•Food is passed through central mouth to
•internal cavity in which digestion takes place.

•Simple colonial coral.

Corals: Rugosa



•Many different species present throughout the Permian.

•All became extinct during Permo-Triassic extinction event.

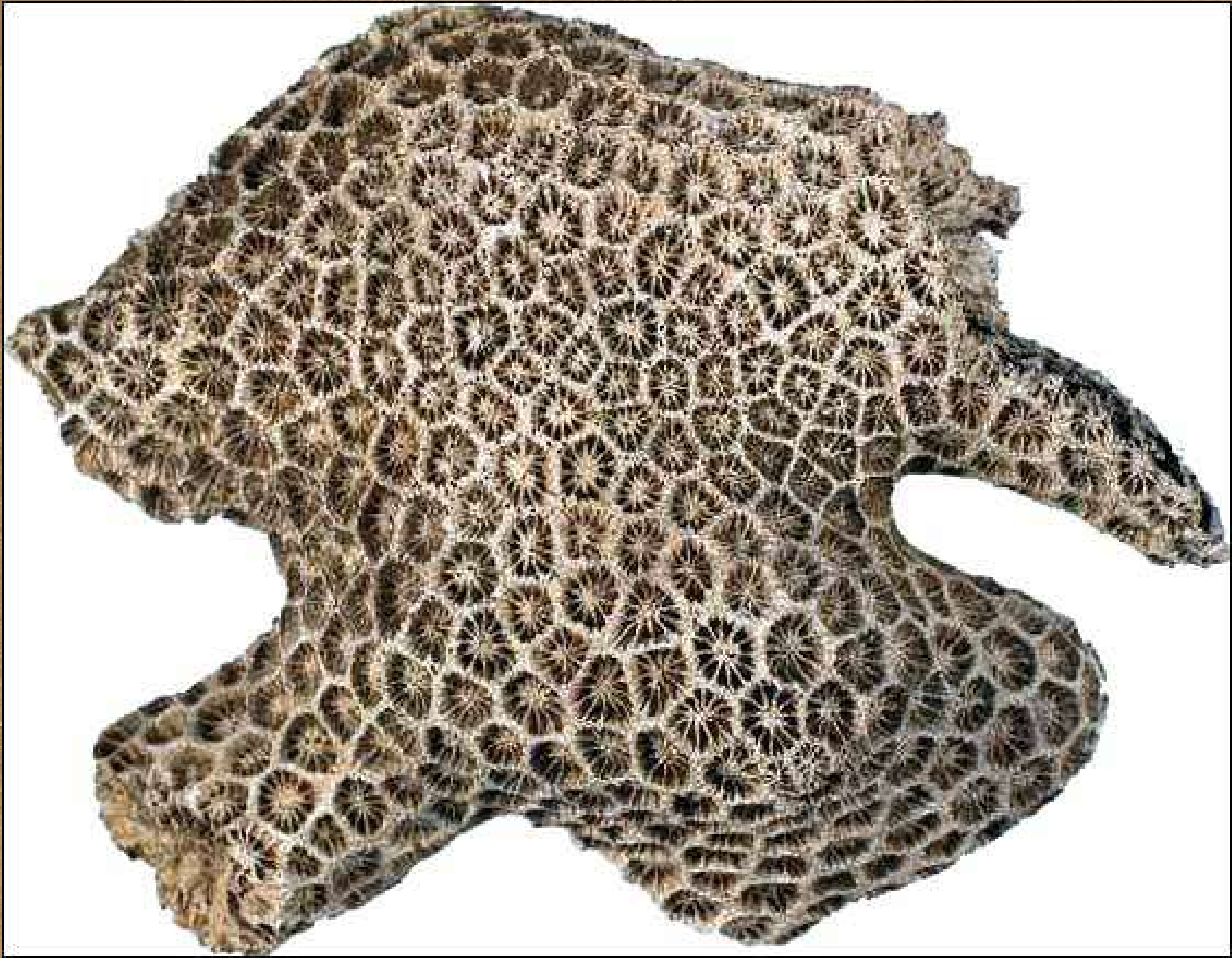
•Any fossils found in Triassic strata are derived from Permian sediments.

•Radially symmetrical coral consisting of two layers of cells united by acellular layer of jelly.

•Food is passed through central mouth to internal cavity in which digestion takes place.

•Range of forms from simple solitary to complex colonial types.

•Have number of features not seen in the simpler Tabulata,
such as dissepiments and various columella structures in the centre of each corallite.



