Life in the Palaeozoic Era

Paleozoic Fossil Record

The Paleozoic was a time with abundant fossils of multicellular organisms with shells. As a result, the fossil record improves dramatically at the beginning of the Paleozoic Era.

Paleozoic Invertebrates

- Representatives of most major invertebrate phyla were present during the Paleozoic, including sponges, corals, bryozoans, brachiopods, molluscs, arthropods, and echinoderms.
- Almost all of the common invertebrate phyla in existence today had appeared by the Ordovician.

Paleozoic Vertebrates

- Vertebrates evolved during the Paleozoic, including:
  - Fishes
  - Amphibians
  - Reptiles
  - Synapsids ("mammal-like reptiles")
- The first vertebrates were jawless fishes, which are found in rocks as old as Cambrian in China.

Paleozoic Vertebrates

- An advanced lineage of fishes with primitive lungs and stout fins gave rise to the four-legged animals or tetrapods.
- The transition from water-dwelling vertebrates to land-dwelling vertebrates depended on the evolution of the amniotic egg.

Paleozoic Plants

- The first primitive land plants appeared near the end of the Ordovician.
- Vascular plants expanded across the land, forming great forests in the Devonian.
- The plants progressed from seedless, spore-bearing plants to plants with seeds but no flowers (gymnosperms).

Paleozoic Extinctions

- Several mass extinctions occurred during the Paleozoic, including the largest extinction of all at the end of the Permian.
- Other mass extinctions occurred at the end of the Ordovician and Devonian periods.

Paleozoic Life

Summary of invertebrate phyla

PHYLUM	BRIEF DESCRIPTION	EXAMPLES
SARCODINA	Single-celled eukaryotes with pseudopodia, including foraminifera and radiolaria	
PORIFERA	Simple, multicellular animals forming colonies and with bodies perforated by many pores. The sponges.	
ARCHAEOCYATHA	Extinct, double-walled, vase- or cup-shaped animals with pores in walls.	
CNIDARIA	Radially symmetrical animals with stinging cells, including corals, jellyfish, and sea anemones	
BRYOZOA	Tiny, colonial animals with U-shaped row of tentacles, often building branching colonies.	
BRACHIOPODA	Marine invertebrates with shell composed of two parts (valves), one dorsal and the other ventral.	
ARTHROPODA	Animals with jointed appendages, segmented body, and armor-like exoskeleton.	
MOLLUSCA	Unsegmented, mostly shell-bearing invertebrates, including bivalves (clams, oysters) snails, chambered nautilus, and octopods.	
ECHINODERMATA	Spiny-skinned invertebrates with radially symmetrical adult bodies and water vascular system. Starfishes, sea urchins, crinoids.	

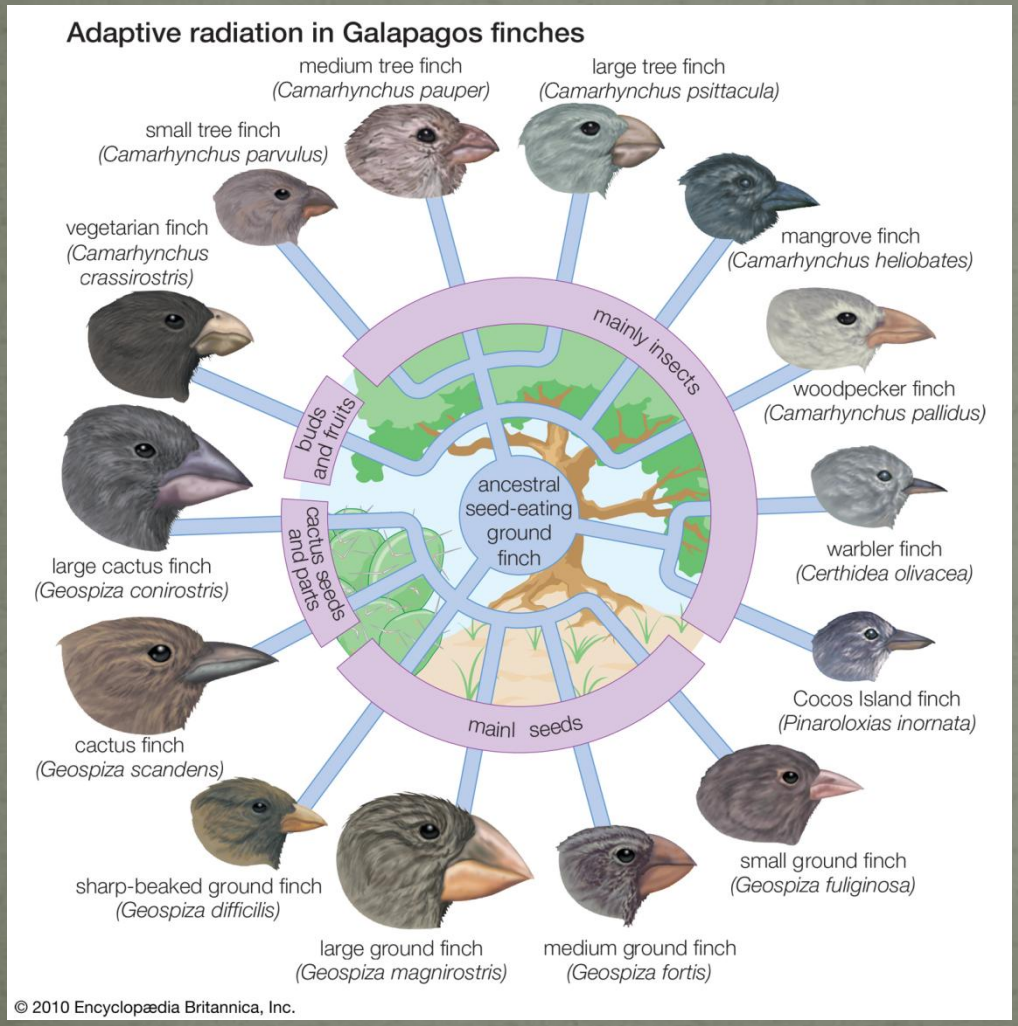
Paleozoic life includes some Precambrian forms, which survived into the Paleozoic, as well as more advanced forms:

- Unicellular eukaryotes
- Animals
  - Invertebrates
  - Vertebrates
- Plants

Adaptive Radiations and Extinctions

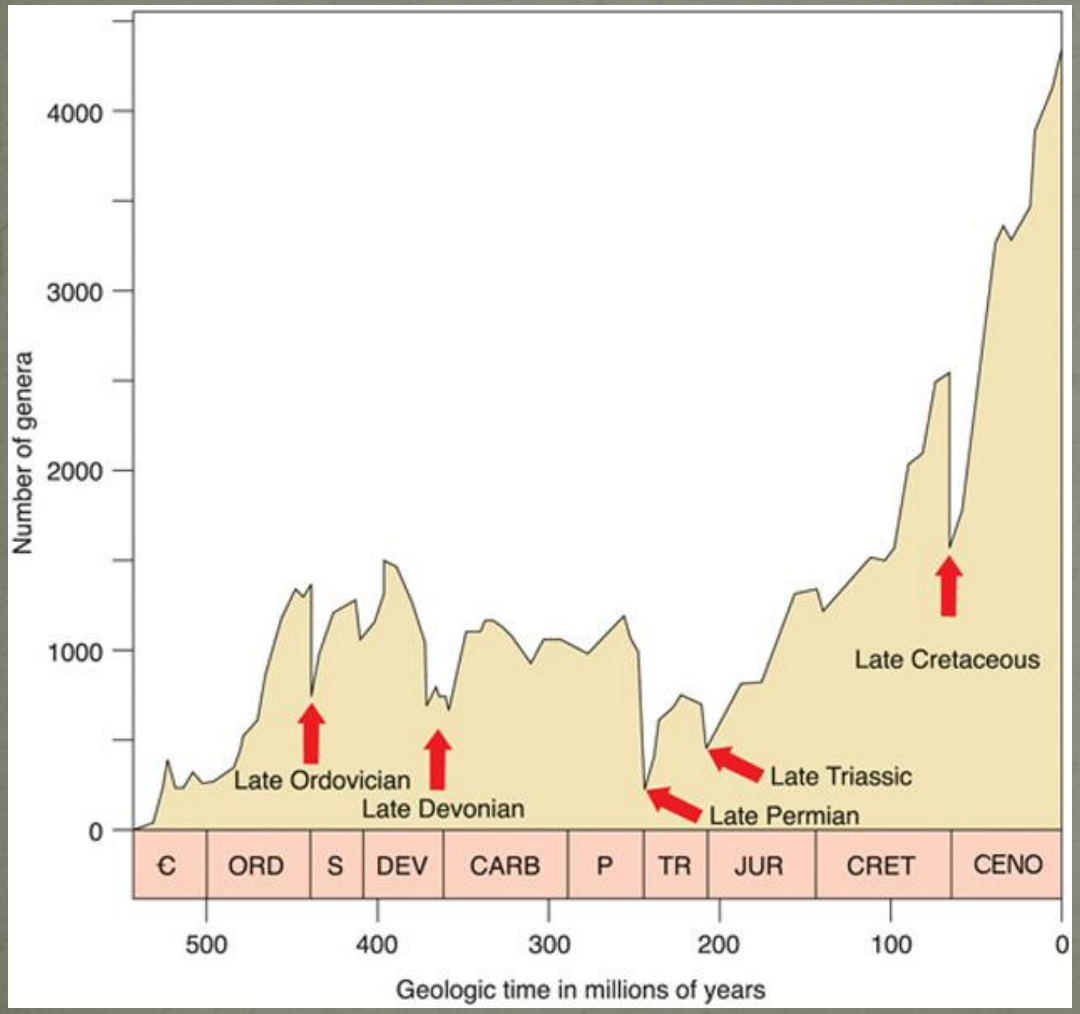
- The Paleozoic was a time of several adaptive radiations and extinctions.
- Many geologic periods began with adaptive radiations (times of rapid evolution).
- Several periods ended with extinction events of varying severity.
- The extinction event at the end of the Permian Period was the worst mass extinction in the history of life.

