Paleoclimatology

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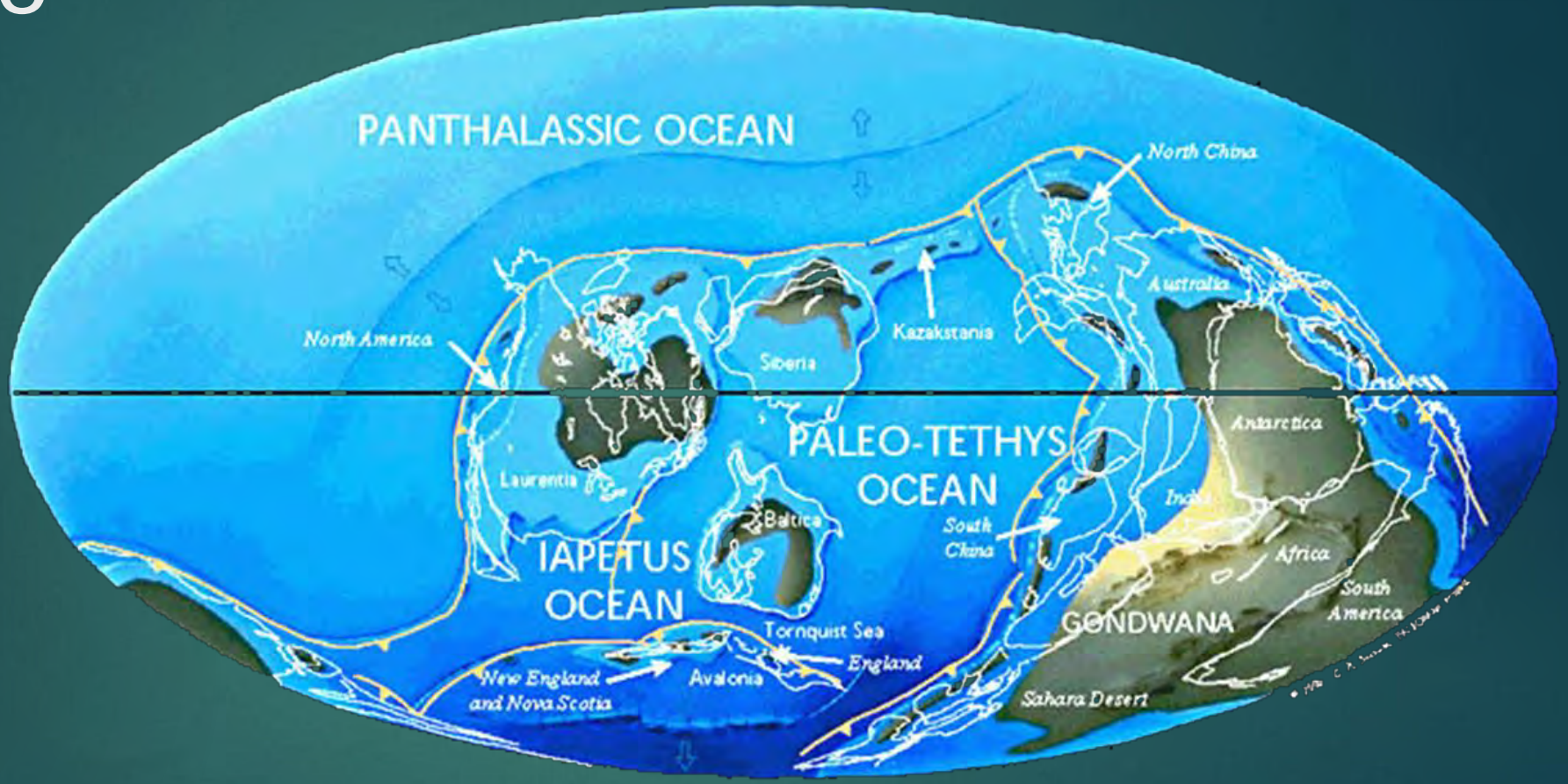
Let’s take a look at some major eras in Earth’s history

The Ordovician World, 488 million years ago

The Ordovician Period lasted almost 45 million years, from 489 to 444 MYA. During this period, the area north of the tropics was almost entirely ocean, and most of the world's land was collected into the southern supercontinent Gondwana.



