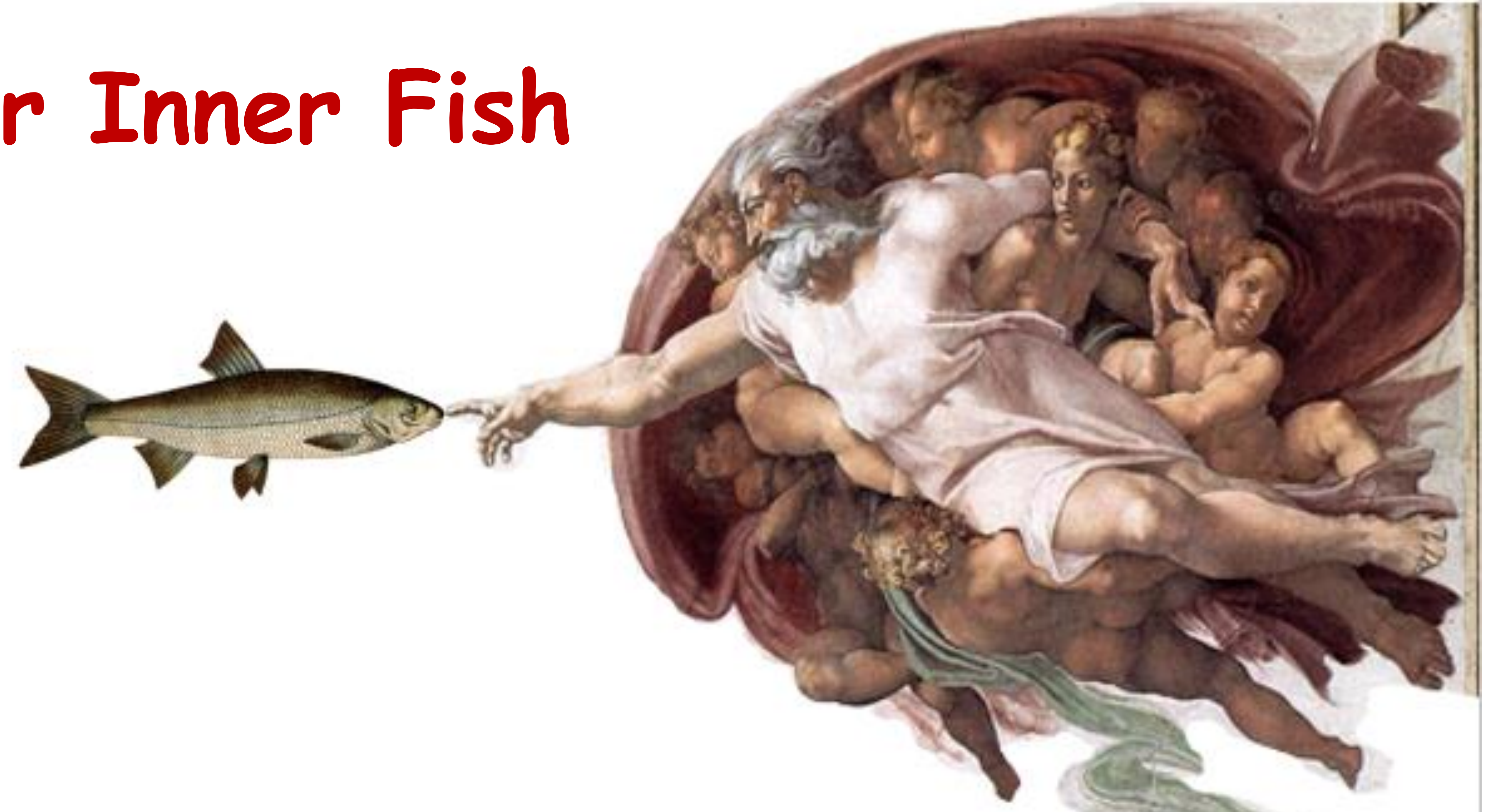
# Your Inner Fish



Many of our seemingly distinctly human characteristics
were inherited from our distant fish ancestors

# Your Inner Fish


Many of our seemingly distinctly human characteristics were inherited from our distant fish ancestors

# Close to home


This session

Upper Devonian – Cobargo to Bunga Head, Mumbulla Mtn, Merimbula surrounds, Eden town headland, Wadbilliga and Deua

Early Devonian – Bega-Cobargo-Moruya Granites

Silurian – Kosciuszko Granites

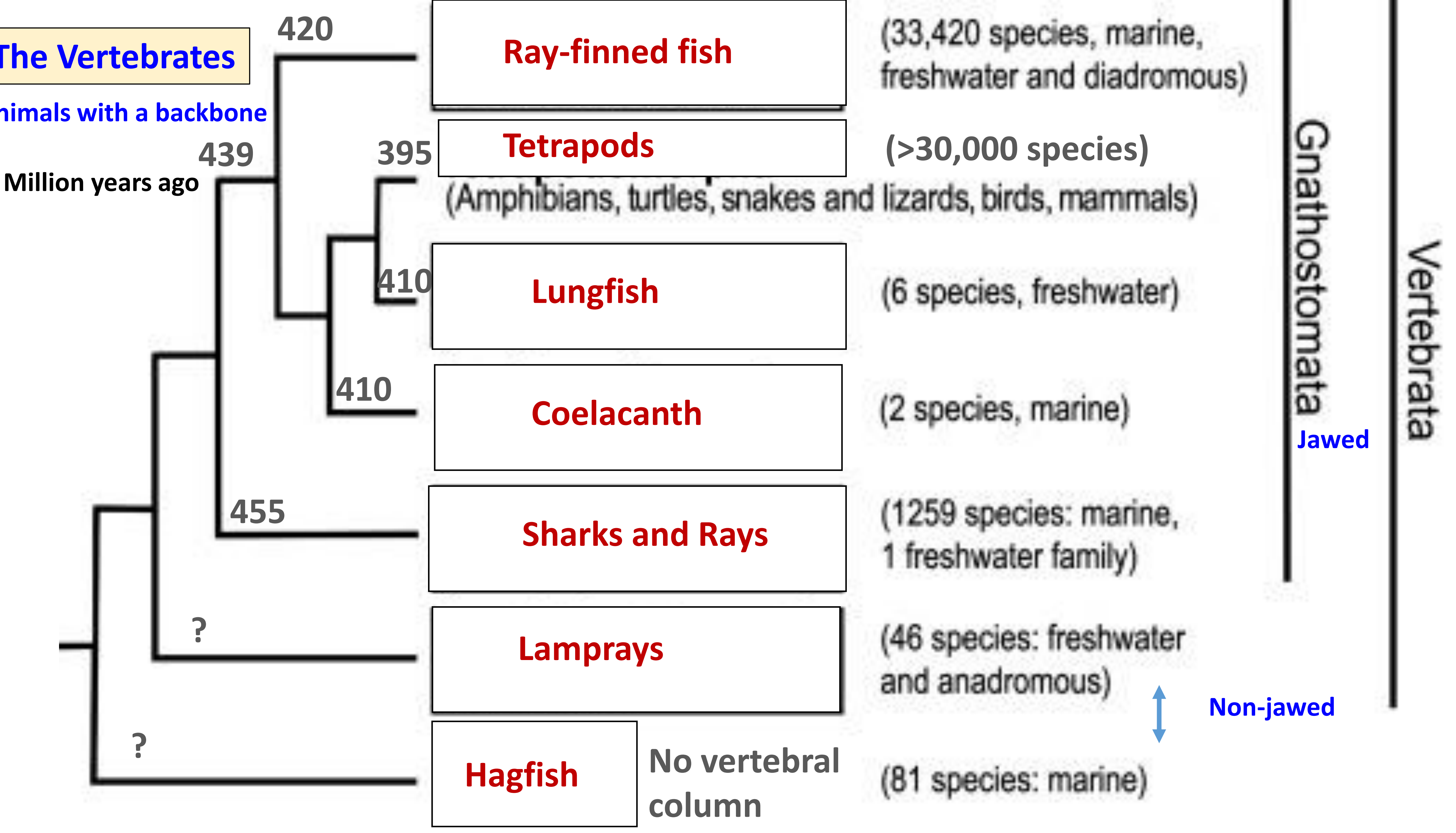
Ordovician – Bermagui headland – regional hinterland