Adaptive radiation



The evolutionof an ancestral species adapted to a particular lifestyle in many diverse species, each of which is adaptively specialized in a particular ecological niche with specific environmental conditions

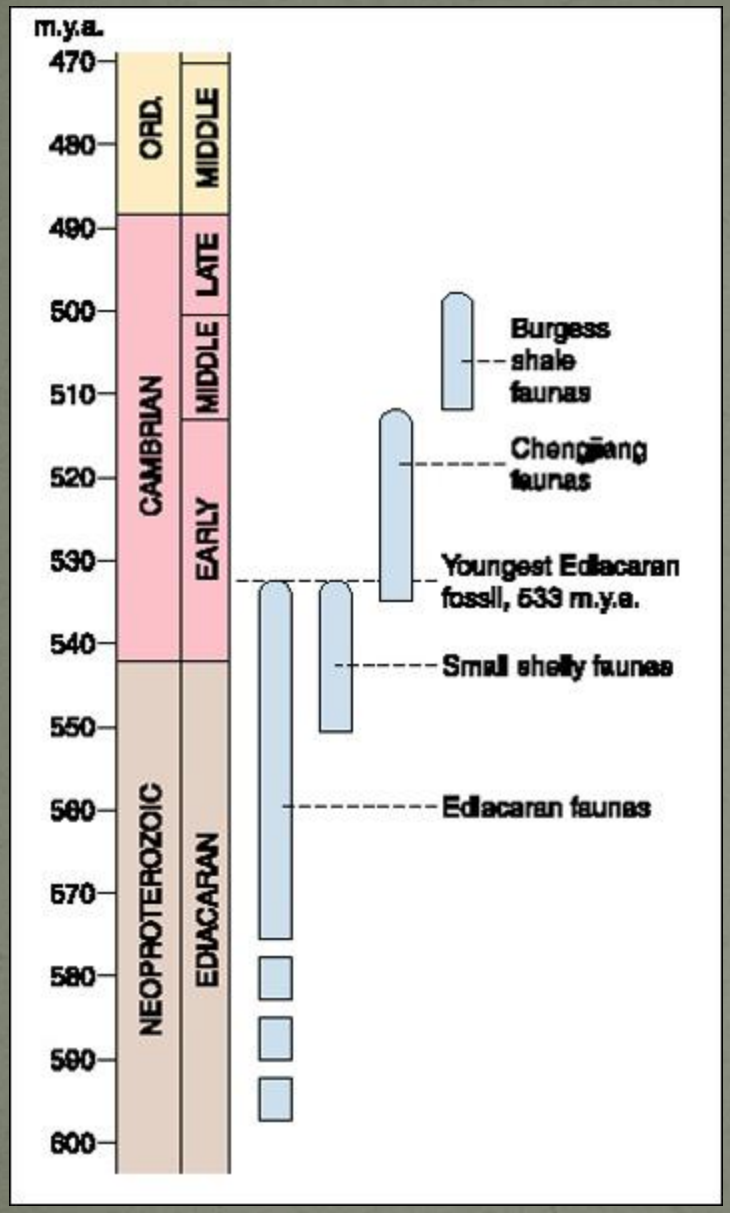
Diversity in the Paleozoic



Red arrows mark extinction events

Soft-bodied Animals

- Multicellular animals evolved in the Precambrian. Soft-bodied Ediacaran-type organisms ranged into the Cambrian period.
- Soft-bodied fossils are infrequently preserved.
- Preservation improved with the origin of hard parts.



- The first animals with shells are called small shelly fossils.
- Small shelly fossils are found at the base of the Cambrian, and in the late Neoproterozoic.
- Most disappeared by the end of the first stage of the Lower Cambrian.

Cambrian Diversification

- The initial Paleozoic diversification is known as "the Cambrian explosion". Abrupt appearance of many types of animals about 535 million years ago, followed by rapid evolution.
- During that episode of explosive evolution, all major invertebrate phyla appeared in the fossil record (except Bryozoa).
- Sometimes this event is referred to as "evolution's big bang".

Cambrian Substrate Revolution

- Infaunal, burrowing animals evolved rapidly during the Cambrian, as indicated by trace fossils and bioturbation of sediments.
- The dramatic change in the character of the seafloor sediments (from undisturbed to highly burrowed) has been called the "Cambrian substrate revolution".

Causes of the explosion

- Physicochemical
- Biological

The scenery

- Breaking of the supercontinent of Rodinia
  Ice-melting, regression, continental seas
  New ecological niches of shallow water

At the beginning of the Cambrian

Due to the above:

Extensive shaking of sea water, transfer of nutrient-rich waters to the surface and shallow waters of the sunlight zone.

Significant quantities of P come to the euphotic zone.

P necessary for life and could significantly affect the evolution of organisms.

Evidence: extensive phosphorus deposits, a significant increase in the ^{32}S / ^{34}S of the sulfur isotopes usually present in stagnant deep non-toxic waters.

At the beginning of the Cambrian

- Production of Acritarchs increases.
  The calcification of cyanobacteria increases.
  Carbon removal from the continents and shallow waters deposited as carbonate rocks at the bottoms.
  Oxygen levels in the atmosphere are increasing, allowing for more energy in advanced multicellular organisms.

Best conditions

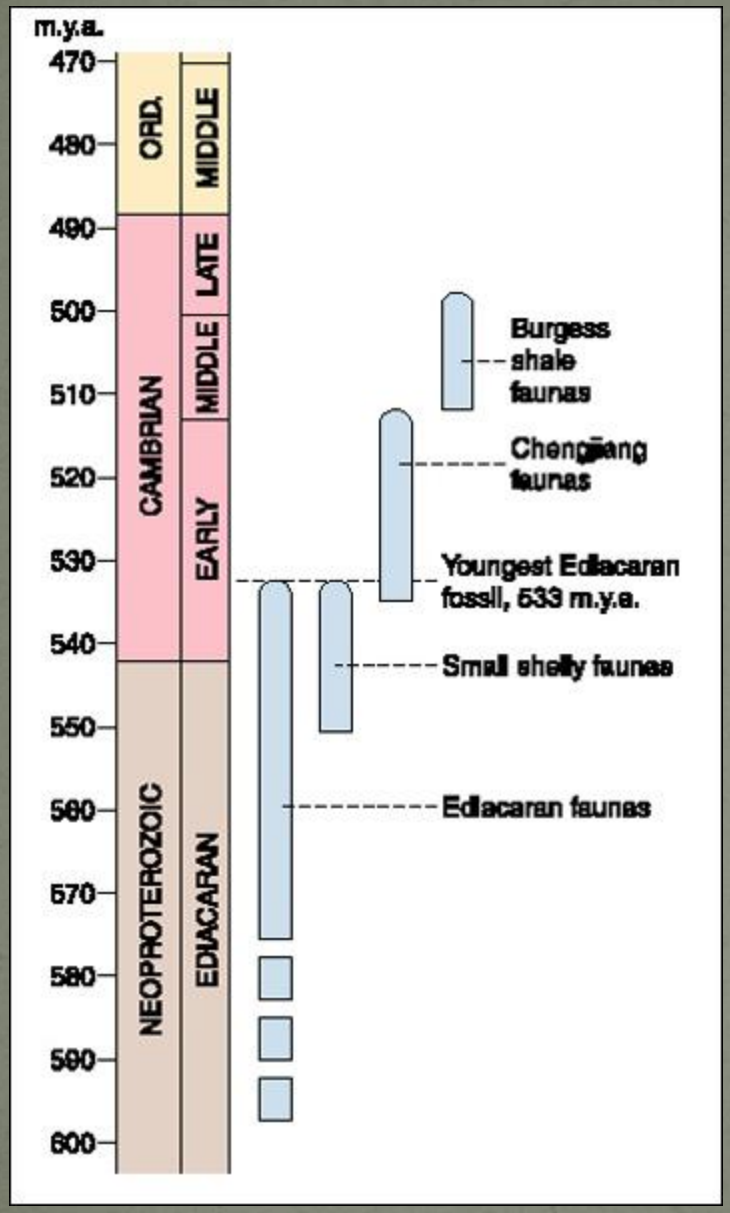
- At the beginning of the palaeozoic, shallow marine environments were enriched in both nutrients and oxygen, two essential components that could push and facilitate the evolution and differentiation of multicellular eukaryotic organisms.

Biological factors

- Eukaryotic cells have much more genetic material than prokaryotic cells, of which only a small percentage is used for protein production and for functions.
  Underused genetic information is potentially a powerful force for change.
  Thus, eukaryotic cells have benefited from optimal conditions (oxygen, nutrients)

Lack of predators

- Another factor was the originally small number of predators, as well as the absence of competitors in the new ecological niches.
  When, however, competition became intense (eg due to overpopulation), the strong predation began.
  Then, apparently, the Cambrian revolution of the substratum would began when the "hunters" would begin to look for places and ways to hide, and thus to create new forms.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CAMBRIAN
LATE
MIDDLE
EARLY
NEOPROTEROZOIC
EDIACARAN
Burgess shale faunas
Chengjiang faunas
Youngest Ediacaran fossil, 533 m.y.a.
Small shelly faunas
Ediacaran faunas

The Chengjiang fauna

- In 1984, the Lower Cambrian (535 my old) Chengjiang fossil site was discovered in Yunnan Province, China.
- More than 100 species of invertebrates have been found, with extraordinary preservation, including many soft bodied forms

The Chengjiang fauna

- Jelly fish
- Annelid worms
- Cnidaria
- Porifera (sponges)
- Brachiopods
- Arthropods
- Early chordates similar to *Pikaia*
- The world's oldest known fish (*Myllokunmingia*)
- Other species of unknown phyla