The Ordovician Period 489-444MYA

- The climate was initially very warm (ocean temperature 42°C [108°F]; it slowly cooled, until it was reasonable by the middle Ordovician. Temperature then rapidly declined, leading to intense glaciation and sea-level fall.
- In the beginning, oxygen levels were around 17%*, and CO_2 about 15X today's value.
- Ended around 444MYA with a mass extinction that killed 85% of living species (the second most severe of all extinction events!).

*Equivalent to about 5,000 feet above sea level today

The Ordovician Period

- The early Ordovician climate was warm and wet. Shallow seas covered most of the continents.
- During this period invertebrates diversified
  - Coral reefs appeared (though the corals were *tabulate* corals, not the modern scleractinian corals)
  - Mollusks became apex predators of the oceans, including the cephalopods (nautiloids), clams and snails.
- The first land plants appeared.
- Arthropods became the first animals to invade the new habitat: land.
- The first vertebrates (early fish) appeared.

Orthocerus (Orthocone sp.)

Life in the Ordovician

- Because of the extremely high sea levels, a shallow tropical sea (The Great American Carbonate Bank) covered North America (ankle deep: you could wade from a tropical beach in Wisconsin to Texas).
- Rivers didn't exist; plants had not developed roots, so nothing held banks in place. Watercourses were braided.
- The day was 20 hours long
- The Moon was some 10,000 km closer and appeared 5% larger in the sky.
- Most life was in the shallow seas. Life on land was restricted to patches of liverworts near the shores and lichen further inland.
- Atmospheric CO_2 was high, 3,000 to 9,000 ppm (415ppm today), largely due to massive volcanic activity in an island chain in the Iapetus Ocean (the islands eventually collided with North America to form the basis of the Appalachians [Including Mt. Greylock, near Pittsfield, MA]).

Life in the Ordovician (cont'd)

- It was a good time for life: the biggest expansion* in the history of the earth. Numbers *tripled* in 10 million years. Some call it the second act or finale to the Cambrian Explosion.
- Oxygen was at times higher than today (26% vs 21%), good for large animals to develop (some straight-shelled nautiloids reached 12 feet long!) Oxygen would plummet toward the end of the period to as low as 12%.
- In the mid-Ordovician there was a period of meteoric impacts, probably debris from an asteroid collision some millions of years before outside the orbit of Mars.

*measured as the number of new species that arose

Invertebrates of the Ordovician

Eurypterid

Orthocone

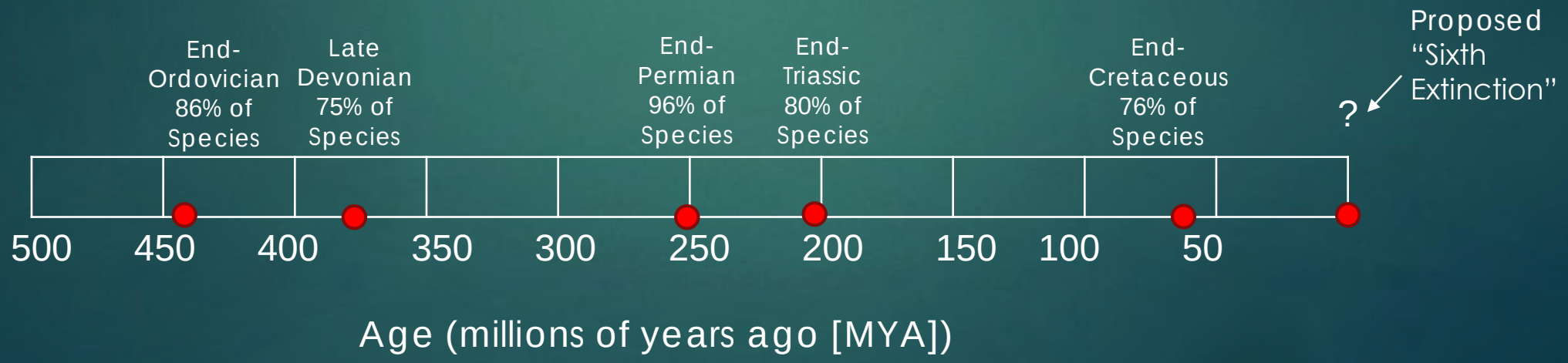
Brachiopod

The End of the Ordovician

THE FIRST OF THE "BIG FIVE" CLIMATE-DRIVEN EXTINCTION EVENTS

What is an "Extinction Event"

- Mass extinctions—when at least half of all species die out in a relatively short time—have occurred only a handful of times over the course of our planet's history.
- The largest mass extinction event happened around 250 million years ago, when perhaps 96 percent of all species of both plants and animals went extinct, leaving an exhausted and nearly dead, silent world. It would take almost ten million years to recover, and the world would never be the same.