Scleractinian coral

Coral reefs

- Colonial scleractinians from modern tropical seas are now the world's primary reef formers. Colonial corals consist of large numbers of polyps, cemented together by the calcium carbonate that they secrete. In the brain coral shown above, the individual polyps are no longer visible, having fused into long, meandering rows that resemble the wrinkles of a human brain.

A. Reef composition.

1. Hard corals build by secreting calcium carbonate skeletons.

2. Boring organisms such as sponges, worms, and bivalves; along with grazers such as parrotfish and sea urchins break down the coral skeletons. Borers and grazers usually attack dead coral. The resulting sediment settles into spaces in the reef.

3. Coralline algae, encrusting bryozoans, and minerals cement the dead organic matter, stabilizing the reef structure.

B. Reef formation and types of reefs.

1. At one time it was mistakenly thought that coral grew at the bottom of deep tropical seas and succeeding generations grew on top of the dead calcium carbonate skeletons. This idea was dispelled by dredging operations that indicated that reef corals were able to grow only in shallow water.

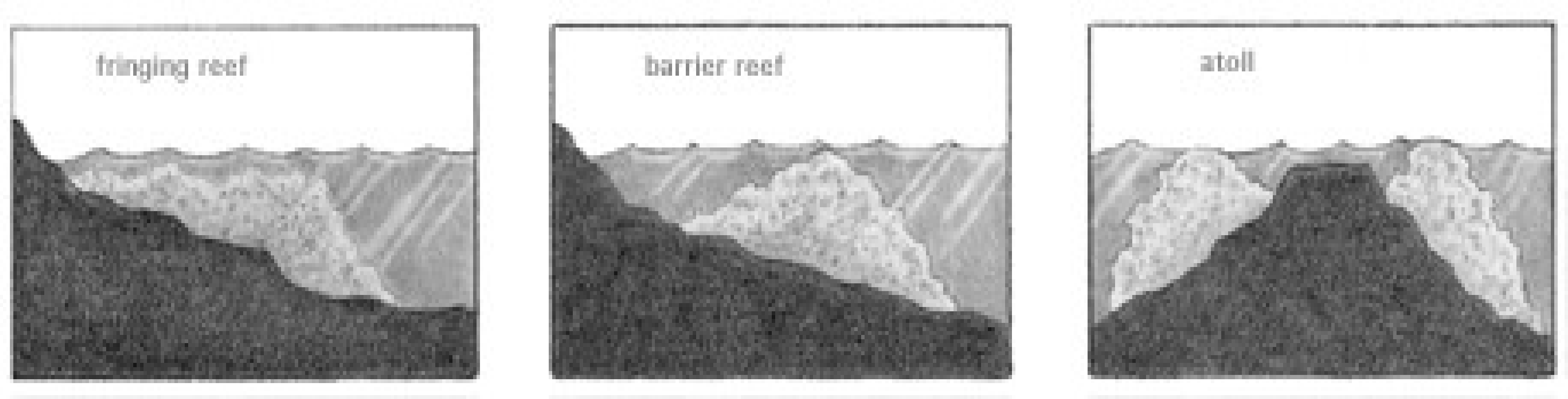
2. Naturalist Charles Darwin's theory of coral formation is widely accepted. This theory recognizes three types of reefs: the fringing reef, the barrier reef, and the atoll.

   a. The first type is a fringing reef. Fringing reefs border shorelines of continents and islands in tropical seas. Fringing reefs are commonly found in the South Pacific Hawaiian Islands, and parts of the Caribbean.

   b. The next type is the barrier reef, which occurs farther offshore. Barrier reefs form when land masses sink, and fringing reefs become separated from shorelines by wide channels. Land masses sink as a result of erosion and shifting crustal plates of the earth. (Crustal plates lift or sink the seafloor and adjacent land masses.) Barrier reefs are common in the Caribbean and Indo-Pacific. The Great Barrier Reef off northern Australia in the Indo-Pacific is the largest barrier reef in the world. This reef stretches more than 1,240 miles (2,000 km).