Eoredlichia intermedia

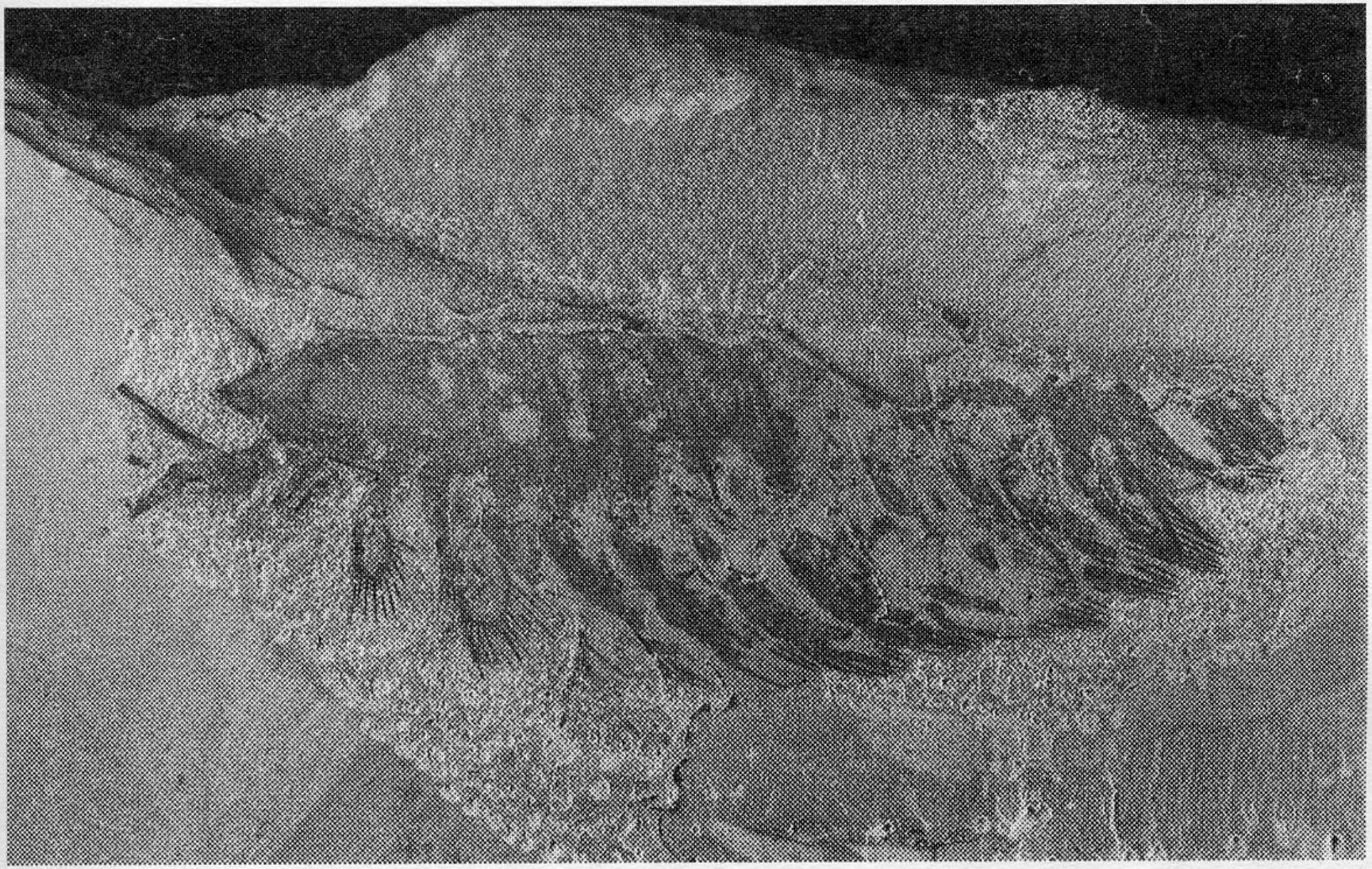


Fig. 59. The Chengjiang arthropod *Leanchoilia illecebrosa* from South China. Specimen is about 2.5 cm long. [Photograph courtesy of Hou Xianguang (Museum of Natural History, Stockholm and Institute of Palaeontology, Nanjing).]

Fig. 60. The Chengjiang lobopodian *Microdictyon sinicum* from South China. Specimen is about 2 cm across. [Photograph courtesy of Hou Xianguang (Museum of Natural History, Stockholm and Institute of Palaeontology, Nanjing).]

The oldest chordate

- *Cathaymyrus diadexus*
- 535 my
- Other orimitive chordates *Yunnanozoon and Haikouella*

The oldest fishes

Myllokunmingia fengjiaoa

Haikouichthys ercaicunensis

Zhongjianichthys rostratus

Ordovician Diversity

- The Cambrian is characterized by the creation and differentiation of basic body shapes at the phylum and class level.
- Following a slight dip in diversity at the end of the Cambrian, the Ordovician was a time of renewed diversification.
- Global diversity tripled.
- The number of genera increased rapidly, and the number of families increased from about 160 to 530.
- The increase was particularly dramatic among trilobites, brachiopods, bivalve molluscs, gastropods, and corals.

Ordovician Diversity

- The overall picture of the Ordovician radiation is also a model for the other periods of the Phanerozoic.
  Although other species are involved, biotic transitions in the Phanerozoic should have been controlled by the same mechanisms.
  Eg. The reduction of sessile detritus feeding organisms can be caused by local and regional changes in natural environments, conditions that are good enough for deposit-feeding organisms. Increased orogenetic activity may have resulted in significant strains of clastic sediments that favored deposit-feeding organisms.

Ordovician Diversity

- Bryozoans first appeared
  The tetracorals also appeared in Ordovician and became abundant in Devonian and the Carboniferous. Mostly solitary.
  The trapezoids (corals) also appeared in Ordovician and, during the Silurian, they were the main "builders" of the reefs as they formed colonies. Significantly diminished after the Silurian.
  Scaphopods, eurypterids (arthropods), blastoids, asteroids, echinoids appear.
  Apparent reduction of the stromatolites. Why?

Hallopora, Βρυόζωο

Brachiopods of the Ordovician

Rafinesquina

Hebertella

Lepidocyclus

Leptaena


Flexycalymene

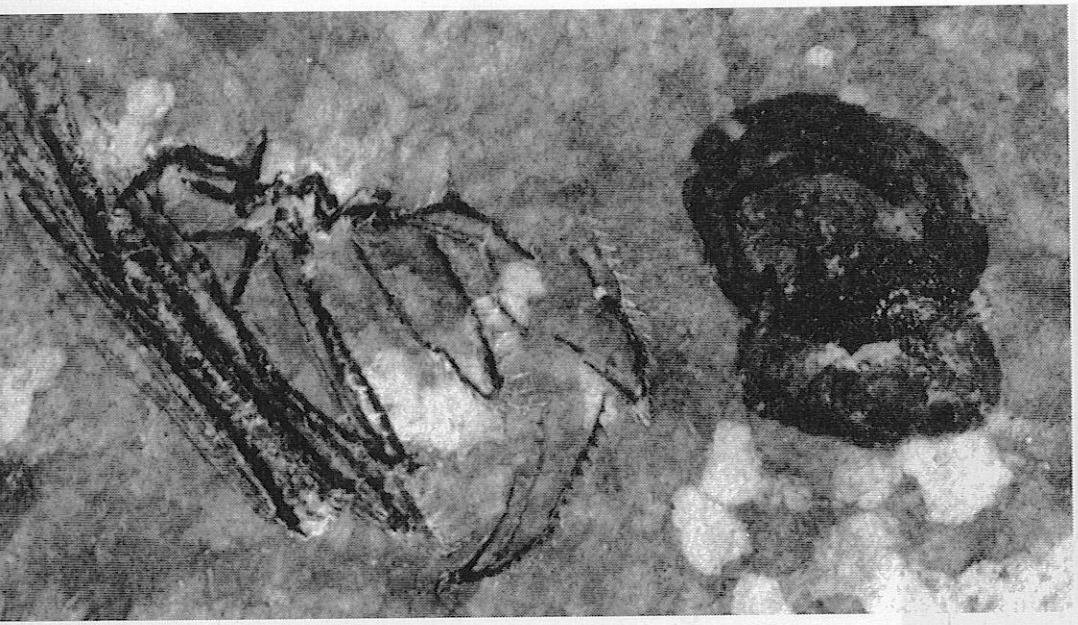
Graptolites

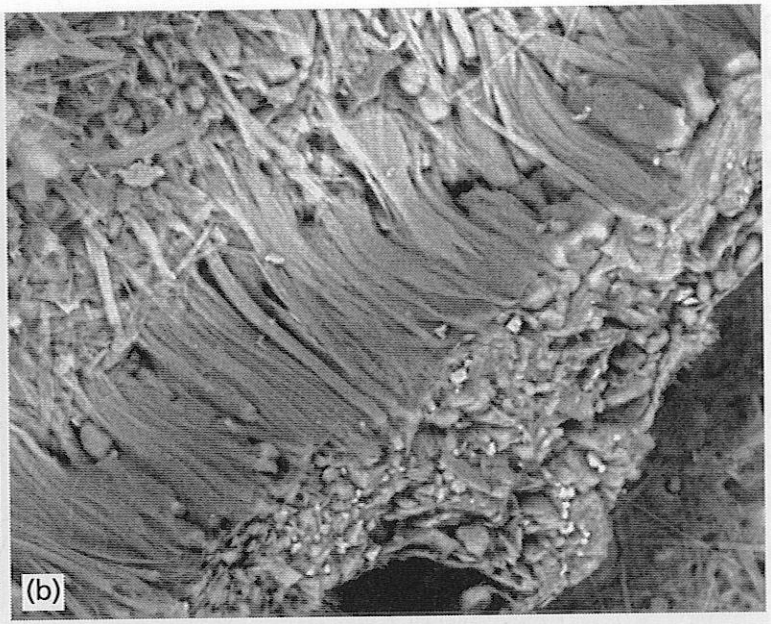
Orthograptus

Shoom Shale Fauna

- Typical locality of an Up. Ordovision, Shoom Shale in South West South Africa.
  Extremely preserved fauna (preserved soft tissues)
  Undisturbed sediments (pelites, siltstones)
  Fauna characterized by swimming taxa, conodonts, jawless fish, orthoconic cephalopods, brachiopods, trilobites, other large arthropods, chitinozoa and many enigmatic forms.

Shoom Shale





4.1 Preservation of conodont features in the Soom
) Complete feeding apparatus, mostly mouldic, with
sules preserved as carbonized films; anterior to right,

×9. (b) Scanning electron micrograph of muscle fibres associated with eye capsules on another specimen, preserved as clay mineral replications, ×560.

Fig. 3.4.4.2 A large, enigmatic, segmented, soft-bodied animal, preserved in the Soom Shale by clay mineral replacement, ×0.3.