Cambrian – Camel Rock submarine basalt

Folded Ordovician beds

# The Vertebrates

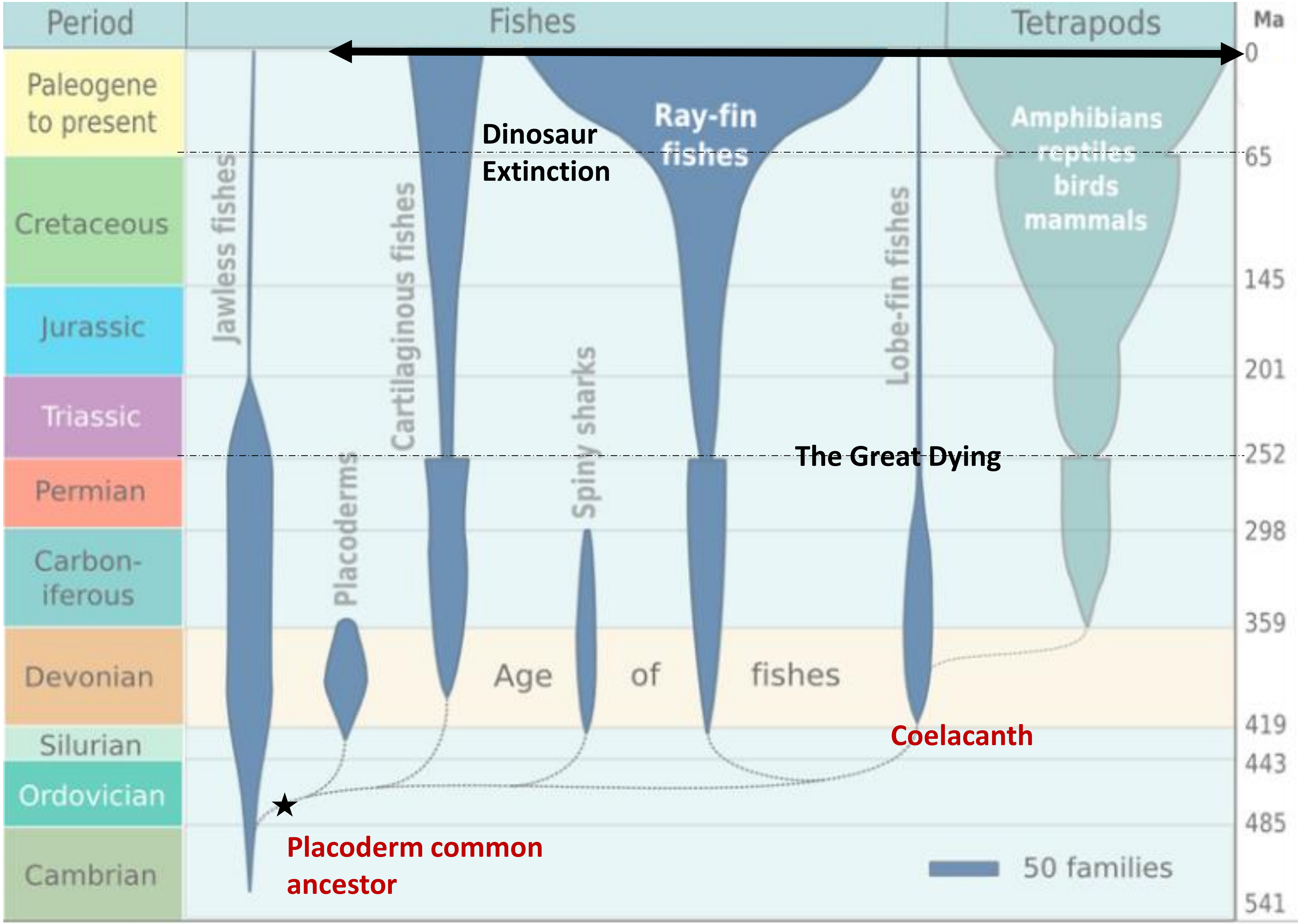
Animals with a backbone

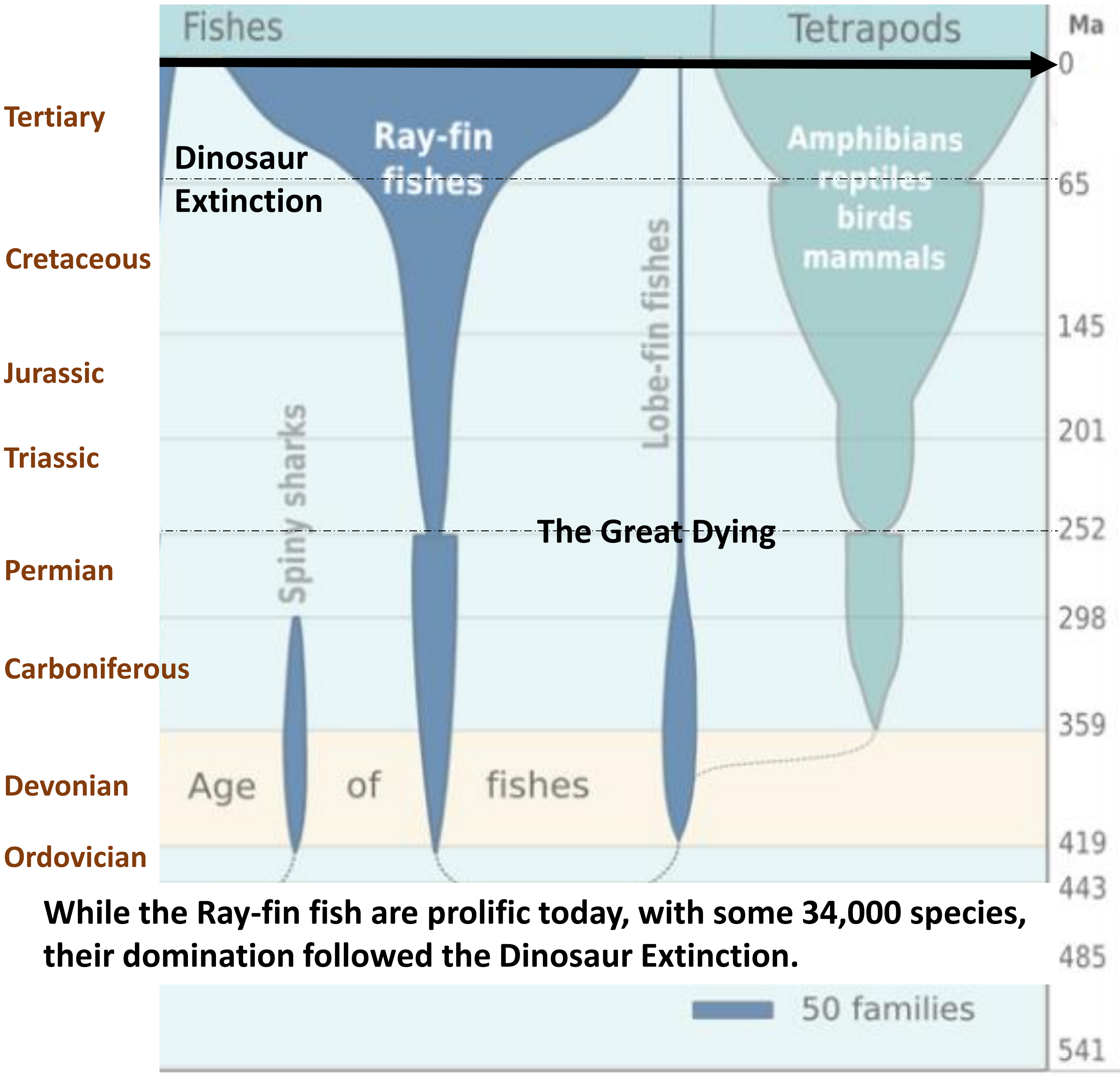


# ‘Tetrapod’

**‘Four foot’ (from ancient Greek)**

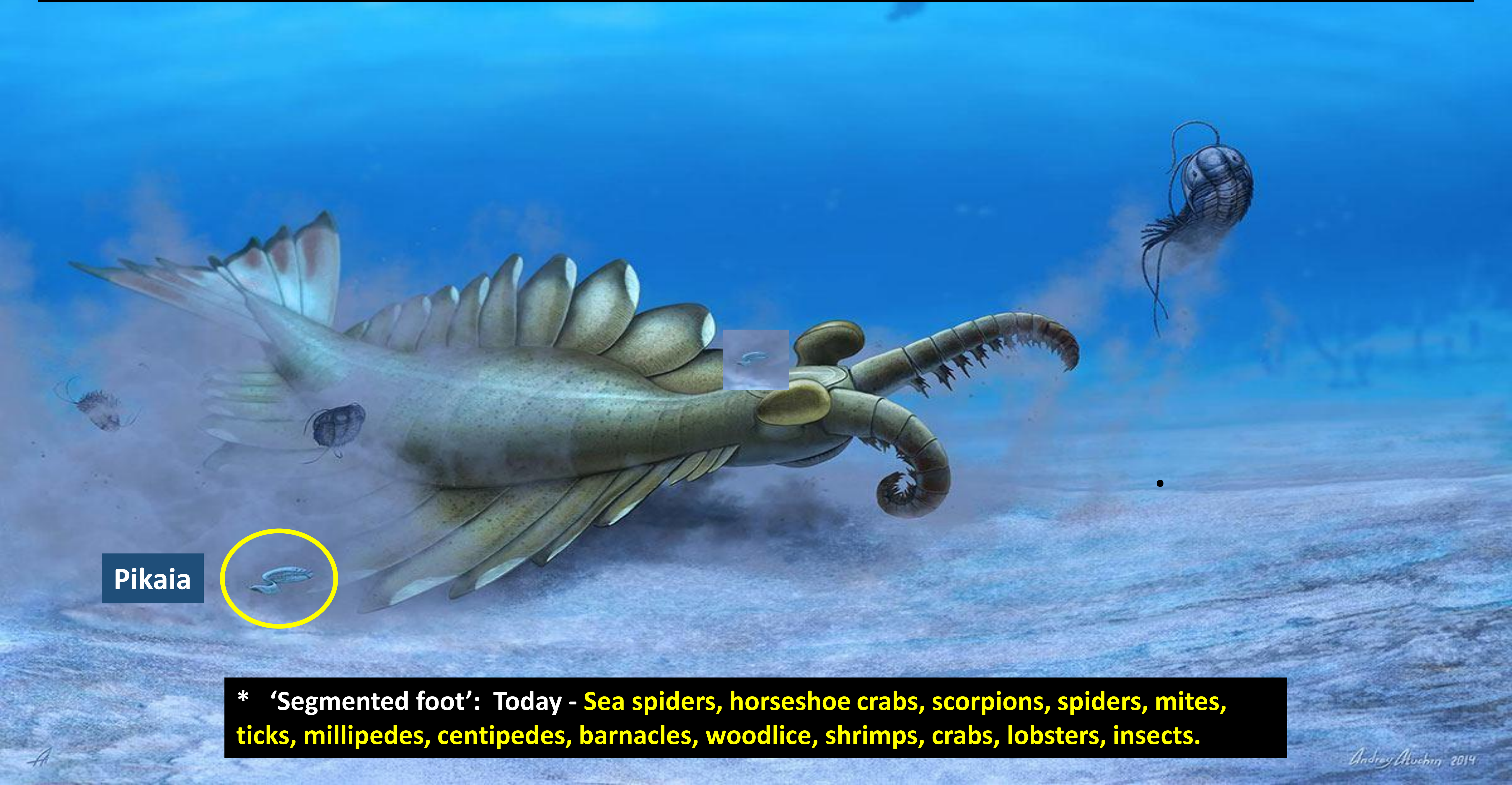
## The jawed vertebrates



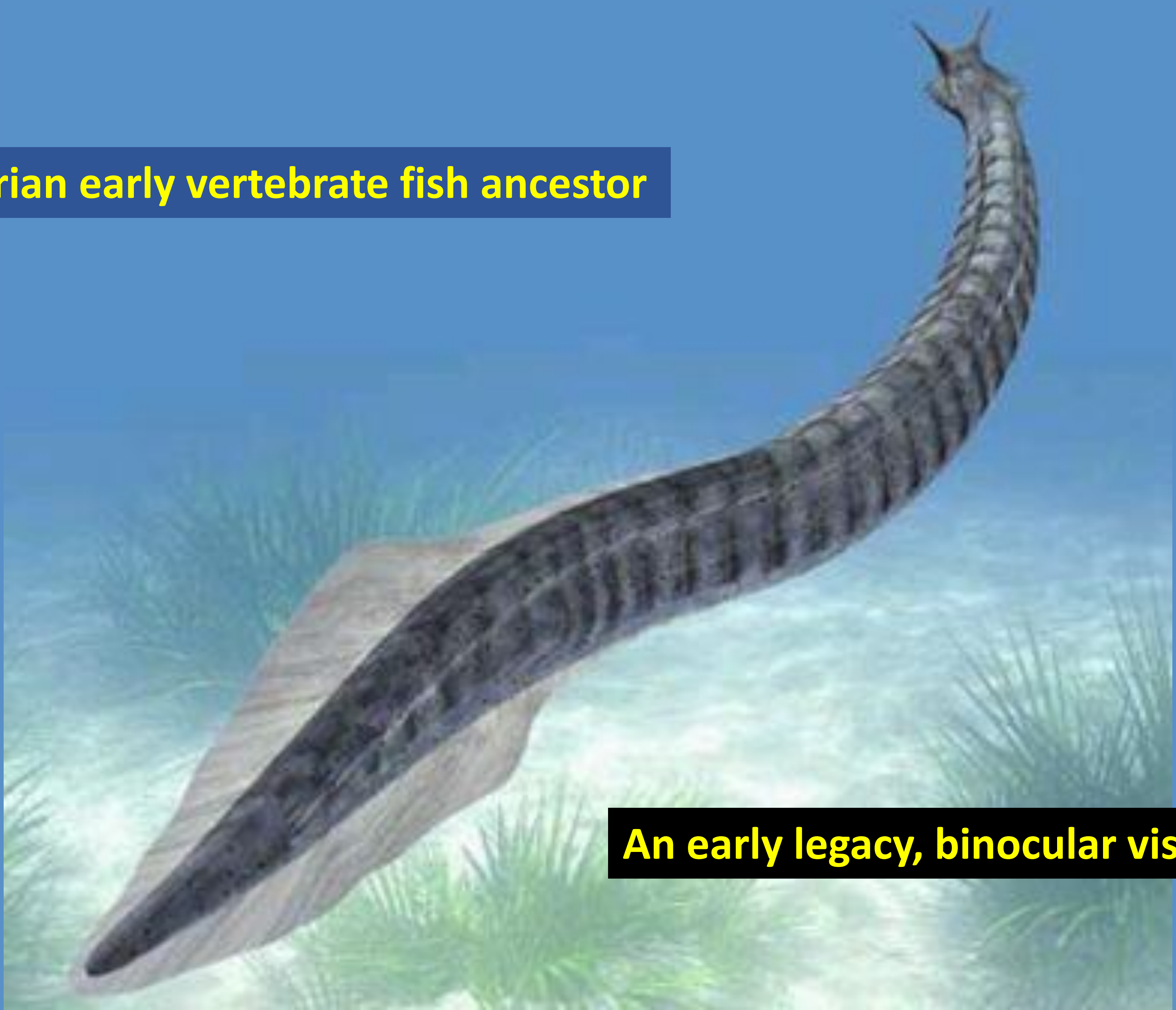

**While the Ray-fin fish are prolific today, with some 34,000 species, their domination followed the Dinosaur Extinction.**

# The story starts with protofish vertebrates dodging arthropod * apex predators in the Cambrian Explosion




* ‘Segmented foot’: Today - Sea spiders, horseshoe