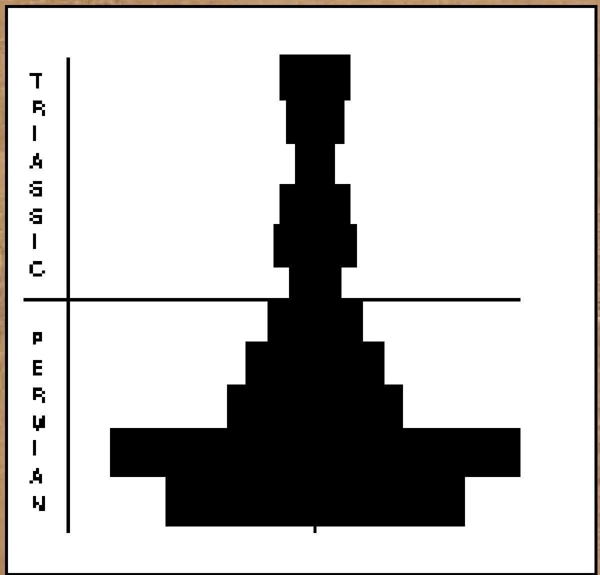
   c. If the land mass is a small island, it may eventually disappear below the ocean surface, and the reef becomes an atoll. Atolls are reefs that surround a central lagoon. The result is several low coral islands around a lagoon. Atolls commonly occur in the Indo- Pacific. The largest atoll, named Kwajalein, surrounds a lagoon over 60 miles (97 km) long.

There are 3 types of coral reefs



Existing coral reefs have been formed since the last of three glacial periods in the Pleistocene epoch, 10,000 years ago. Seawater trapped as ice in enormous glaciers caused sea level to fall. Consequently, all previously formed coral reefs probably died from exposure. When the glaciers melted, sea level rose to its current position and present-day reefs began to develop.

Bryozoa



Suffered a lot in prolonged decline of species through Permian.

128 genera to 28 in the Late Permian.

5 families with vastly reduced diversity survived through to Triassic, but became extinct quickly.

Aquatic colonial organisms. -Skeletal material of chitin or calcium carbonate, with usually only the calcareous form being preserved.

-Colonies are small, 5-150mm, in fan-shaped, stick-like or lobate forms.

-Soft parts are similar to those of Brachiopods.

Permian Bryozoa *Fenestella multiporata.*

- **Bryozoans first appeared in the Ordovician Period (434 to 490 million years ago) and quickly became abundant.**

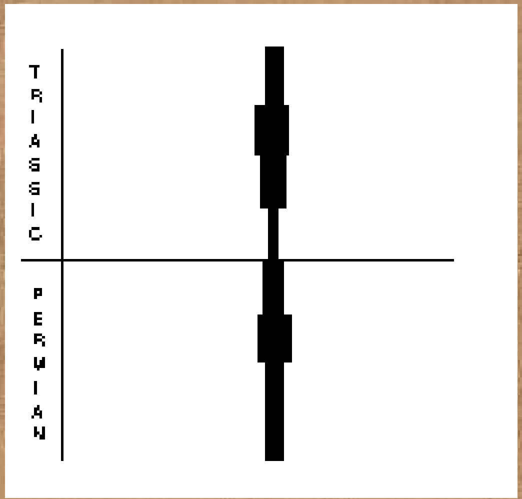
- **Many species disappeared in the mass extinction at the end of the Permian Period (about 251 million years ago), but those that survived were able to recolonise the oceans.**

- **Over 15000 fossil species are known, and the 3500 species which are living today are widespread in all oceans, particularly the western Pacific.**

- **They are found at all depths, but particularly favour depths between 20 and 80 metres, where they encrust rocks, seaweed and coral reefs.**