The “Big Five” Extinction Events

- Ordovician-Silurian Extinction: 440 million years ago
  - Small marine organisms died out.
- Devonian Extinction: 374 million years ago
  - Many tropical marine species went extinct.
- Permian-Triassic Extinction: 250 million years ago
  - The largest mass extinction event in Earth's history
  - affected a wide range of species, including many vertebrates.
- Triassic-Jurassic Extinction: 210 million years ago
  - The extinction of other vertebrate species on land allowed dinosaurs to flourish.
- Cretaceous-tertiary Extinction: 65 Million Years Ago
  - Also called the “K-T” Extinction
  - Asteroid strike in Chicxulub wipes out non-avian dinosaurs and many other species.

End-Ordovician Extinction: A climate-related disaster in two pulses

- Most evidence points to glaciation for the first pulse:
  - Vast glaciers formed at the poles and moved toward the equator, locking up a huge quantity of seawater and drastically lowering sea levels. The shallow seas covering the continents were drained, killing all their occupants. Then too, oxygen levels fell as photosynthesis declined.

- What caused the glaciation?
  - Cooling due to CO_2 removal through weathering, particularly in the recently uplifted Appalachian mountains*. Also, Gondwana had drifted over the south pole, becoming glaciated, increasing the Earth's albedo and incidentally killing life on that continent.

*Dropping sea levels exposed more carbonate surface leading to more weathering (tipping point).

End-Ordovician Extinction: A climate-related disaster in two pulses

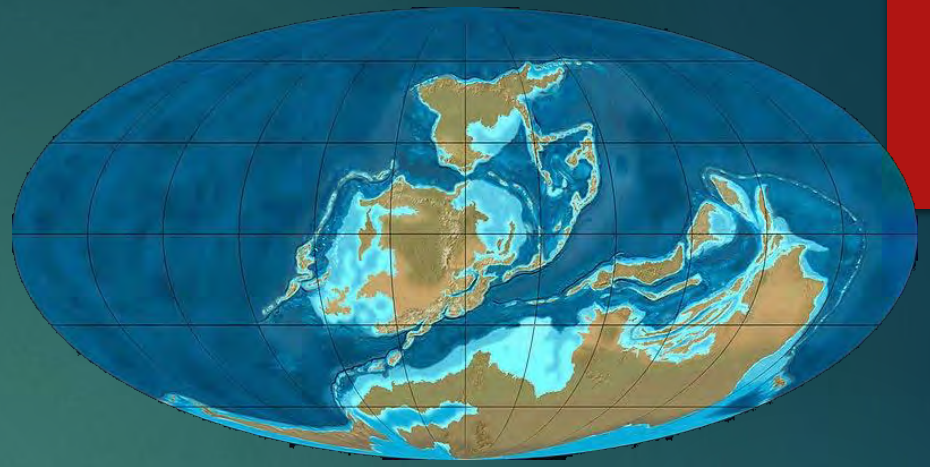
Evidence points to the second pulse being a warming trend and severe anoxia.

Volcanism released large quantities of CO_2 into the atmosphere causing global warming, flipping from icehouse to greenhouse conditions.

- Causes of the anoxia are heavily debated. Possibly melting glaciers freed land, and erosion sent nutrients into the oceans leading to algal blooms. As the algae died the decay consumed oxygen, leading to anoxic seas.
- Whatever the cause, global O_2 levels dropped to around 12% (21% today)*

No matter the specific cause, it was the rapidity of change that was the lethal factor. Organisms simply couldn't adapt fast enough.