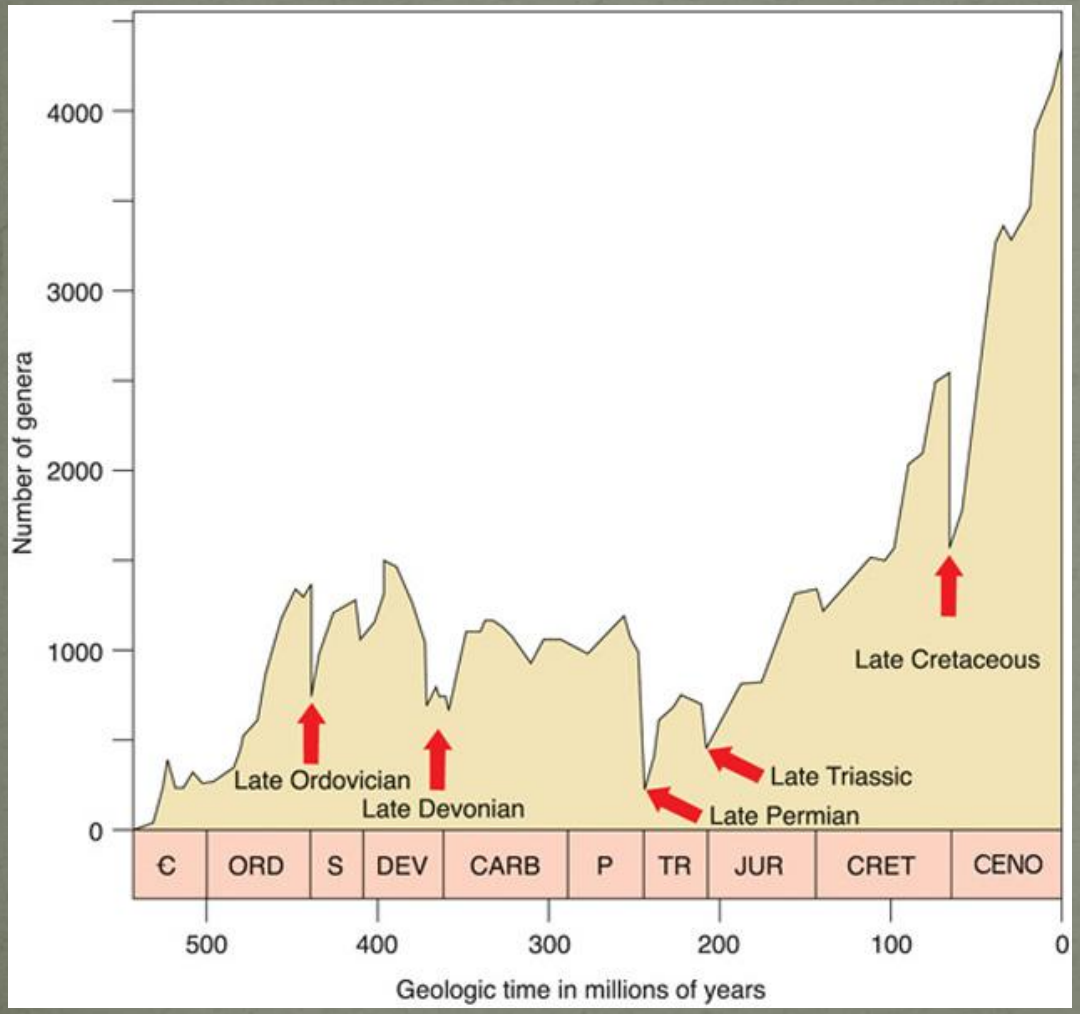
The first terrestrial plants

- The first plants that invaded the land were spore-bearing plants.
  The first evidence of the existence of terrestrial plants is the presence of spores in land-based rocks of the Ordovician. Spores are reproductive structures of plants. Known such plants are mosses and ferns.

Late Ordovician Extinctions

- Both phases of the extinction event were related to global cooling and the growth of glaciers in Gondwana.
- Glaciation was coupled with the lowering of sea level and a reduction in shallow water habitat.
- As the climate cooled, tropical organisms showed the greatest decline.
- As warming occurred and the glaciers began to melt, organisms which were adapted to the cooler conditions began to suffer extinction. This was the second phase of extinctions.
- The first recorded mass extinction in the history of the earth.

Diversity in the Paleozoic



Red arrows mark extinction events

Late Ordovician Extinctions

- The extinction occurred in two phases.
  - First phase - affected planktonic and nektonic (floating and swimming) organisms such as graptolites, acritarchs, many nautiloids and conodonts, as well as benthic (bottom-dwelling) organisms such as trilobites, bryozoa, corals, and brachiopods.
  - Second phase - affected several trilobite groups, corals, conodonts, and bryozoans.

Silurian Diversity

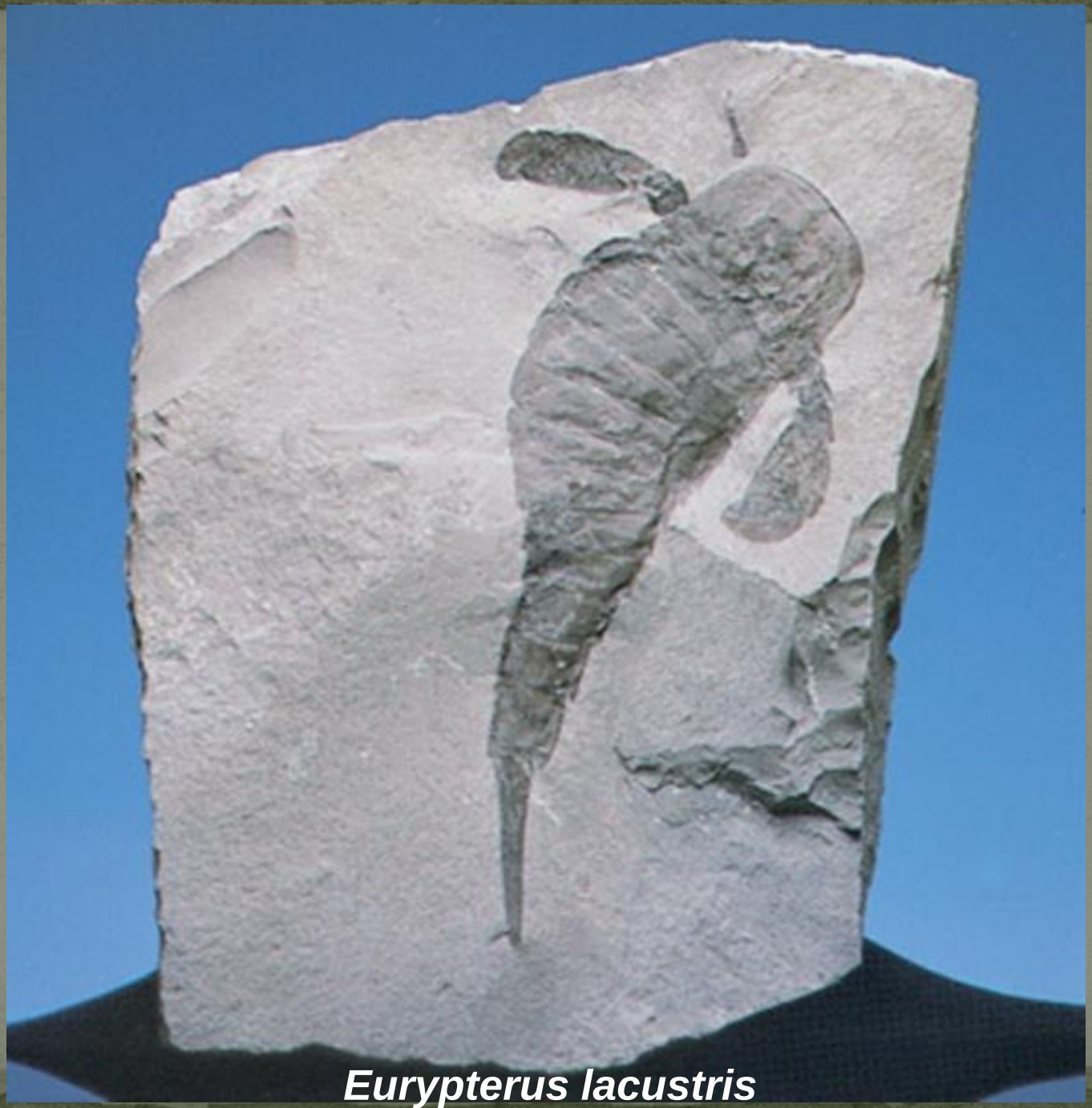
Diversification of marine animals occurred again at the beginning of the Silurian Period.

The period ended with only a slight drop in diversity.