crabs, scorpions, spiders, mites, ticks, millipedes, centipedes, barnacles, woodlice, shrimps, crabs, lobsters, insects.

# Pikaia – Cambrian early vertebrate fish ancestor

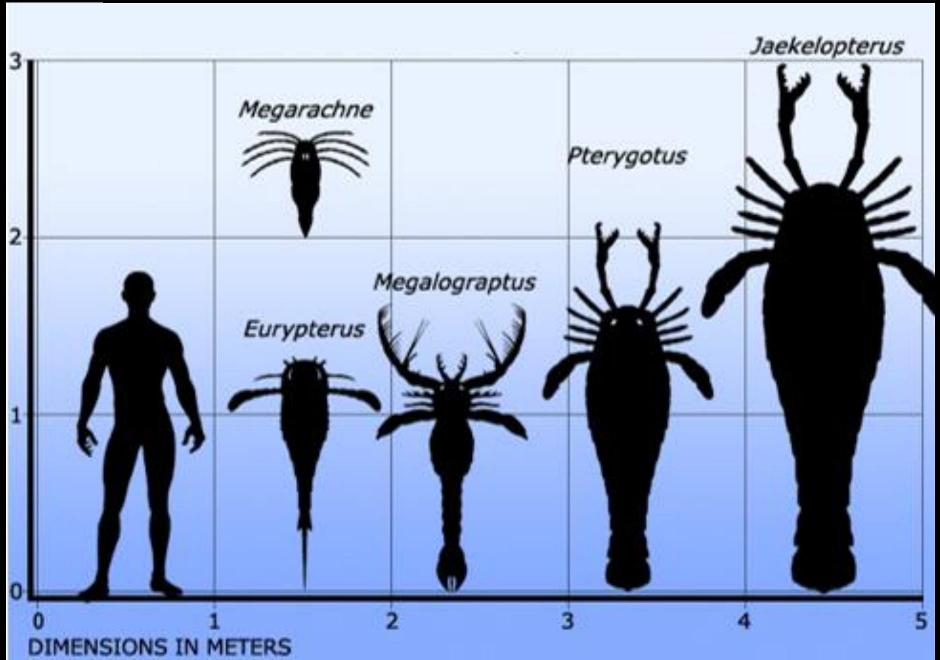


An early legacy, binocular vision and a spine

To avoid becoming lunch you need to develop speed and armour plate

# Into the Ordovician from the Cambrian – the predators got a lot more ugly

Sea Scorpion – the Eurypterids




Cameroceras

Sea Scorpion – the Eurypterids

# Cameroceras - The nautilus ancestor from hell

**Today's *Nautilus* is the sole survivor of this ancient mollusc in the *cephalopods* (which includes octopus and squid).**