The Devonian Period: 416-358Ma



- Began with a low oxygen environment (12%), which then rose by the Carboniferous to greater than 33%
- Most of the land mass was in the supercontinent Gondwana in the southern hemisphere, with Euramerica equatorial.
- Known as "The Age of Fish" due to a great diversification of fish. Bony fish (teleosts) with swim bladders and fins arose, and cartilaginous fish (sharks and rays) became common. By the end of the Devonian vertebrates appeared on land. The first fossil footprints of a terrestrial tetrapod date from 400 MYA.

The Devonian Climate

- During most of the Devonian Period, the climate was relatively mild and the continent of Euramerica, which straddled the equator at the time, set the scene for the spread of tropical and equatorial forests. The position of this land mass also meant that many communities of vertebrate animals were concentrated near the equator where the warm climate encouraged their growth and evolution.*

*https://www.miguasha.ca/mig-en/climate.php

Plants of the Devonian

- Plants continued to make evolutionary progress during the Devonian. Lycophytes, horsetails and ferns grew to large sizes and formed Earth's first forests. By the end of the Devonian, progymnosperms were the first successful trees, growing up to 98 feet tall with a trunk diameter of more than 3 feet. They did not have true leaves but fern-like structures connected directly to the branches. There is evidence that they were deciduous, as the most common fossils are shed branches. Reproduction was by male and female spores that are accepted as being the precursors to seed-bearing plants.

Animals of the Devonian

Pteraspis
(Placoderm)

ammonite

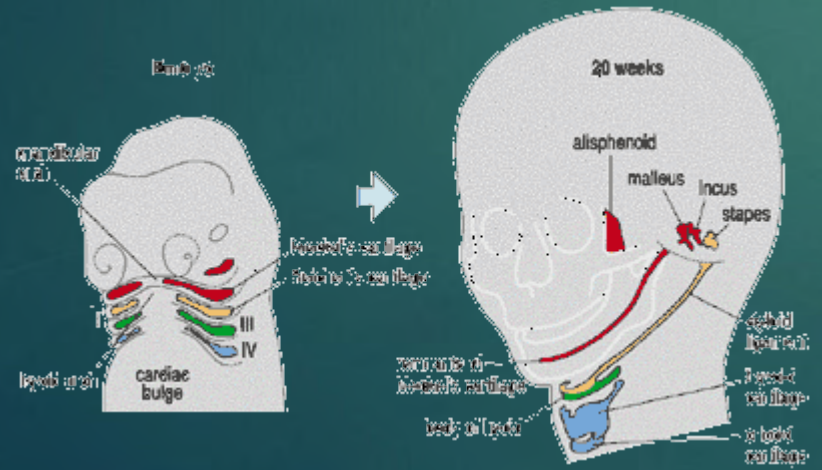
Placoderm (Dunkleosteus sp.)

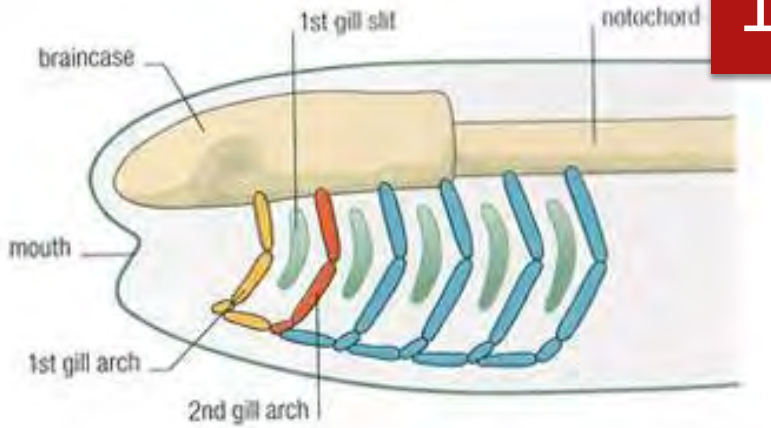
Eurypterid

Ostracoderm
(agnathan)