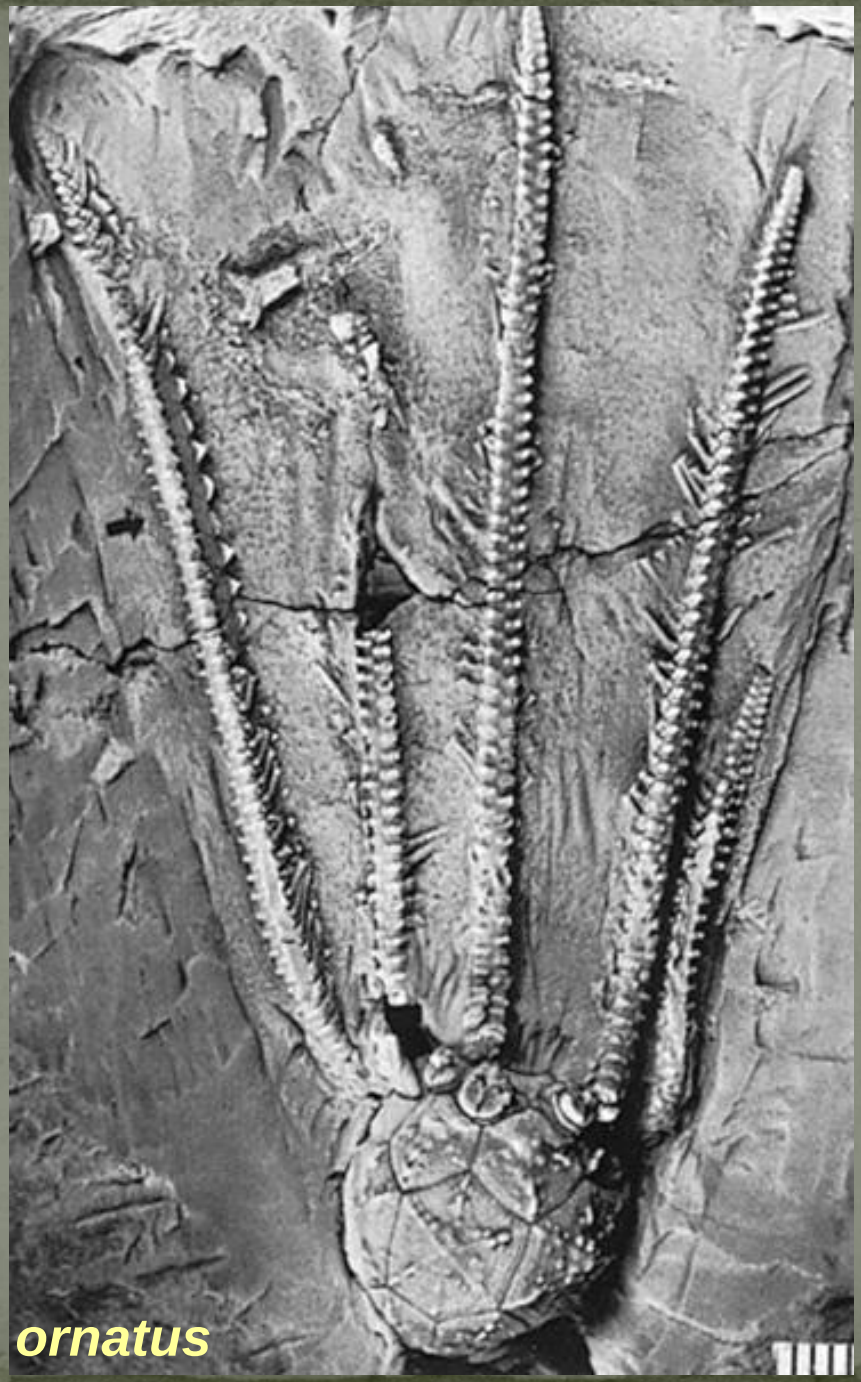
In the up. Silurian the arachnids appear (the scorpions first, they were marine and in Devonian passed on ashore), the first Gnathostoms (Acanthodians, Placoderms, and probably the first chondricthians), the bonyfishes (actinopterygians, sarcopterygians)

Orthoceras,

Barrandeoceras,



Eurypterus lacustris



Caryocrinites ornatus

Tracheophytes

- The oldest plant fossils with vascular tissues appear in the rocks of Silurian.
  Small plants without leaves and thinly branched stems.
  These are called Psilophyta.
  Spores are observed at the tips of Cooksonia stalks.

***Cooksonia pertoni*,**

The first terrestrial plants

- They radically altered the environment.
  Their roots retained the soil and reduced the rate of soil erosion.
  The decomposition of plant matter helped to form soils.
  The plants provided food and shelter to the first animals that had landed.
  The transition from marine to terrestrial plants was certainly a very difficult process and that was why it took so long.

The evolution of jaws

- The first fishes with jaws appeared in non-marine rocks (river and lake deposits) in Upper Silurian (420 my).
  The development of jaws extended the adaptive spectrum of vertebrates.
  They used them both to hold / grab and to bite.
  They led to more diverse and active ways of living, and to new sources of food.

Class Acanthodians

- The "barbed" fish.
  The first fish with jaws.
  Age: Silurian - Permian. Greater development in Devonian.
  Lifestyle: Swimming, not marine, just fresh water.

Class Osteichthyes - Bony Fishes

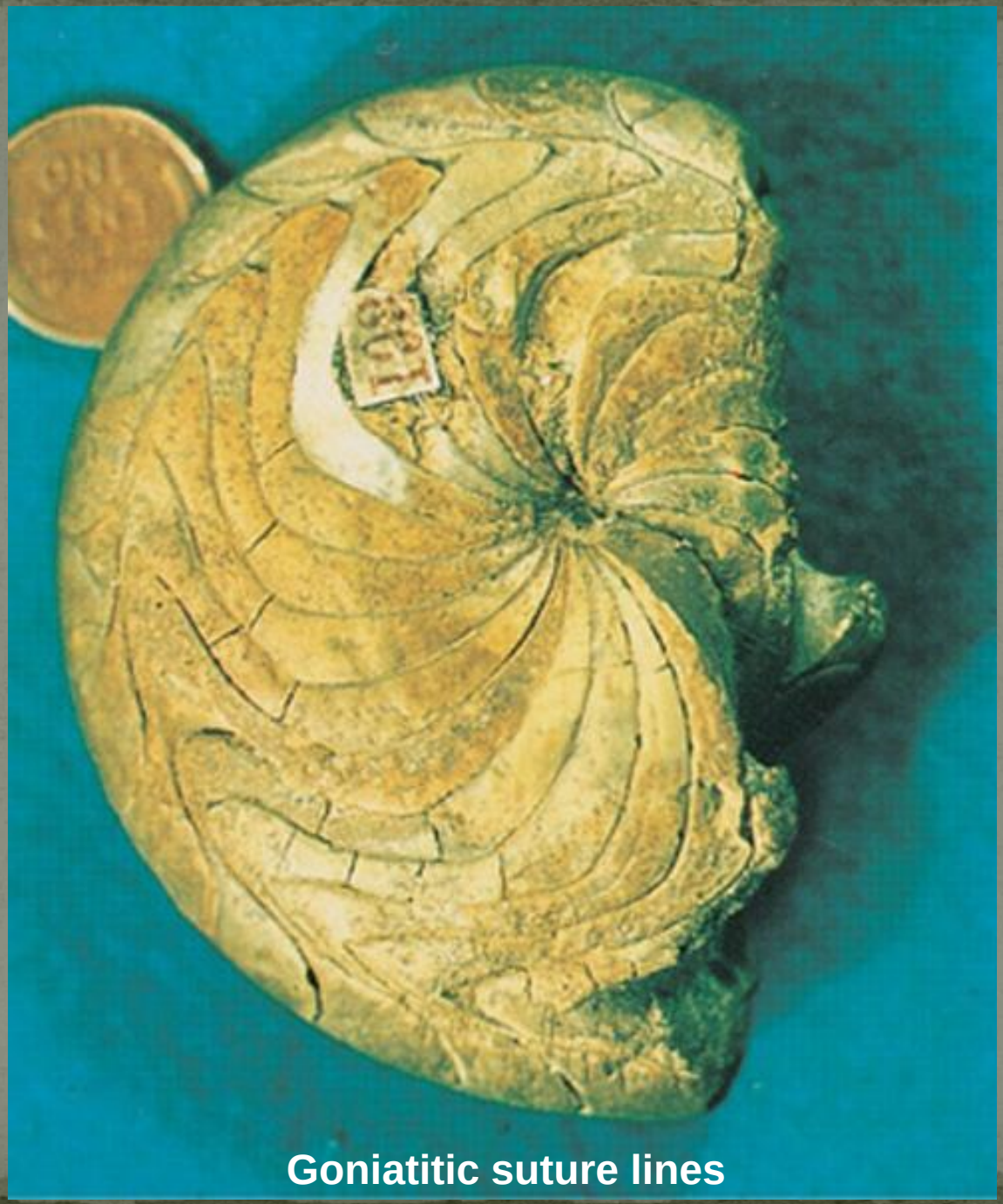
- Bony fishes played a key role in the evolution of tetrapods (four-legged animals).
- Two types of bony fish are significant:
  - Subclass Actinopterygii - the ray-finned fish.
  - Subclass Sarcopterygii - the lobe-finned fish or lungfish.

Devonian Diversity

- The Devonian saw continued diversification, but ended with another fairly large extinction event, which extended over about 20 million years.
- Roughly 70% of marine invertebrates disappeared.
- Because of the long duration, the extinction is unlikely to have been caused by a sudden, catastrophic event.

The ammonites

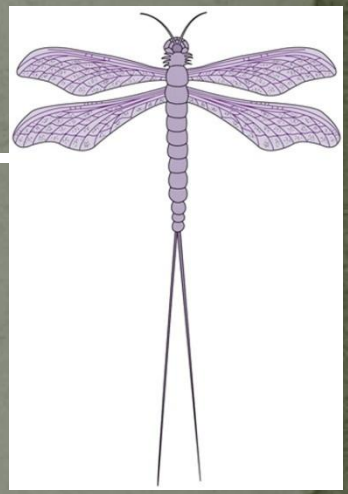
- Cephalopods with complex, pleated septa that produce angular or dendritic suture lines.
  Geological age: Devonian - Cretaceous



Goniatitic suture lines

Order hexapods (insects)

- Insects are the most populous living group, but are rarely found as fossils.
  The first insects had no wings.
  They got wings on the Lower Carboniferous.
  Geological age: Middle Devonian - Today.