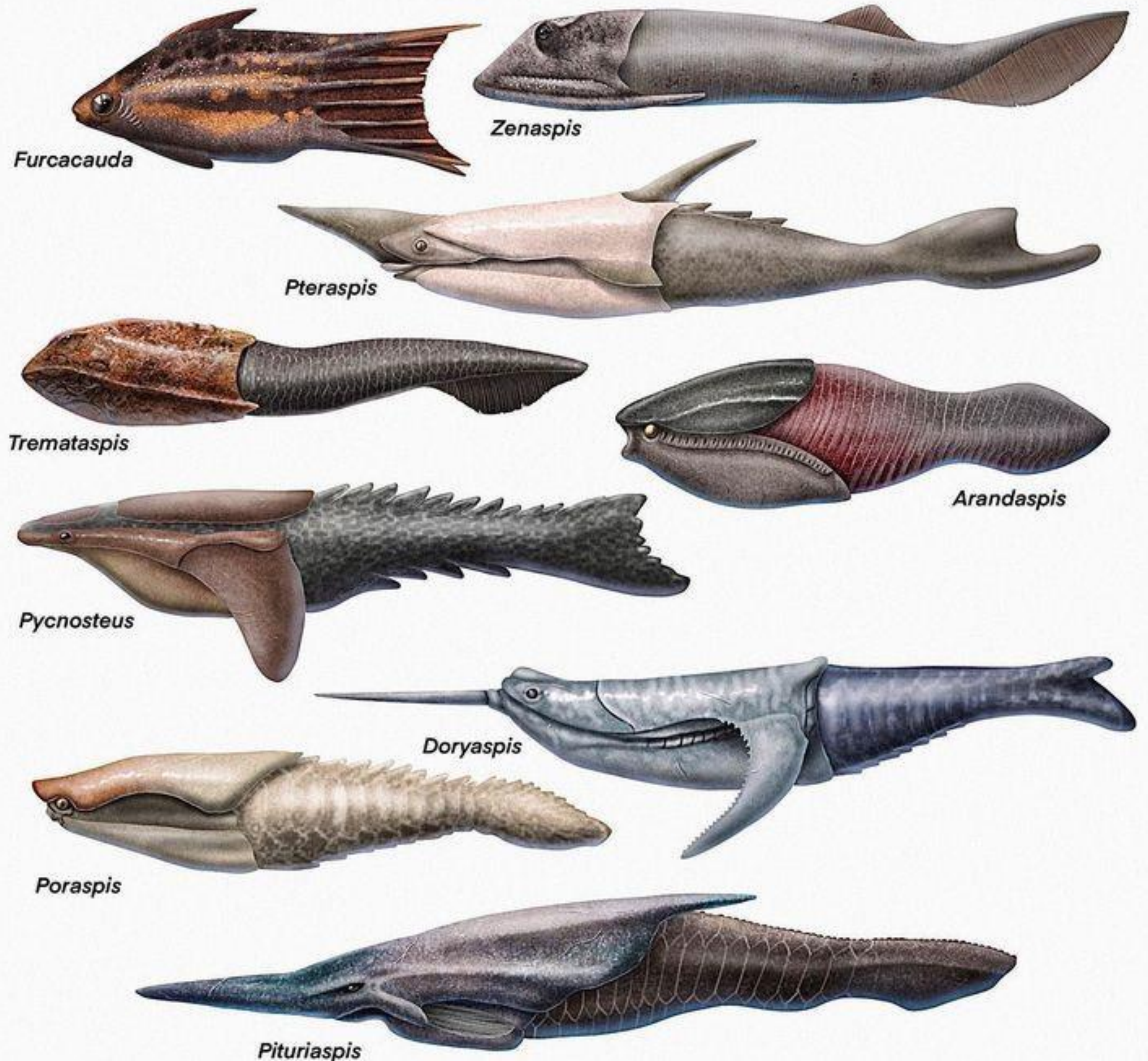
**Nautilus' ancestors used to be bigger in the age of dinosaurs.**

*Ammonites*

To avoid becoming lunch you need to develop speed and armour plate

The first true fish emerged in the Ordovician

Astraspids

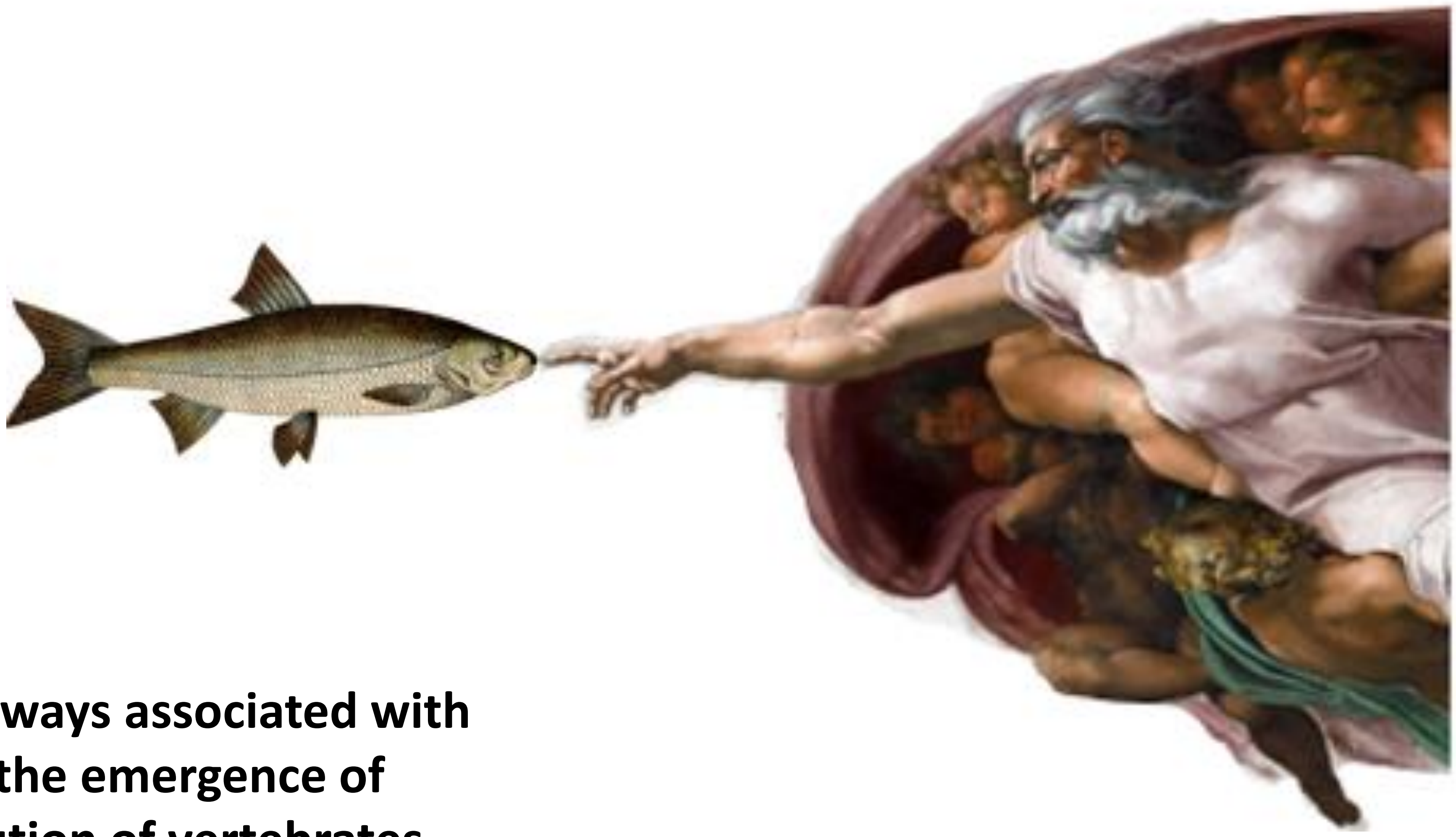



Jawless fish: these animals had a hardened shield on the head and no jaw. After the appearance of jawed fish these fish began to decline, until disappearing in the Devonian.

Ordovician fish had large shields on the head, small, rod-shaped or platelike scales covering the tail, and a slit-like mouth at the front end.

Their skeletons were made of cartilage.