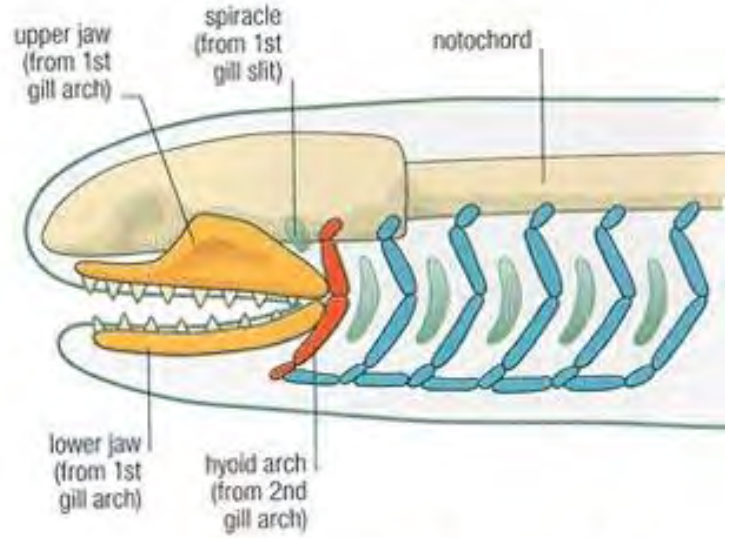
Evolution of Jaws

- By the Silurian, some 440 MYA, the early gill arches of fish had evolved into jaws, a major advance in predation.
- These gill arches today form your middle ear bones.





AGNATHOUS (JAWLESS) VERTEBRATE



GNATHOSTOME (JAWED) VERTEBRATE

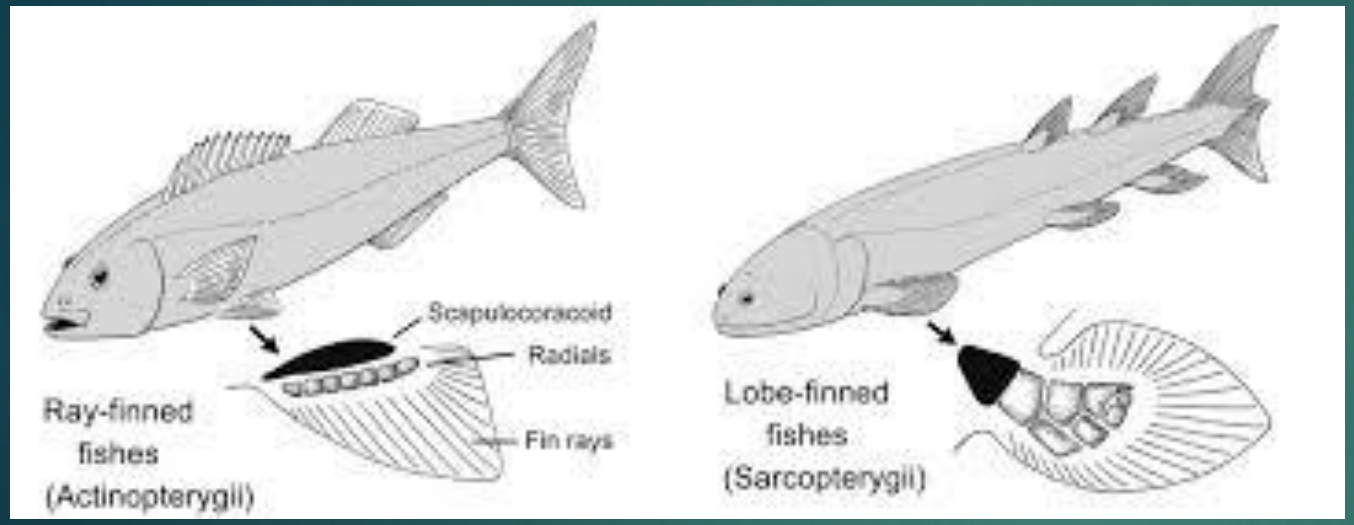
In the Devonian fish diversified into two groups: lobe-finned (Sarcopterygii) and ray-finned (Actinopterygii). The Sarcopterygii gave rise to the Ripidistia, the ancestors of all tetrapods and lungfish (Dipnoi).