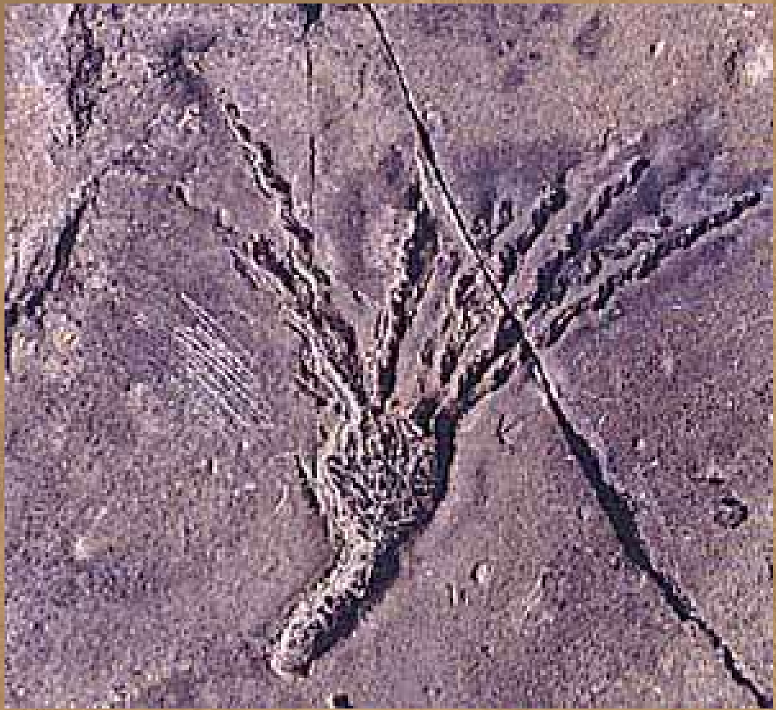
Echinodermata

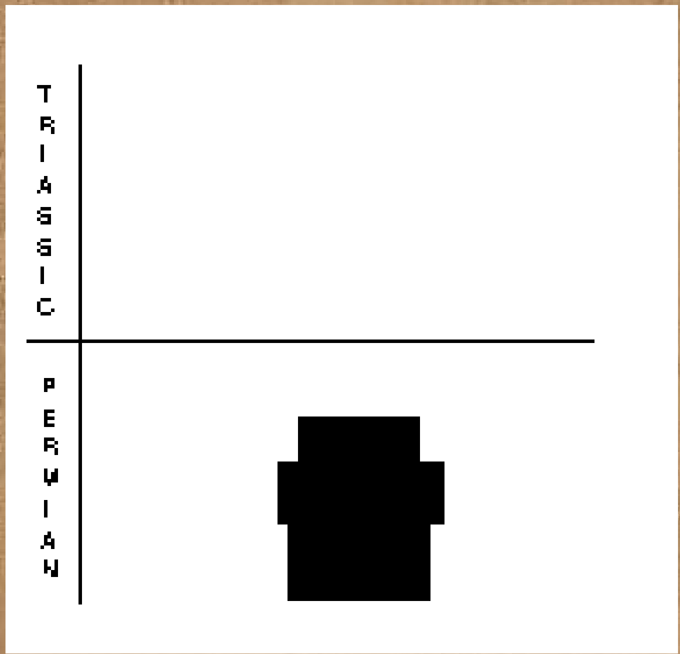
- Echinoidea
- Blastoidea
- Crinoidea



Echinodermata: Echinoidea

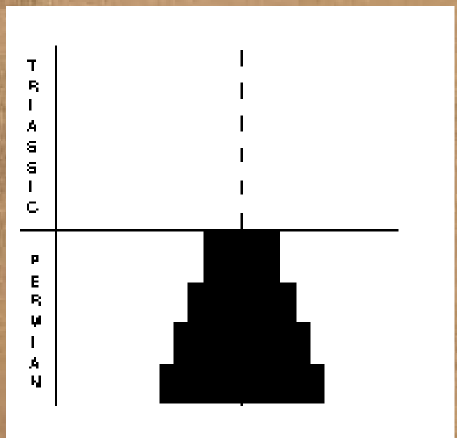
- Emerging from pores on the perforate rows are tube feet, which are connected to an internal water vascular system responsible for locomotion and respiration.
- Extinction is not of special significance in the evolution and development, but did dramatically reduce numbers.
- Few fossils found pre and post extinction.
- Similar morphology and diversity each side of the boundary.
- Entirely marine organism with test made up of calcareous plates or spicules. -Different from other invertebrates in that test is secreted from middle body layer rather than outer layer, thus becoming enveloped by soft tissue.
- Each plate or spicule is a single crystal of calcite.
- Have characteristic spinose, spherical and radially symmetrical test.
- Typically this test is composed of twenty vertical rows of plates arranged in pairs, five rows are perforate alternating with five imperforate ones.





Echinodermata: Blastoidea

- Have unusual vacillitating history with local bursts and extinctions.
- Became extinct in epoch just before P-T boundary.
- Entirely marine organisms with tests made up of calcareous plates or spicules.
- Different from other invertebrates in that test is secreted from middle body layer rather than outer layer, thus becoming enveloped by soft tissue.
- Each plate or spicule is a single crystal of calcite.
- Presumed to have evolved from cystoids (primitive Echinodermata, became extinct in Carboniferous).
- Consists of stalk surmounted by a calyx which contains 13 plates arranged in 3 rows.



Echinodermata: Crinoidea

- Stem is made up of individual oscicles, which make up the majority of crinoid remains found. Palaeozoic crinoidea underwent mass extinction at boundary.
- One genus, the articulate Isocrinus, has been found to have survived which then radiated to form the Mesozoic Crinoidea recovery.
- Very few Triassic age fossils are found, with the recovery essentially post Triassic.
- Entirely marine organism with test made up of calcareous plates or spicules. -Different from other invertabrates in that test is secreted from middle body layer rather than outer layer, thus becoming enveloped by soft tissue.
- Each plate or spicule is a single crystal of calcite.
- Consists of a stem surmounted by a calyx of 2 or 3 rows of plates, bearing 5 pinnate arms.
- Arms collect small food particles which are passed into the mouth.