# Linkages to our inner fish

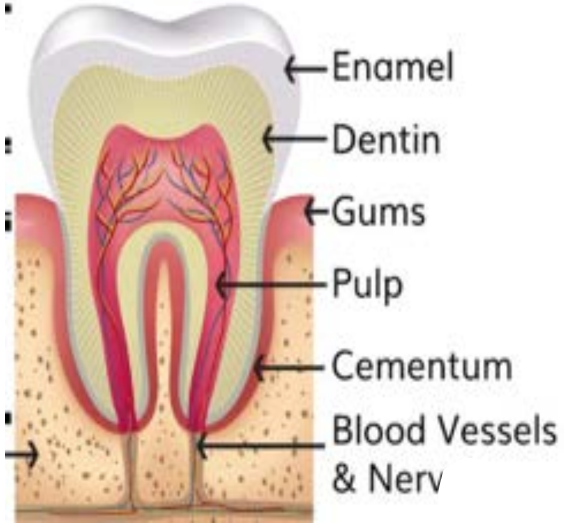


**We shall look at teeth first.**

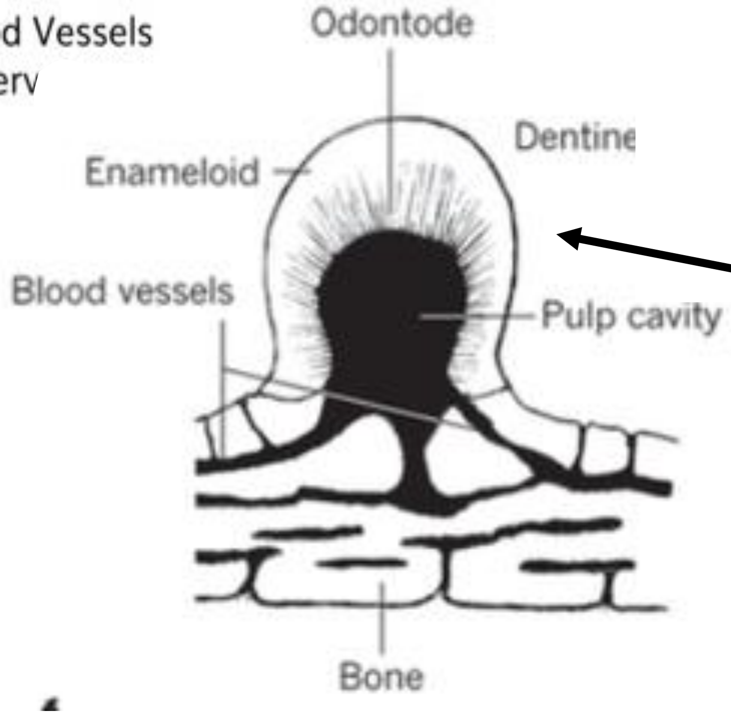
**The  biomineralisation pathways associated with teeth also set the stage for the emergence of jaws and bones in the evolution of vertebrates, including you.**

# Teeth

The head shield was made up of nodules (odontodes) which, through evolution, adapted in mouth parts as teeth.




All the elements of the modern tooth




Showing off her Ordovician jawless fish armoured headshield odontodes.

The teeth biomineralisation pathway also became the vital component in transforming cartilage to bone.

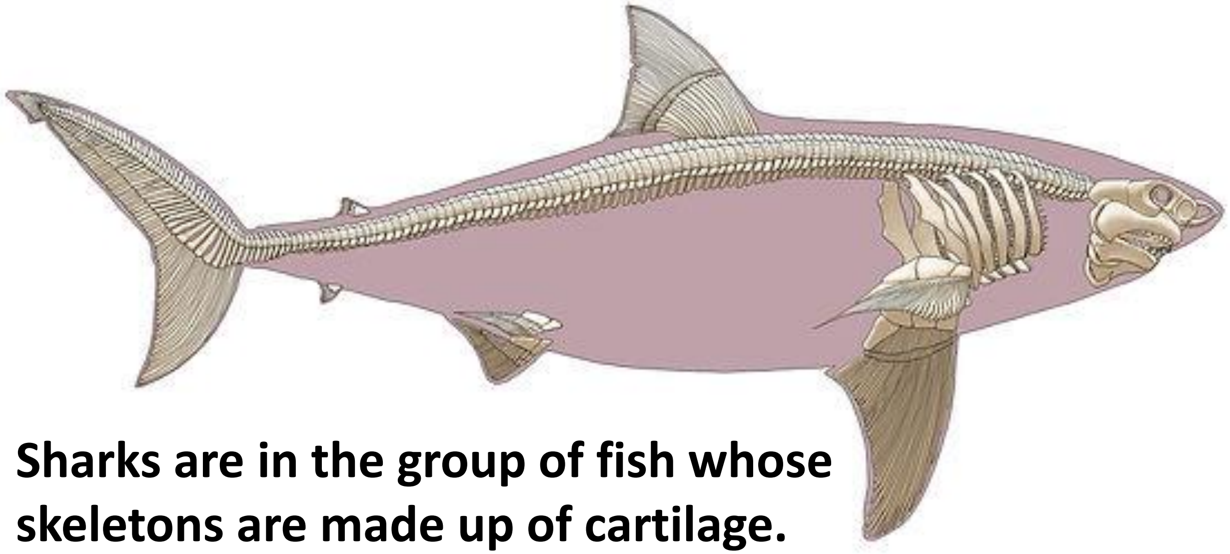
## Convergent evolution – same biomineralisation pathway

**The Sheepshead Fish.**

*Archosargus*

*Homo sapiens*

## Cartilage - the rubbery scaffold



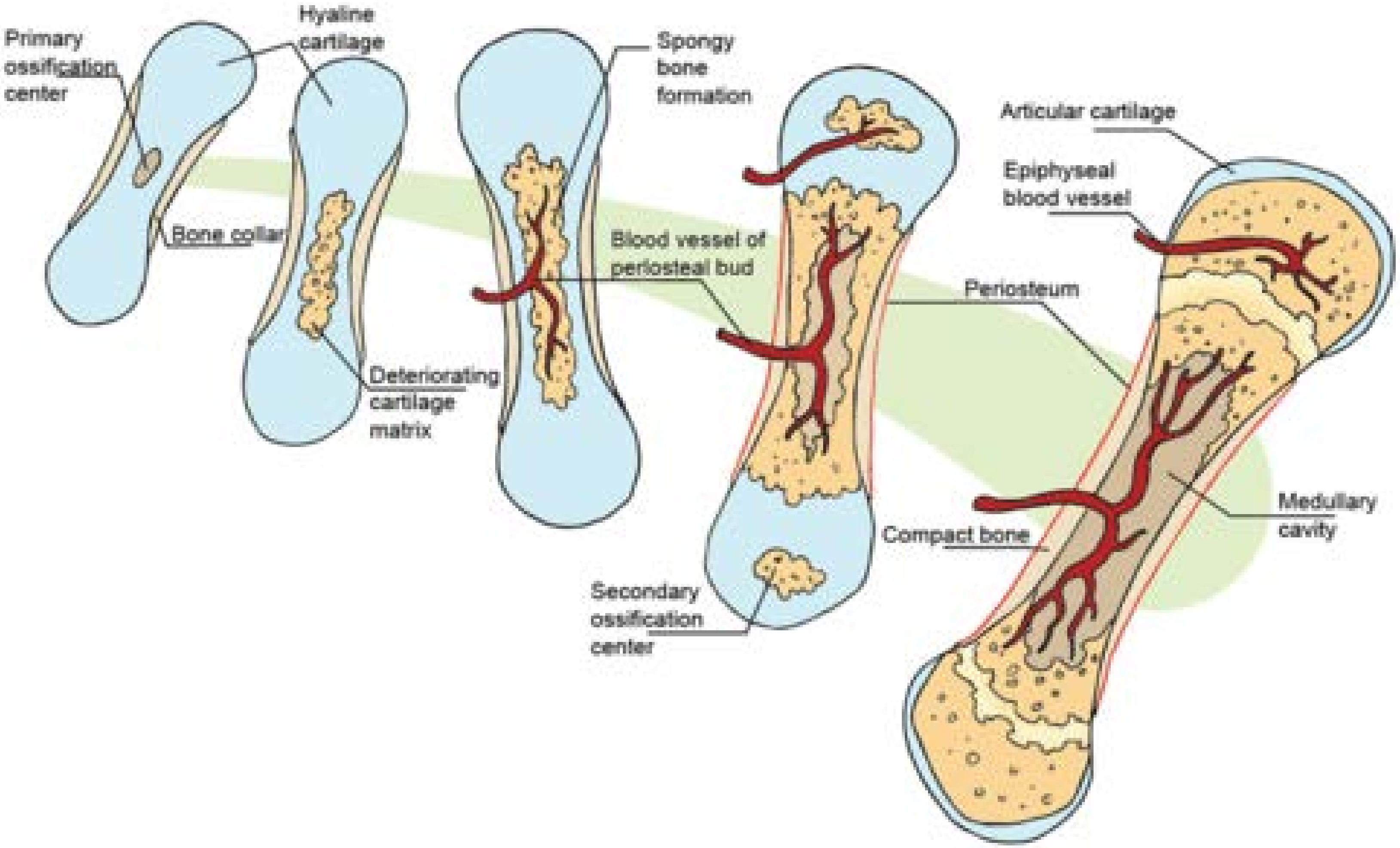
Sharks are in the group of fish whose skeletons are made up of cartilage.