Amphibians

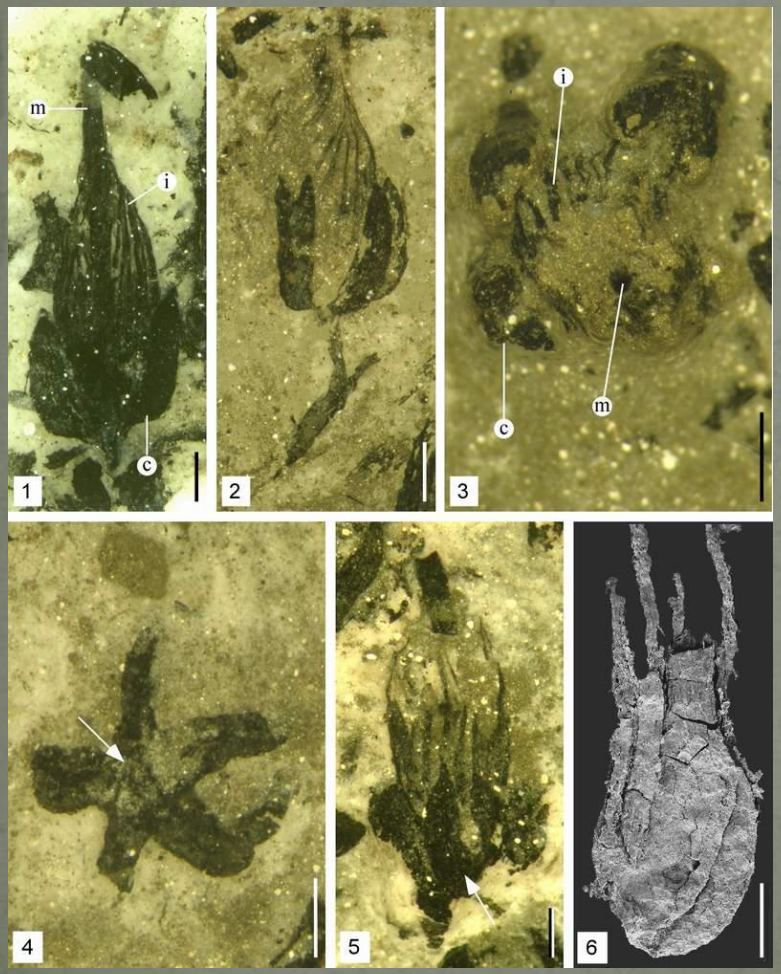
- Age: upper Devonian - today.
  For 50 my from the upper Devonian to the middle Carboniferous the only vertebrates on land.
  They dominated the marshes of the Carboniferous and were abundant and varied.
  Different lifestyles, terrestrial as well as aquatic.

Tiktaalik roseae

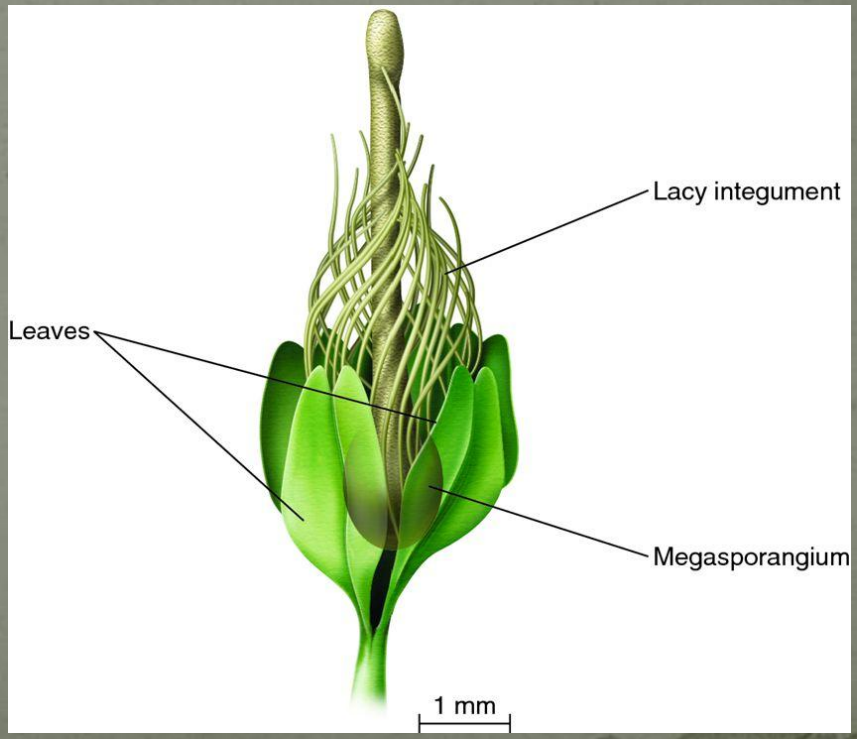
- Age: 375 my
  Transitional form leading to amphibian

The first seeds

- In upper Devonian (365 my), although we do not know yet which plants produced them.
  Plants with seeds became more abundant in the Carboniferous.
  The seeds were important because they freed plants from their dependence on wet environments and allowed them to colonize dry areas (adaptation like the amniotic egg).

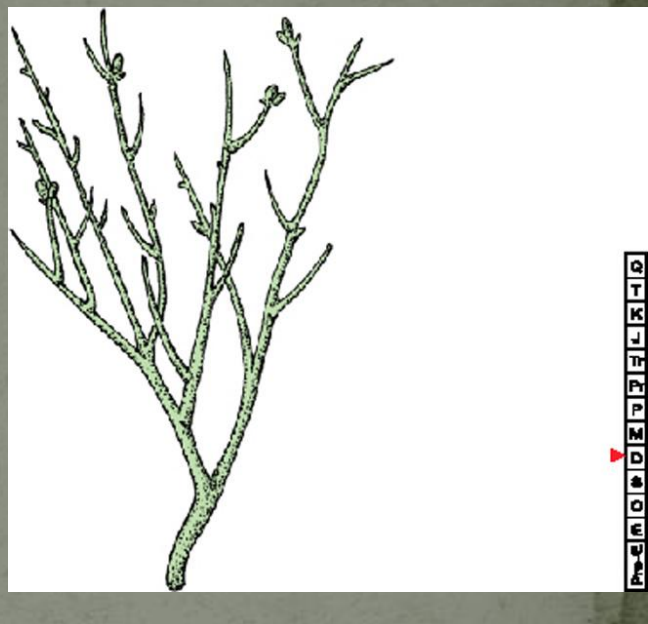


Runcaria heinzelinii a possible transitional form of primitive spermatophyte (385 million years)



Evolution of wood

- When the plants evolved the wood tissue they were able to withstand the force of gravity and to get higher. In the middle Devonian, the first woody tissue appeared in the plants of the genus Rhynia.



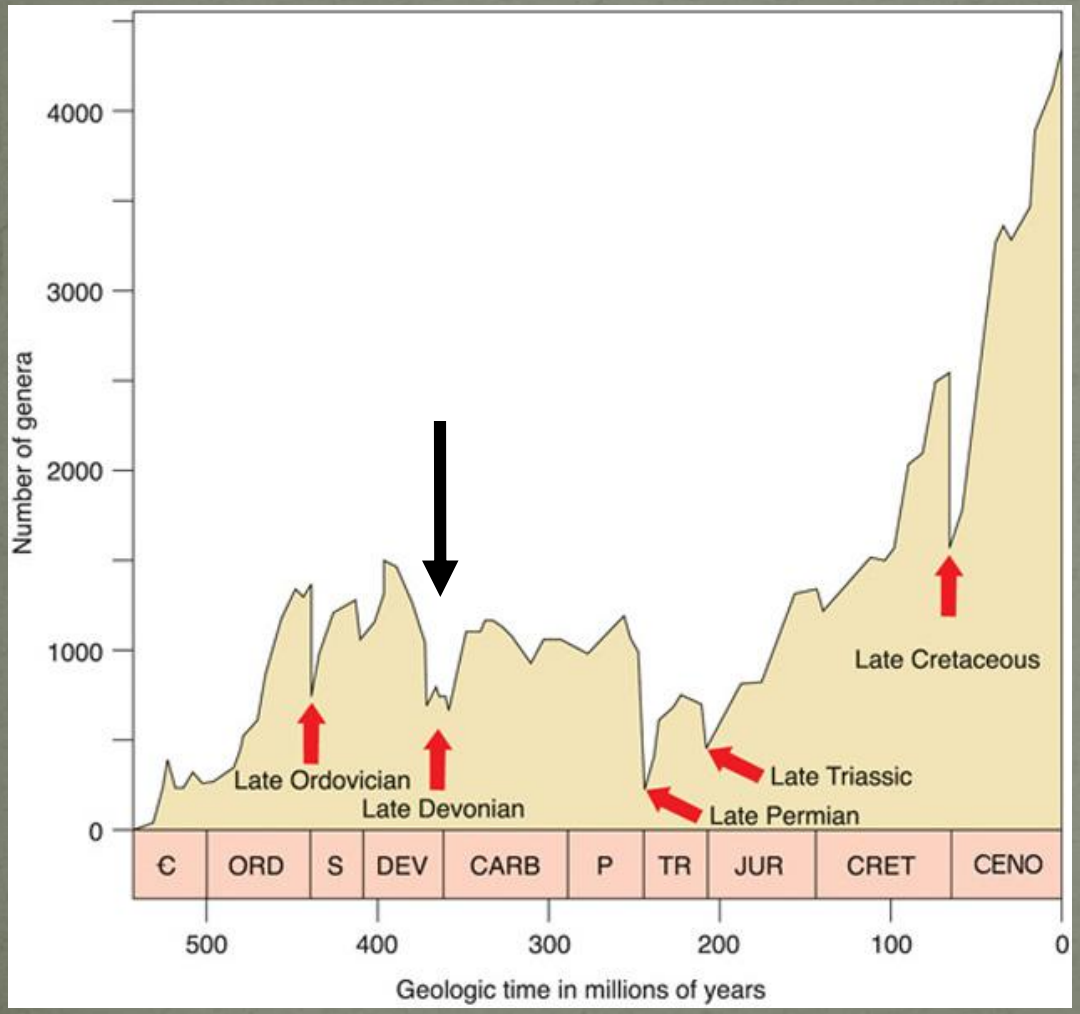
Rhynia,

The first trees

- Until the end of the Devonian, the first trees appeared.
  In the Carboniferous trees reached a height of 30 m or more with trunks of a diameter exceeding 1 m.

Δάσος του Δεβονίου

Late Devonian Extinctions



Late Devonian Extinctions

The Late Devonian extinctions occurred over a span of about 20 million years, and appear to have been the result of an ecological crisis in the seas, perhaps induced by changes occurring on the land.

More than 24 extinction events can be distinguished during this period.

Due to the long duration, extinctions can not have been caused by a single, sudden catastrophic event.

It was probably the result of a major ecological crisis in the seas, most likely caused by shore-based changes.

Late Devonian Extinctions

- The Devonian was the time of the appearance of trees and spread of land plants. This would have accelerated weathering rates, leading to large volumes of nutrients being washed into the seas.
- Large quantities of nutrients in the water (such as phosphorus) causes algal blooms.
- Bacteria breaking down large quantities of dead algae uses up all of the oxygen in the water, causing anoxic conditions (= "without oxygen").
- This process is called eutrophication, and it occurs today in lakes, and causes massive "fish kills".