Crinoid *Periechocrinus moniliformis*, from the Silurian of England

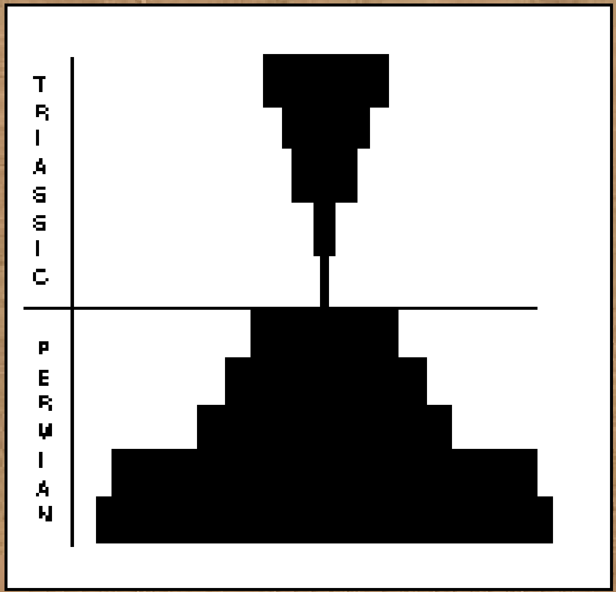
- **Fossil crinoids date back almost 500 million years to the Cambrian Period.**

- **They were very abundant during the Palaeozoic Era and sometimes lived in large accumulations known as 'crinoid gardens'.**

- **They resembled long-stemmed flowers, with a central 'cup' containing the soft parts of the animal, numerous branching 'arms' and a stem up to 30 metres long which attached the animal to the ocean floor.**

- **When the animals died, the ocean currents often broke up the remains and rolled them together in vast amounts to form thick deposits of limestone.**

Brachiopoda



Divided into two classes:

-the primitive Inarticulata which possess no hinge structure and are commonly chitinous and the Articulata which have a hinge and are usually calcareous.

Numerically the most important fossils in Late Permian beds.

Found abundantly in formations around the world.

60 genera decreased to 10 over the P-T boundary, having also suffered a slight decline through the Permian.

Bivalved animals living in benthonic zone.

Range in size from 5-200mm.

Shells are generally unequal in size, usually symmetrical, composed of chitin or calcium carbonate, and situated ventrally and dorsally to the animal.

The larger valve has an aperture through which a muscular stalk protrudes to anchor animal to the sub-stratum.

The valves are opened and closed by adductor muscles, with filter feeding internal organs supported by internal structures.

Brachiopods *Mucrospirifer thedfordensis* from the Devonian of Ontario, Canada

- **Brachiopods were once very common, but are rarer now-there are 12000 fossil species known, but only 300 species still living today (some in Westernport Bay). The first Brachiopods arose in the Cambrian Period (490 to 545 million years ago) and various fossil species are often used to date rocks, especially in the Carboniferous and Permian periods (354 to 251 million years ago).**

Mollusca: Bivalvia

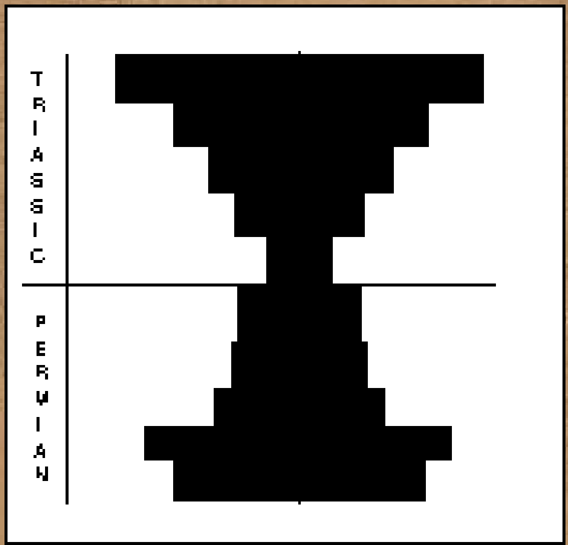
Declined from 50 genera/112 species at start of Late Permian to only 9 genera at P-T boundary.

Common and diverse fossils found throughout strata.