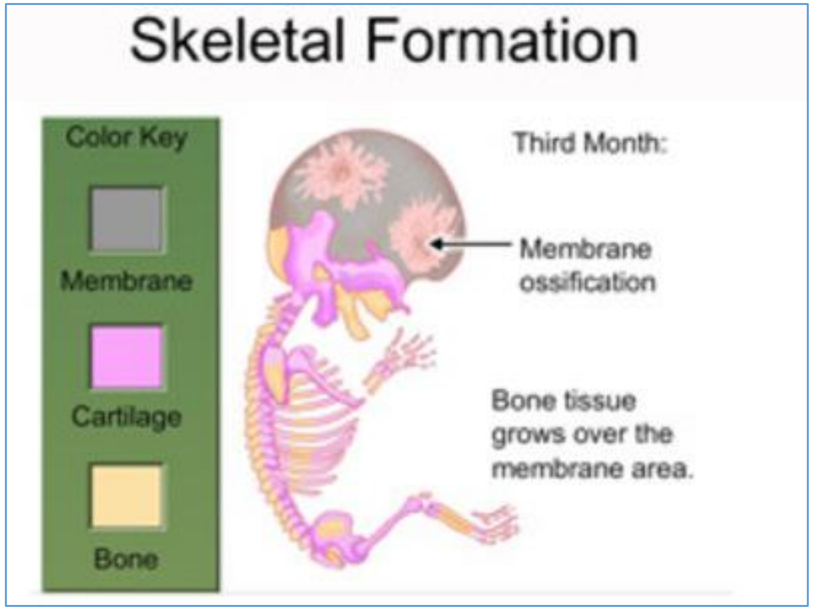
Collagen is **the most abundant protein in the body.** Its fibre-like structure is used to make connective tissue. This type of tissue connects other tissues and is a major component of bone, skin, muscles, tendons, and cartilage. Collagen exists as a family of separate types with different genetic pathways.

It was common in the biota of the Ediacaran period but its evolutionary origin has not yet been determined.

Cartilage is in a wide variety of animals, from cuttlefish, horseshoe crabs, fish, mammals to humans, is structurally very similar. Animals either utilize cartilage ( including modified as bone) or use some other very different structural support system such as chitin.

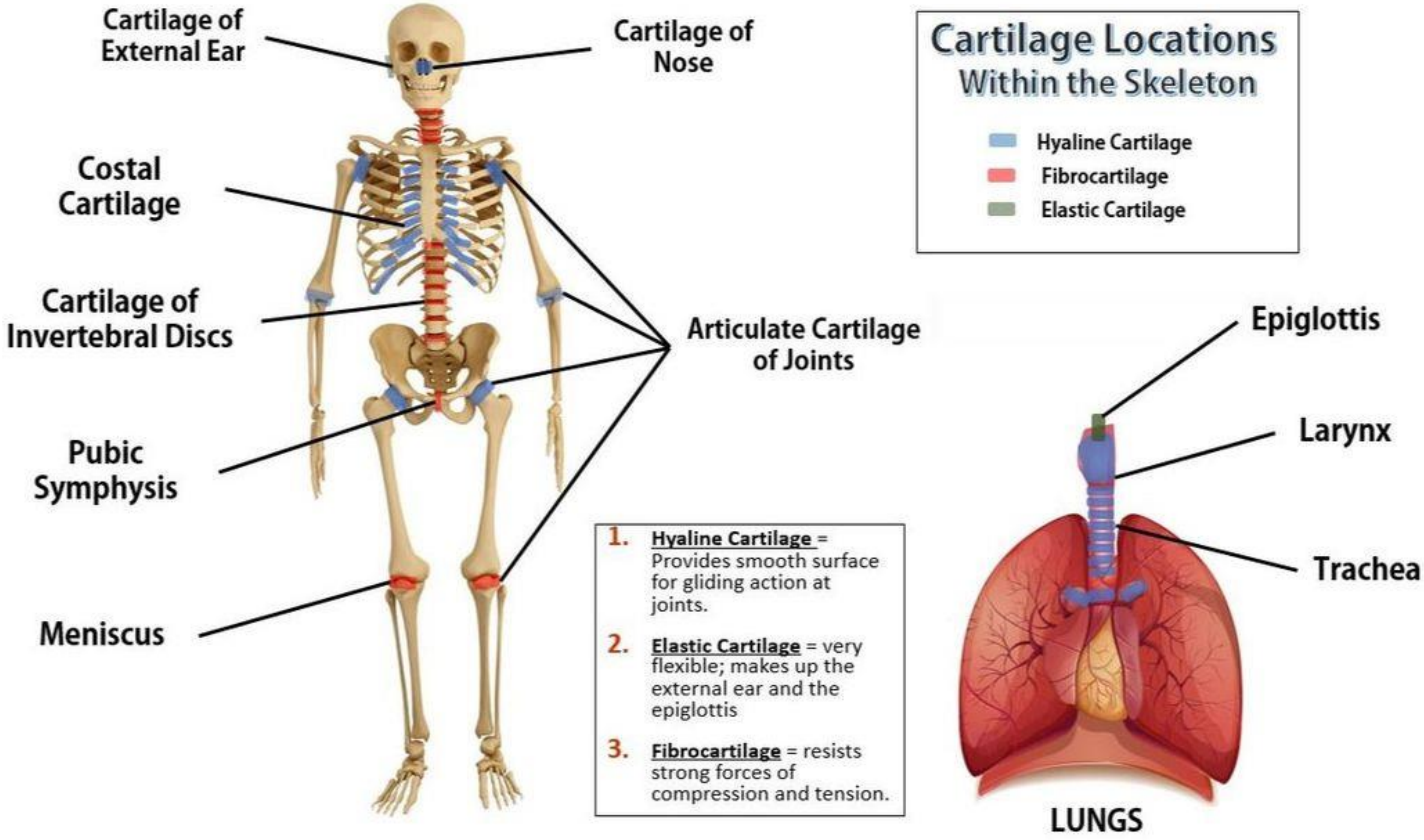
Cartilage even exists in so-called primitive animals, including, worms, arthropods and molluscs . Also, in arachnids, sea spiders, horseshoe crabs and cephalopods (for example, squid, octopus).




**The human foetal skeleton starts out as cartilage, reflecting an ancient origin. Throughout foetal development and into childhood, bone forms in the cartilaginous matrix.**

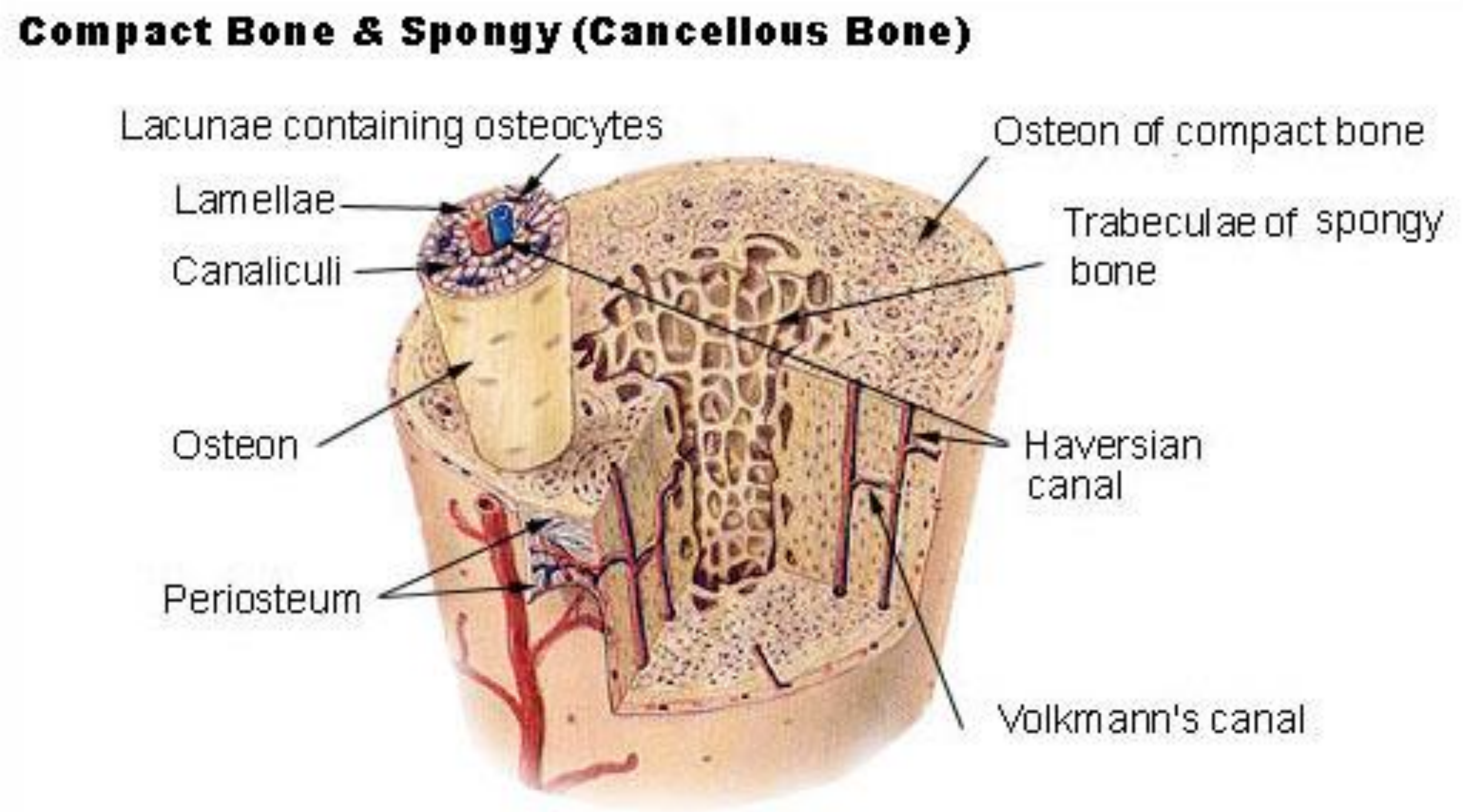
**By the time a foetus is born, most of the cartilage has been replaced with bone. Some additional cartilage will be replaced throughout childhood, and some cartilage remains in the adult skeleton.**