Late Devonian Extinctions

- Extensive Devonian black shale deposits suggest the widespread occurrence of anoxic conditions in the Devonian sea.
- Glaciation may have been an additional contributing factor. By the Late Devonian, South America had drifted over the South Pole, and glaciations occurred.
- Overall, 70% of marine invertebrate families went extinct in the Late Devonian.

Late Devonian Extinctions

Organisms most strongly affected (but not totally wiped out) by the Devonian extinction were:

- Tabulate corals
- Rugose corals
- Stromatoporoids
- Brachiopods
- Goniatite ammonoids (cephalopod molluscs)
- Trilobites
- Conodonts
- Placoderm fish

Meteorites;

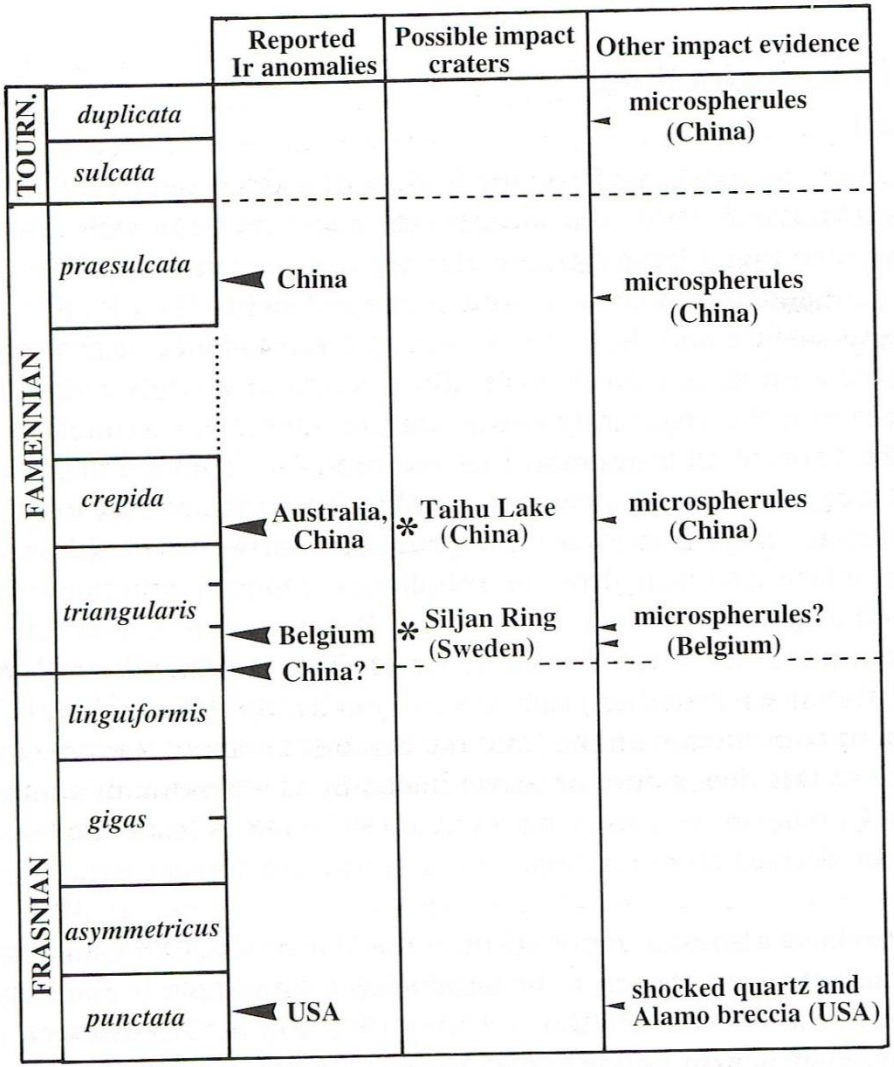


Fig 4.11 Stratigraphic location of the various lines of evidence for bolide impact in the Late Devonian to Early Carboniferous interval.

Carboniferous-Permian Diversity

- In the early Carboniferous, diversity once again increased.
- Diversity of marine animals remained fairly constant throughout the Carboniferous and Permian.
- The Late Permian is marked by a catastrophic extinction event which resulted in the total disappearance of many animal groups.

Class Reptilia - The Reptiles

- *Mode of life*: Complete colonization of land was achieved by the reptiles, which can lay their eggs on dry land.
- *Geologic range*: Late Carboniferous to Recent.
- The oldest reptile fossils, genus *Hylonomus*, (300 m.y. old) are found in Nova Scotia inside fossilized hollow trees filled with sediment. These reptiles were about 24 cm (1 ft) long. They resemble modern insect-eating lizards.

Characteristics of the Amniotic Egg

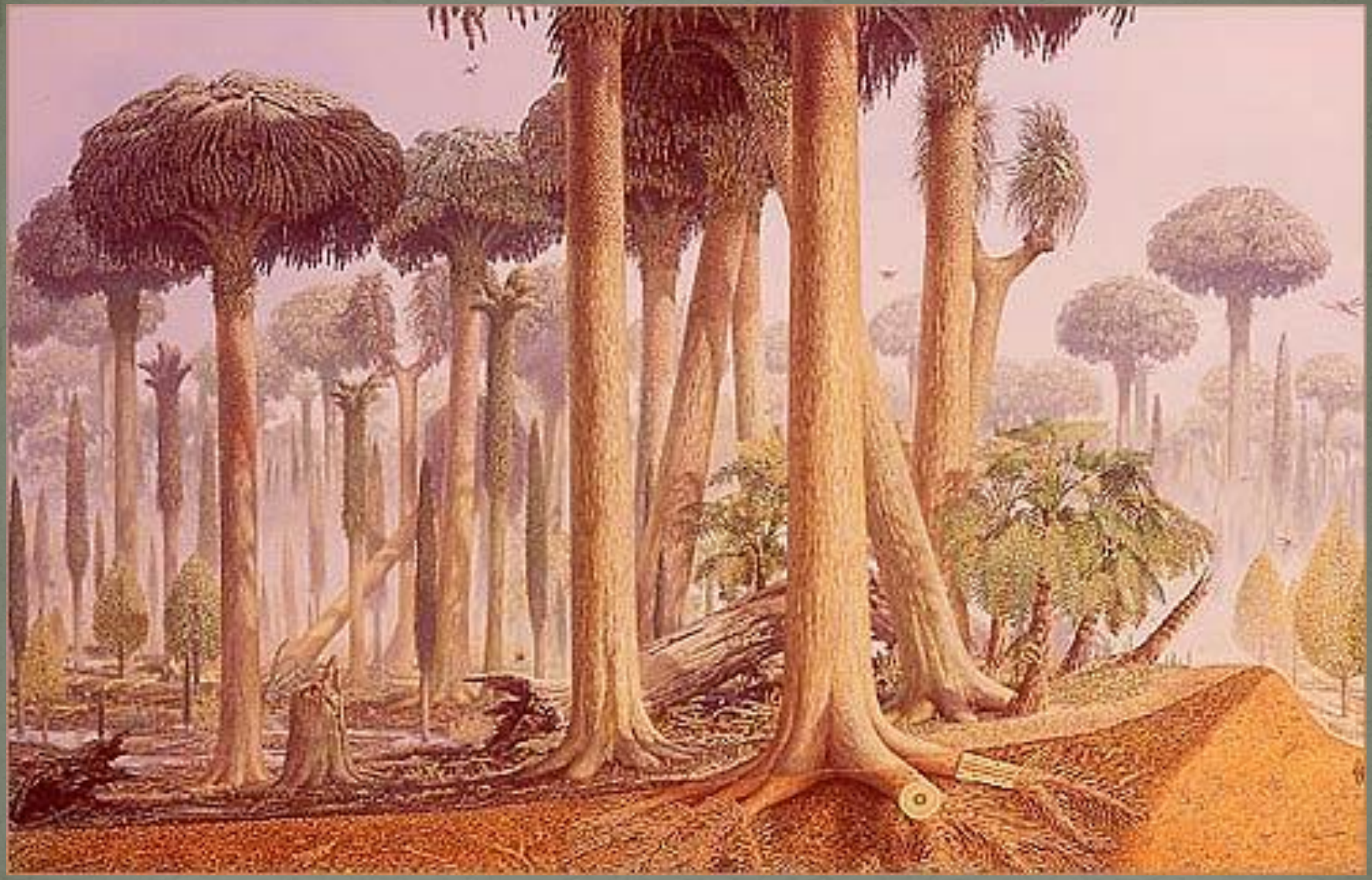
- Durable outer shell protects embryo from drying
- Egg can be laid on land
- Yolky part of egg provides nutrition; sac contains embryo and another sac collects waste products.
- Eliminated need to lay eggs in water, allowing vertebrates to live and reproduce on dry land for the first time.
- Amniotic egg probably evolved in Carboniferous.
- First fossil eggs are Early Permian

Significance of the Amniotic Egg

- Provided freedom from dependency on water bodies.
- Helped the vertebrates live in diverse types of terrestrial environments.
- An important milestone in the evolution of vertebrates.