Latimeria, a crossopterygian living fossil

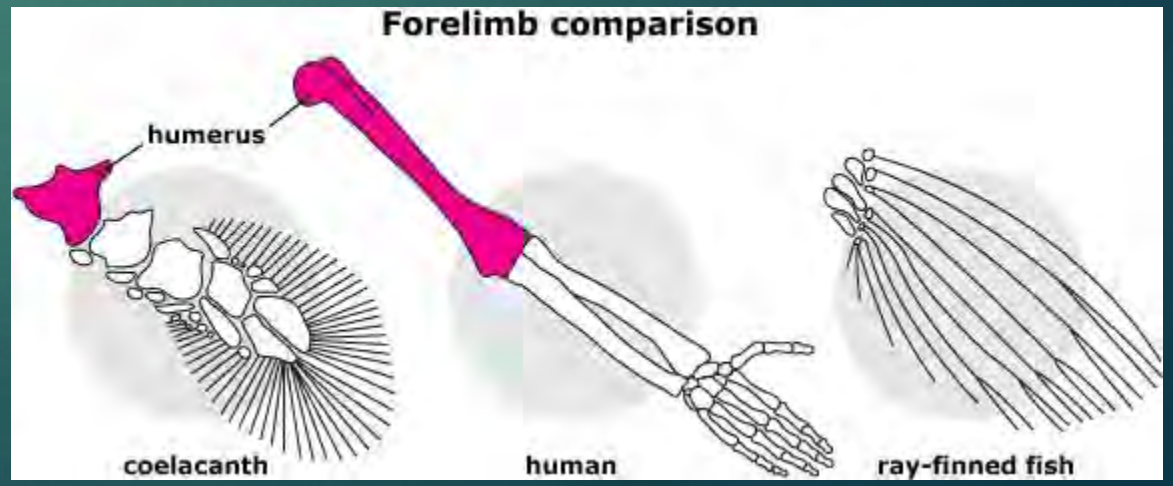
Trout, an actinopterygian

(Crossopterygii = Sarcopterygii)