There isn't a perceptible diversification in the Mesozoic forms from those found in the Palaeozoic after the decline.

Triassic "newcomers" may have originated in the Permian just before the P-T boundary.

Aquatic bivalved molluscs.



Calcareous shells, (usually aragonite), situated laterally around soft body.

Valves usually symmetrical and of equal size.

Usual range of 5-100 mm, with very occasional examples of up to 1500 mm.

The valves are opened and closed by muscles which allows filter feeding.

Classification is based on the number of teeth within the hinge, with the earliest forms having many teeth, progressively reducing in number with evolution.

- **Bivalves are very common shallow-water molluscs, and include scallops, oysters, and clams.**
- **Bivalves are mostly benthic (bottom dwelling) and marine, although some live in fresh water.**
- **Some bivalves are burrowers, some attach themselves to rocks or to the sea floor, while others live in cavities.**
- **All bivalves have a shell consisting of two hinged components ('valves') which enclose the animal's soft body parts.**
- **The valves are partly open when relaxed, but are held shut by muscles when danger from predators (birds, starfish, gastropods) threatens.**
- **Some bivalves can swim short distances by clapping their two valves together.**

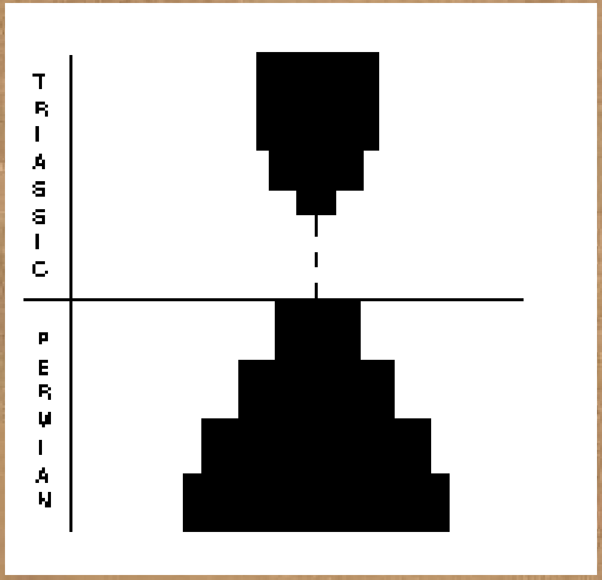
Bivalve *Panenka gippslandica*, from the Lower Devonian

- Bivalves first became common in the *Ordovician Period* (434 to 490 million years ago), and became widespread in the Mesozoic Era (65 to 251 million years ago) as burrowing species evolved. Since then they have become the dominant group of hard-shelled marine animals.

The Scissurellids are an antiquated group of limpets

- the split is typical of Paleozoic fossils.

Gastropoda



32 genera last seen at Middle-Late Permian boundary.

Unseen at the Permo-Triassic boundary.

Reappear in Triassic sediments with very similar morphology to those which had seemingly disappeared; Lazarus taxa.

As more fossils are found the similarities between pre and post P-T boundary faunas increases.

May have lived in oceanic sediments, which have as yet not been found.

Benthonic, univalved molluscs. -Secretes calcium carbonate shell from mantle.

Range in size from 1-100mm, although exceptionally can reach up to 500mm.

The shell is usually coiled, typically helical.

Classification of order is based on the shape and aperture of the shell.

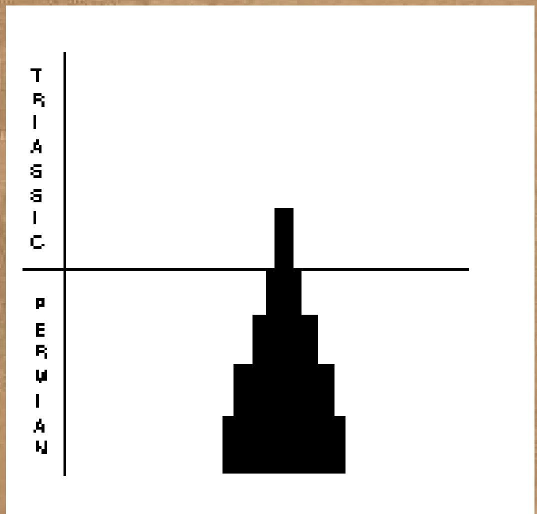
- **Gastropods arose early in the Cambrian Period (490 to 545 million years ago), and became very diverse in the Carboniferous Period (298 to 354 million years ago).**