Cartilage Locations
Within the Skeleton
Hyaline Cartilage
Fibrocartilage
Elastic Cartilage
Cartilage of External Ear
Cartilage of Nose
Costal Cartilage
Cartilage of Invertebral Discs
Articulate Cartilage of Joints
Pubic Symphysis
Meniscus
Epiglottis
Larynx
Trachea
LUNGS
1. Hyaline Cartilage = Provides smooth surface for gliding action at joints.
2. Elastic Cartilage = very flexible; makes up the external ear and the epiglottis
3. Fibrocartilage = resists strong forces of compression and tension.

**All of the early fish, and sharks and rays today, have cartilage skeletons.**

# Bone

Cartilage is an inert rubbery scaffold.  Bone is that and much more, as well as providing scaffolding, it is a complex organ in its own right.




Bones protect the various other organs of the body, produce red and white blood cells, store minerals, provide structure and support for the body, and enables mobility.

Bones consist of living cells (osteoblasts and osteocytes) embedded in a mineralized organic matrix.

The primary mineral component of human bone is hydroxyapatite, a Calcium-Phosphorus material similar to tooth enamel.

The organic components of this matrix consist mainly of collagen fibres which give bone its tensile strength and the interspersed crystals of hydroxyapatite give bone its compressive strength.

‘Bone-like’ structures have been found in jawless fish (with cartilage skeletons) dating back over 420 million years


The first appearance of bony structure was in jawless fishes (cartilaginous) and provided a vital mineral storage function.

Animal survival depended on the capacity to utilise energy in sudden bursts. Either as a predator ambushing prey or prey escaping an attack. The race for energy storage capacity was on.

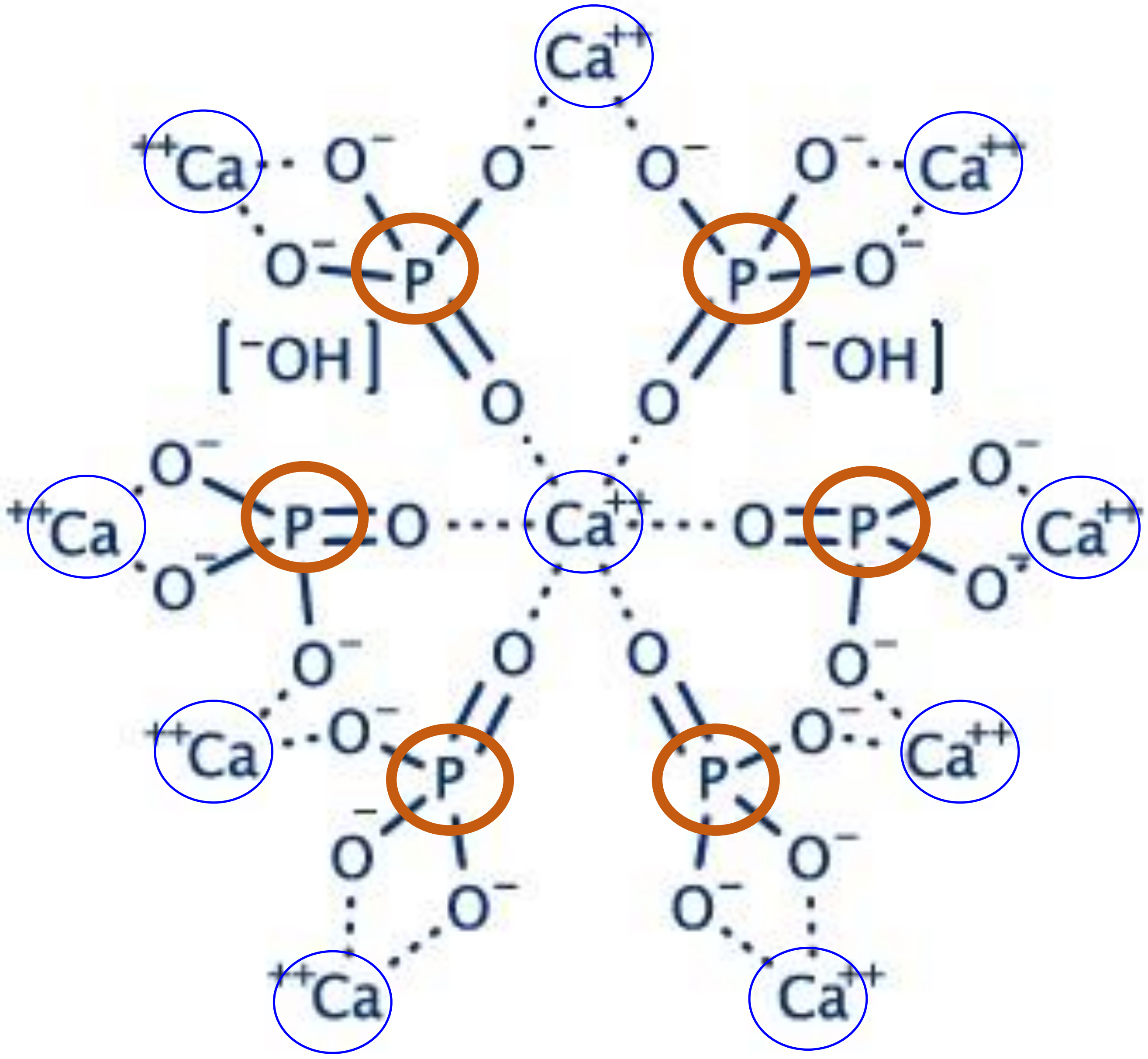
Cells use energy factories called mitochondria to supply their energy needs. The process uses a phosphorus based molecule for the task. Phosphorus is obtained from food.

The phosphorus in teeth enamel is a ready source (but it must be replaced) so the tooth biochemical pathway was adapted to provide phosphorus storage organs. Because the mitochondrial energy process produces acid (Lactic) vital calcium based structures can be dissolved. The enamel-based warehouse should thus store both phosphorus and calcium.

'Bone' thus started off as a *phosphorus-calcium* storage facility, facilitating the energy race between predator and prey. This happened very early in the evolution of fish.

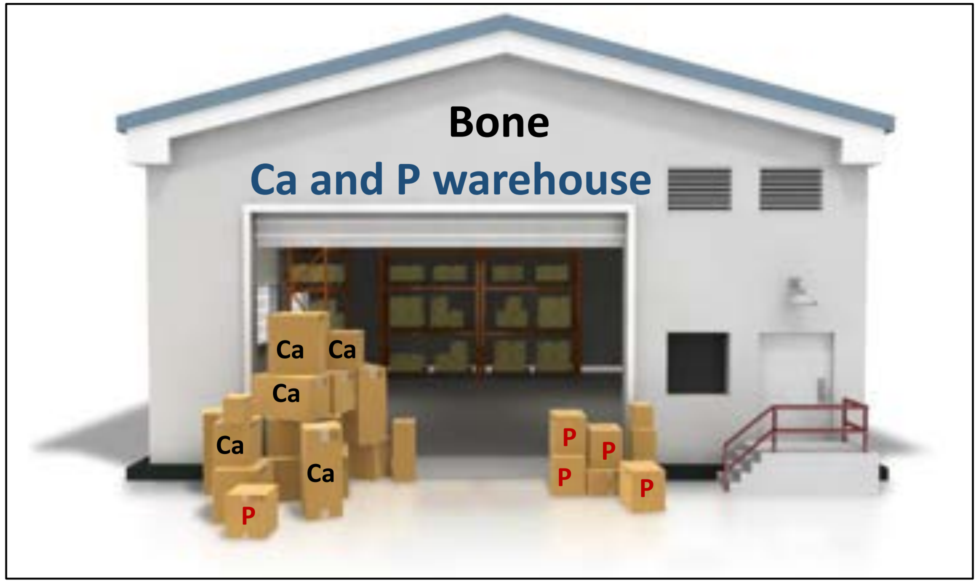
A side benefit was the enamel was also a very strong structural material so it (as bone) replaced cartilage as the skeletal scaffold for the main lineages of fish.