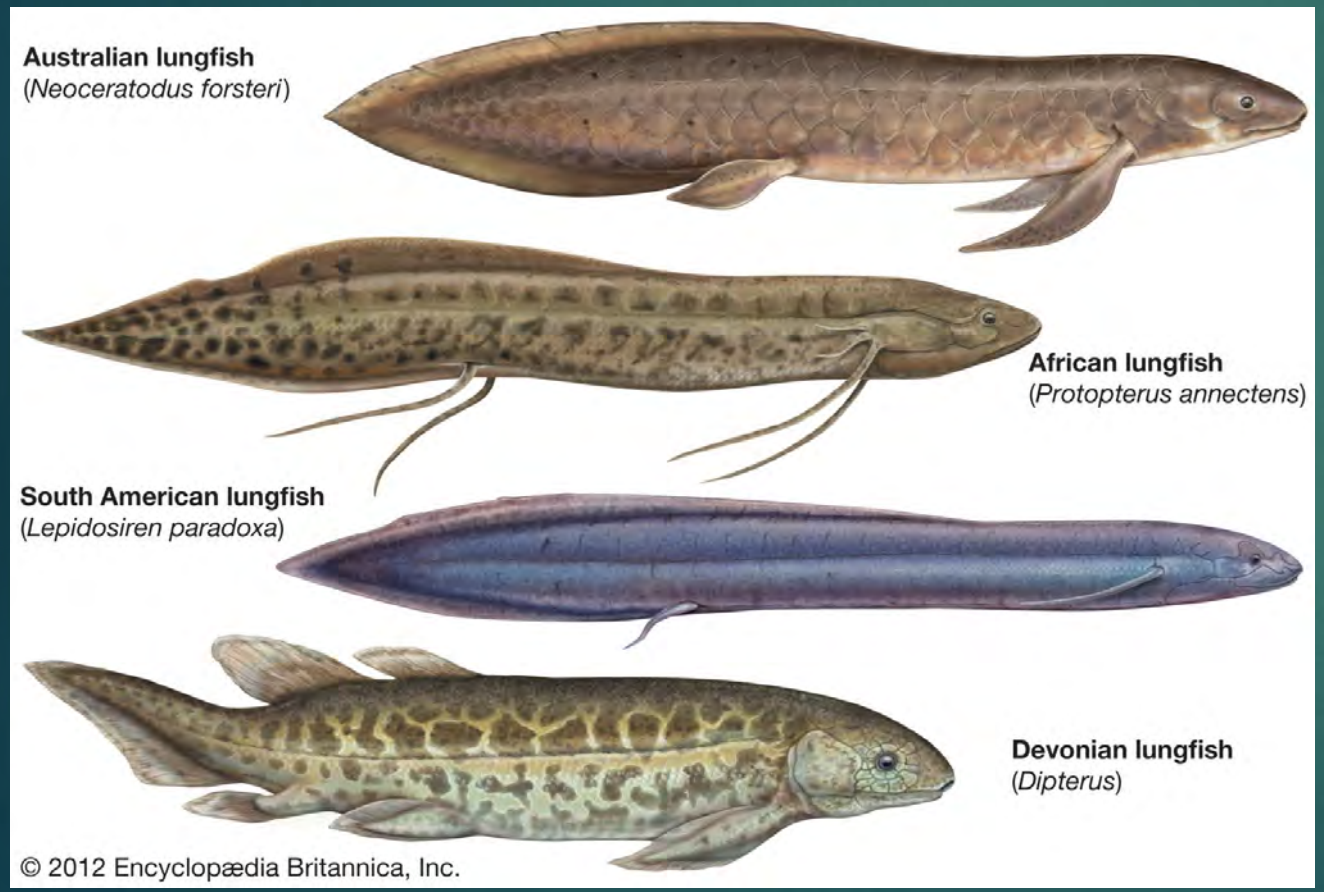
Tetrapods arose from crossopterygians



Finding the Coelacanth



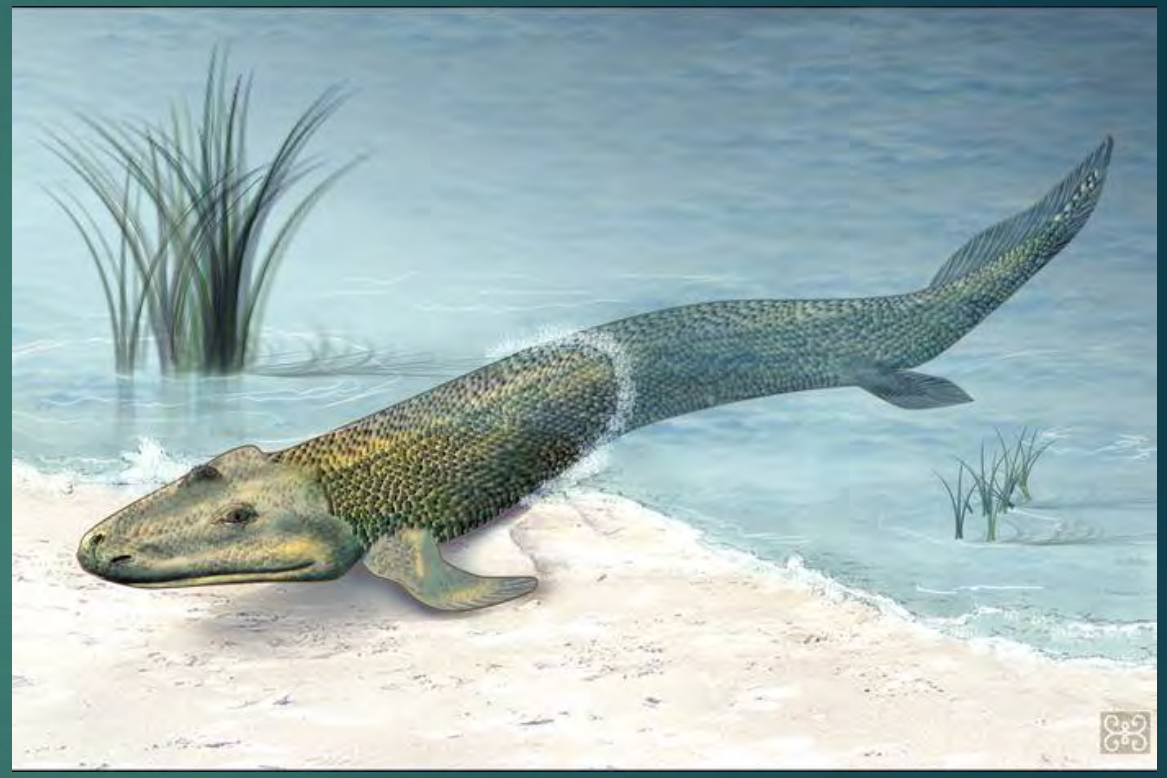
Dipnoi (lungfish): Crossopterygian relatives of terrestrial tetrapods



Dipnoi appeared in the late Devonian, and some persist to today. The presence of lungs and fleshy fins with bones gave them the ability to move on land.
They are freshwater fish, implying that the route from sea to land went through fresh water.