Common plants in the Carboniferous

1. Lycopods or Lycopsids - club mosses
2. Sphenopsids - horsetails, scouring rushes
3. Ferns
4. Gymnosperms
    a. Seed ferns
    b. Cordaites
    c. Conifers
    d. Ginkgoes



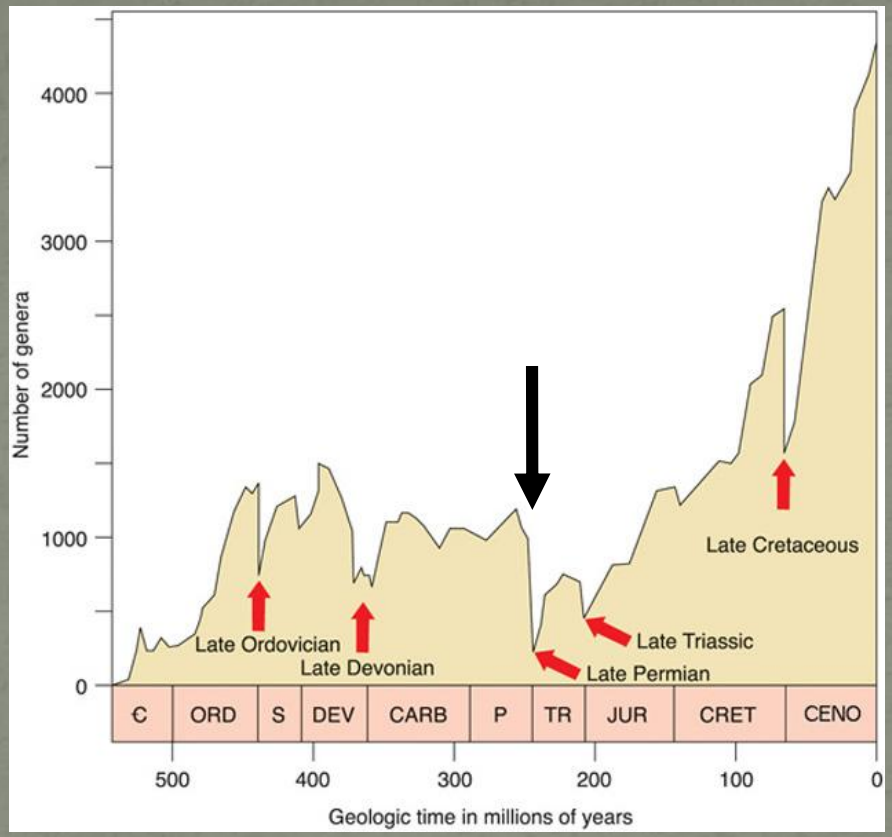
Carboniferous forest

Carboniferous Coal

- There are more plant fossils in Carboniferous strata than in any other geologic interval.
- Plants gave the Carboniferous its name, because of the vast coal deposits which formed from plant remains in lowland **swamps.** Coal is dominated by the element carbon.
- Coal represents an enormous biomass of plants because it takes several cubic meters of wood to make one cubic meter of coal.

When life became almost extinct…

- The Late Permian is marked by a catastrophic extinction event which resulted in the total disappearance of many animal groups.
- This was the largest extinction event in the history of life, exceeding even the extinction event at the end of the Cretaceous, which killed the dinosaurs.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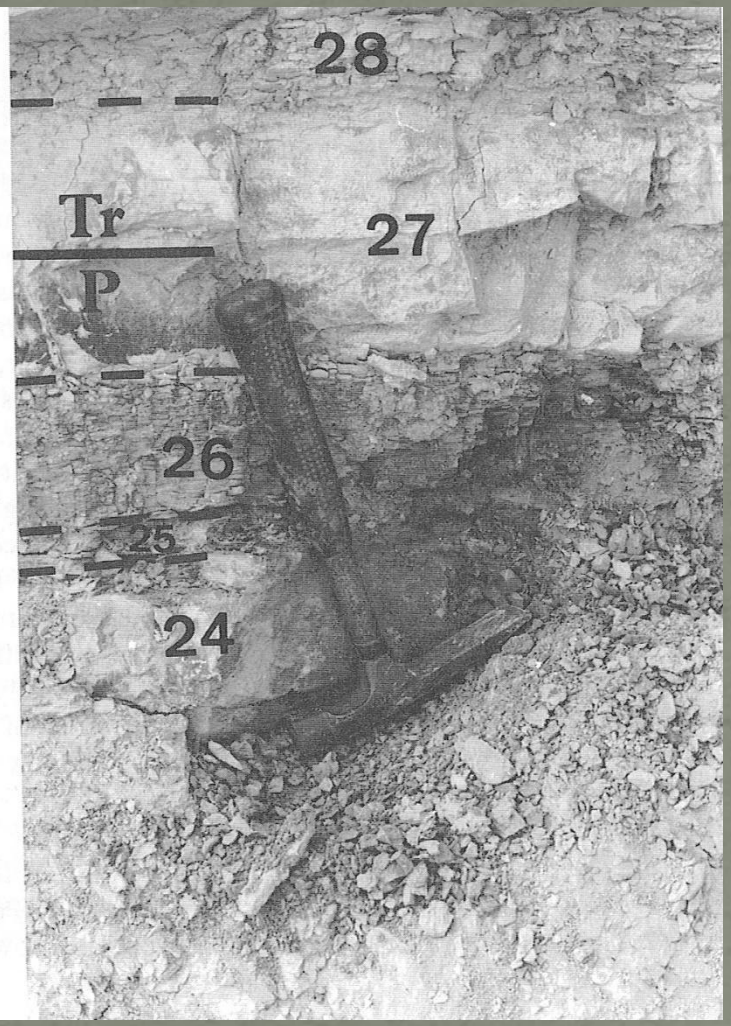


Fig 5.11 P-Tr boundary beds at Meishan, the most likely locality for the eventual choice of the international stratotype. The most commonly utilised bed numbers are shown.

The Late Permian mass extinction event

- More than 90% of all marine species that existed in the Permian disappeared or were severely reduced in number.
- Nearly half of the known families disappeared.
- Tropical forms experienced the most extensive losses.

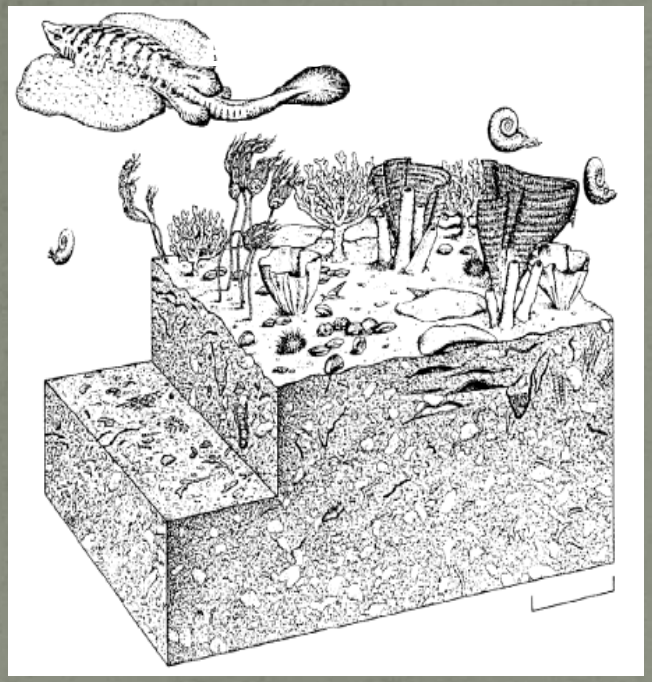
Late Permian Extinctions

- The following marine organisms were extinct by the end of the Permian:
  - Fusulinid foraminifera
  - Rugose corals
  - Tabulate corals
  - Blastoids
  - Trilobites (which had become extinct somewhat earlier in the Permian)

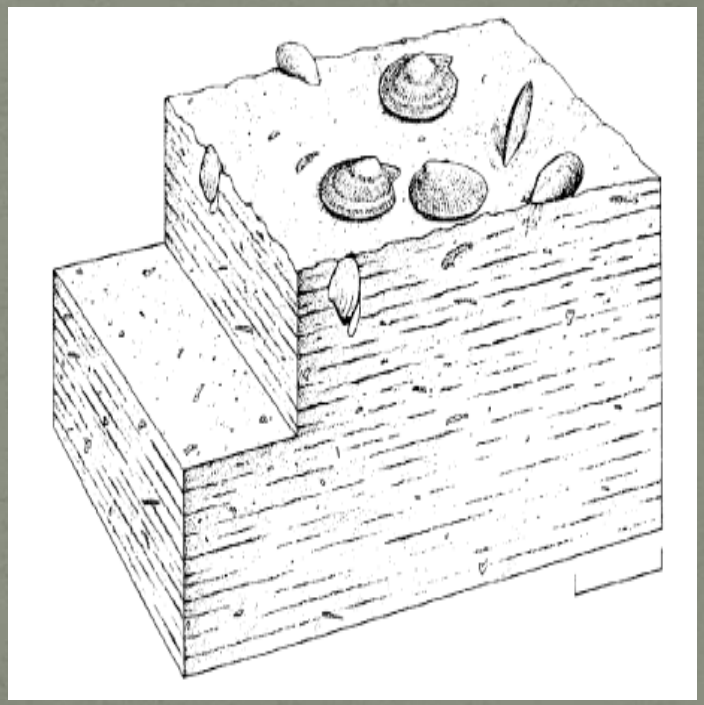
Late Permian Extinctions

- Other groups of organisms were severely reduced in diversity, with some surviving species:
  - Brachiopods
  - Crinoids
  - Bryozoa
  - Ammonoids
- Organisms which inhabited warm waters shifted their distributions toward the equator. Cool conditions prevented construction of reefs and the formation of limestones.

Before



After



Late Permian Extinctions

- The Permian extinction also affected land dwellers.
- More than 70% of land animals disappeared or were severely reduced, including:
  - Amphibian families
  - Reptile families
  - Synapsids (once called "mammal-like reptiles")

Late Permian Extinctions

- Among the plants, the spore-bearing plants that inhabited tropical coal swamps were replaced by seed-bearing gymnosperms, that could inhabit cooler, drier climatic conditions.

Contributing Factors

Many factors may have contributed to the Permian mass extinction:

1. Climatic change associated with assembly of Pangaea –
   Global cooling and drying, along with interruption of equatorial circulation
2. Glaciation at both north and south ends of Pangaea
3. Reduction in epicontinental seas as sea level dropped (habitat loss)

Contributing Factors

4. Unusually active volcanism releasing huge amounts of gases and CO_2 (flood basalts in Siberia), leading to global warming, which may have triggered release of large stores of methane gas frozen in sediments on the sea floor, causing increased global warming.
5. Possibility of an extraterrestrial impact, as indicated by spherical carbon molecules containing an extraterrestrial helium-3 isotope
6. All of these together!!

Volcanicity

- At the end of the Permian, volcanic super eruptions took place in Siberia, ejecting more than 2 million km3 of basaltic lava and covering 1.6 million km2 of Eastern Russia with a thickness of between 400–3000 meters.
- New radiometric dating has found that these huge eruptions took place within a (geologically very short) period of 1 million years, and their age is exactly 252 million years, the Permian–Triassic boundary.
- This was the decisive factor for the destruction of an already degraded environment.