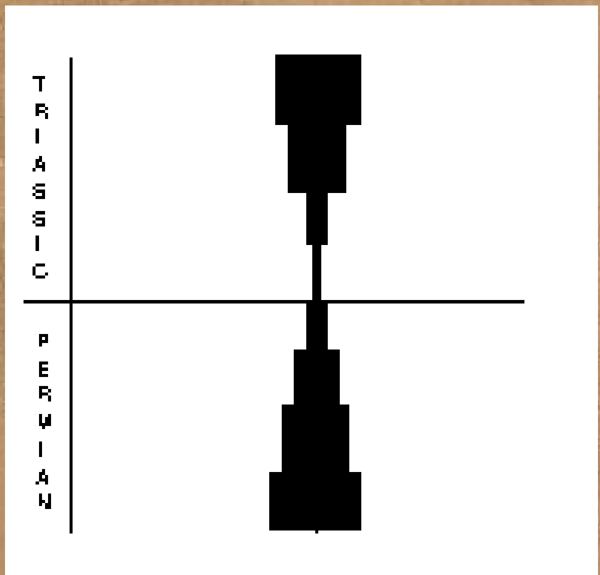
- **They were much affected by the mass extinctions at the end of the Permian Period (251 million years ago), but some species managed to survive, and to start to diversify again.**

- **From the beginning of the Tertiary Sub-era (65 million years ago) to the present, gastropods have come to dominate many of the environments in which they live. They are probably more numerous now than ever before.**

Orthocerida

- Was already in dramatic decline going into Permian, and continued to decline throughout Permian.
- Only two genera and one genus survive into Triassic which became extinct quickly.
- Cephalopod group which seems to resist all attempts for a practical and useful classification.
- As with other celphalopods, (Nautiloidea, Ammonoidea), has univalve shell composed mostly of aragonite.
- Shell is filled with gas, and has one or more chambers within it through which it can govern buoyancy.
- Soft bodied "foot" is modified to ring of tentacles around mouth.





Nautiloidea

- Well represented in Late Permian, with 17 species in 11 genera.
- 8 genera survive into Triassic and radiate from there.
- Marine mollusc with straight, curved or coiled shell.
- Soft bodied "foot" is modified to ring of tentacles around mouth.
- Shell is composed mostly of aragonite and is filed with gas to govern buoyancy.

Ammonoidea

Marine molluscs with straight, curved or coiled shell. Soft bodied "foot" is modified to ring of tentacles around mouth. Shell is composed mostly of aragonite and is filed with gas to govern buoyancy. Group evolved from the Nautiloidea in Silurian times with an increase in complexity of the suture line, and migration of the siphuncle to the outer margin of the shell.
Represented by three orders: the Goniatitida, Prolecanitida and Ceritida.

Goniatitida were the bulk of Permian ammonoids, but were suffering decline throughout the Permian. Suffered abrupt extinction of remaining genera at P-T boundary. One goniatite genus seen in basal Triassic which dies out very quickly.

Prolecanitida were small order which was declining throughout Permian. Only just survived across P-T boundary, before dying out completely in the first Triassic epoch.

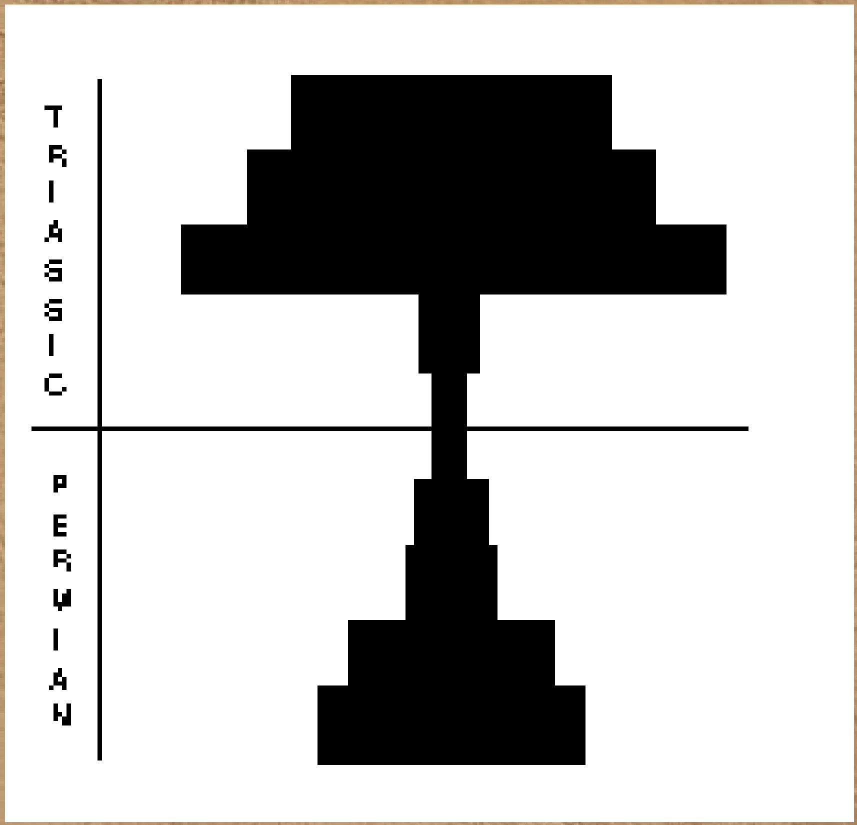
Ceritida evolved and diversified from the Prolecanitida as they were declining in the Late Permian. The order quickly diversified before being decimated by the extinction event. Reappear as Lazarus taxa in the Early Triassic, again rapidly radiating to become dominant ammonoid order. Triassic ceritid "newcomers" first started to evolve before the Mesozoic.