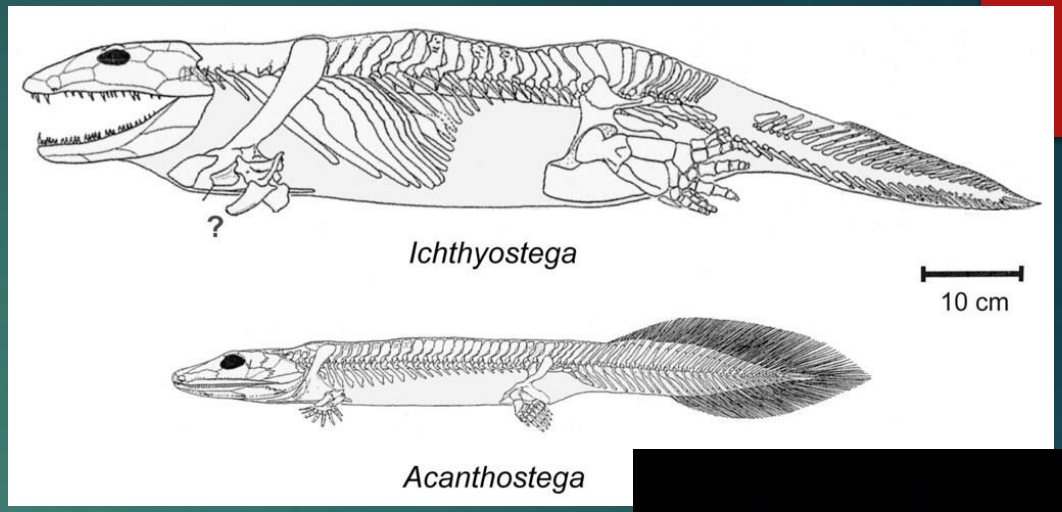
Transition to land: Tiktaalik

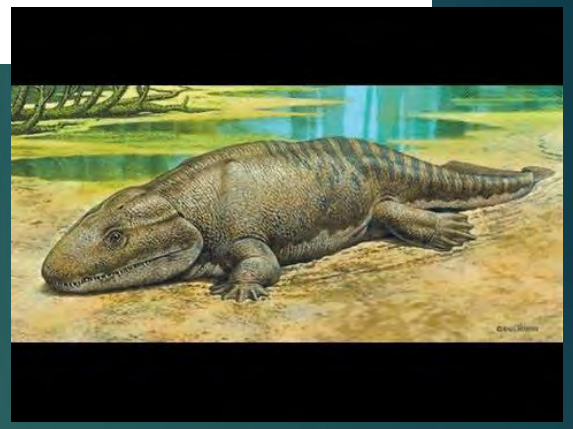
- Tiktaalik dates from about 375 MYA (late Devonian).
- It is highly significant because it shares so many fish and tetrapod characteristics.
- It had gills and scales and a more robust skeleton (rib cage) but could not support its weight on land.
- It probably had primitive lungs and gulped air when the shallows warmed and oxygen concentration dropped.



Invasion of the land

- By the late Devonian vertebrates appeared on land, probably facilitated by a rise in oxygen. The earliest fossils were *Ichthyostega and Acanthostega.*
- They were still rather fish-like. Although they had lungs, they also had gills for use in the water.





End of the Devonian: the Late-Devonian Extinction

Causes of the Late-Devonian Extinction

- The true cause(s) are still a matter of debate.
- The "event" lasted some 20 to 25 million years, and occurred in two waves, with the greatest destruction occurring at 374 and 359 MYA.
- The second event seems to be due to oxygen depletion of the oceans (which led to today's oil-rich shales).
  - The appearance of more sophisticated land plants with root systems may have led to enhanced rock breakup and subsequent eutrophication of the seas.
- The first event is more controversial. Some ascribe it to global *warming* due to volcanic eruptions raising the CO_2 levels, while some ascribe it to global *cooling* due to depletion of CO_2 by all the new land plants. Some even say it was *both*, and the rapid changes themselves are the cause, with most organisms unable to adapt to the swings.