- **Ammonoids are among the most commonly found and well-known of all fossils. They first appeared during the Devonian Period (approximately 410 million years ago).**

- **They almost died out at the end of the Permian Period (251 million years ago), and again at the end of the Triassic Period (205 million years ago). They finally became extinct at the end of the Cretaceous Period (65 million years ago), perhaps as a result of a lowering of ocean levels.**

- **These fossils are especially well known from the Mesozoic Era (251 to 65 million years ago)-that is the Triassic, Jurassic and Cretaceous Periods.**

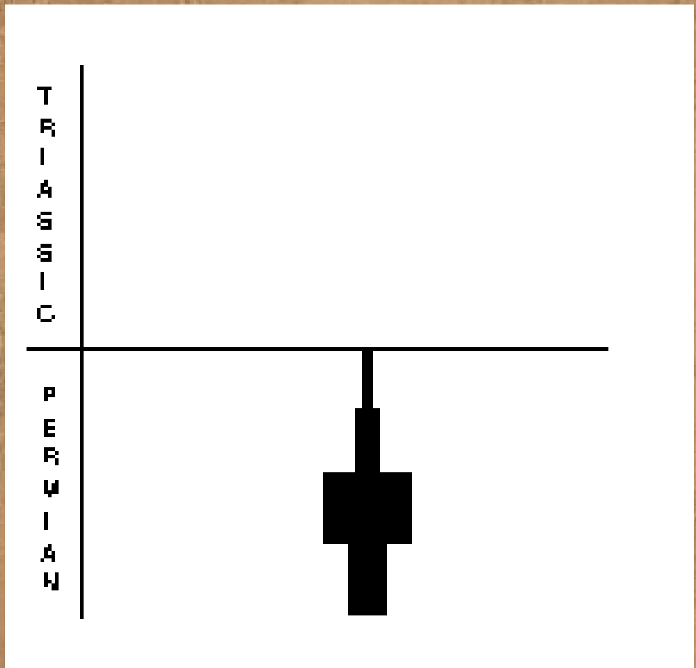
- **Ammonoids are very useful as a means of dating rocks from these three periods, as the various species quickly evolved and replaced each other (around every million years or so) during this time. A few rare early species have been found in Victoria at Buchan.**


TRIASSIC
PERMIAN

Arthropoda: Trilobitae

- Order became fully extinct at the Permo-Triassic boundary.
- Two genera of trilobite still around at the P-T boundary which became extinct.
- No survivors to the Triassic mixed faunas.

- Segmented animals with exoskeleton composed of chitin or calcium carbonate, with jointed limbs.
- Grow to length of 6-750 mm by shedding exoskeleton and rapidly growing while new shell hardens.
- Body is divided into three main sections. The cephalon (head), thorax and pyguidium (tail), with classification of the order dependant on a disparite morphology of these parts.
- Limbs are only preserved in instances of exceptional preservation.



- **The first body fossils of trilobites appeared in the Early Cambrian Period, about 540 million years ago. The trilobite pictured above is an olenellid (probably in the genus *Nevadella*) from the Early Cambrian of south-western Nevada, a very typical trilobite in the Lower Cambrian of North America. It seems likely that trilobites were preceded by soft-bodied ancestors: at several localities, sedimentary rocks with trace fossils of trilobite activity underlie the oldest rocks with trilobite body fossils.**

More about fossils?

Another day……

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