# Hydroxyapatite molecule – the hard stuff of tooth enamel and vertebrate bone

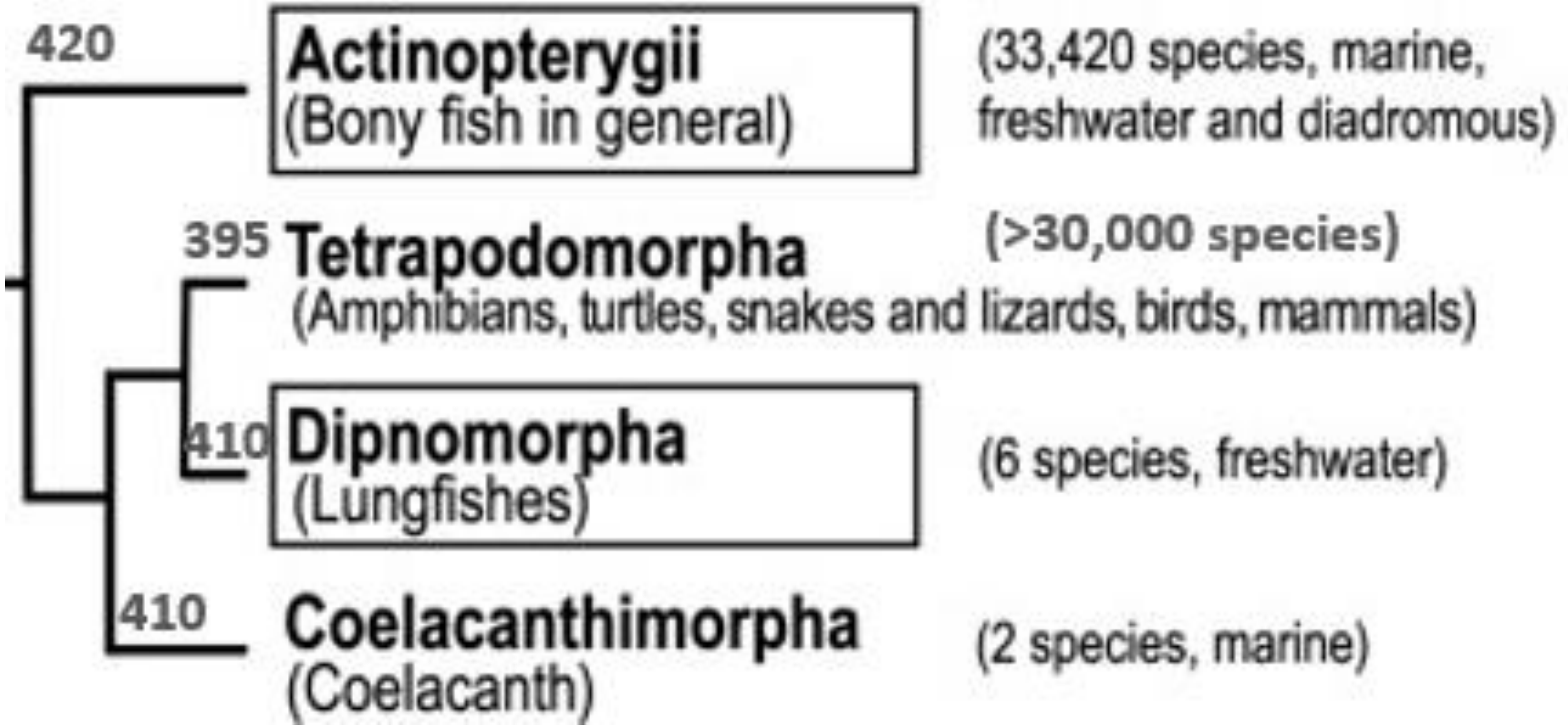



**Note the calcium**

**Note the phosphorus**

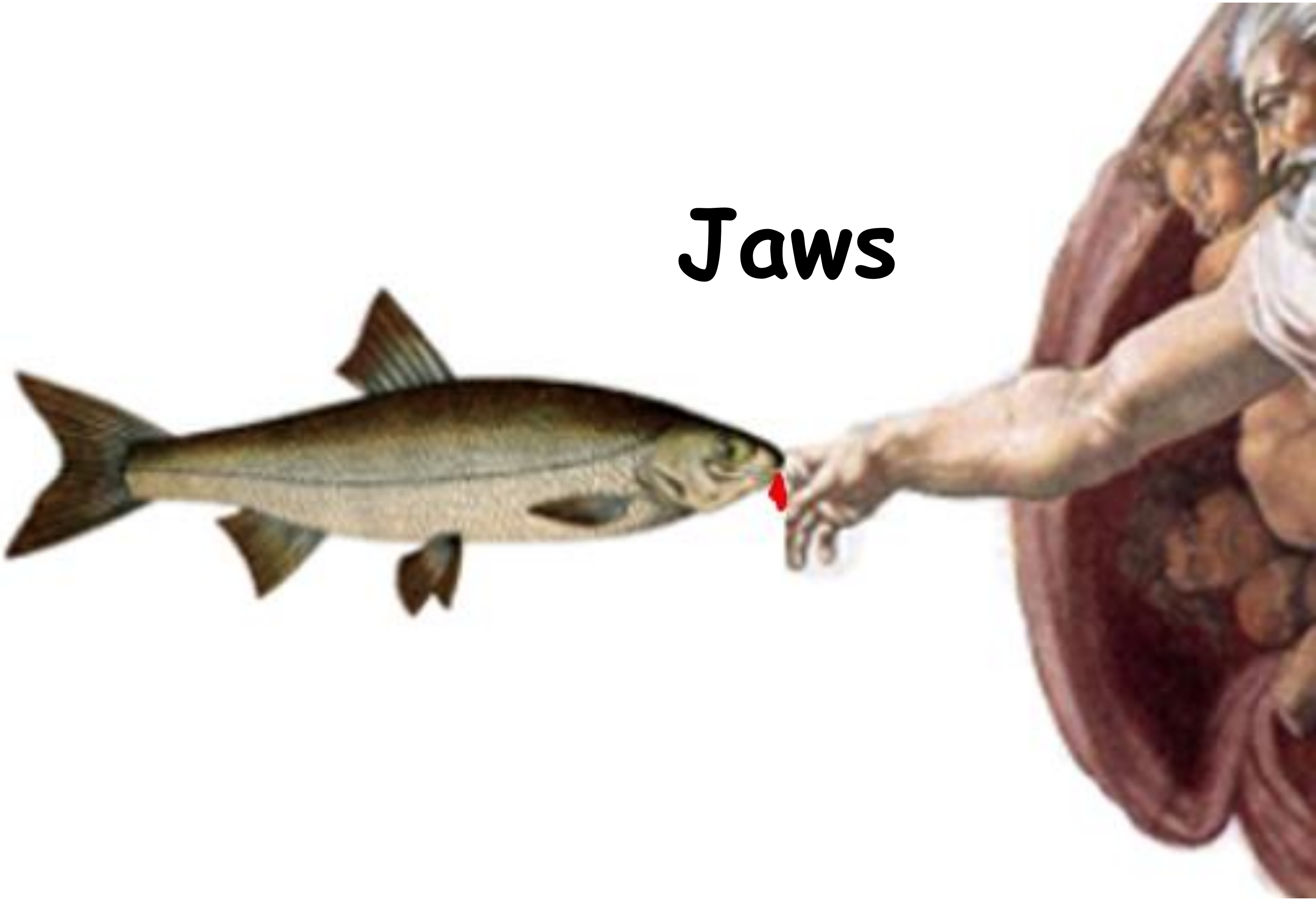


**A fully 'boned' skeleton was a game changer. There are about 1,400 species of non-bone vertebrates today compared with over 60,000 species of bone-based vertebrates.**



*Guiyu*, the earliest known bony fish, lived during the Late Silurian, 425 million years ago. It has a combination of both ray-finned and lobe-finned features.

Jaws



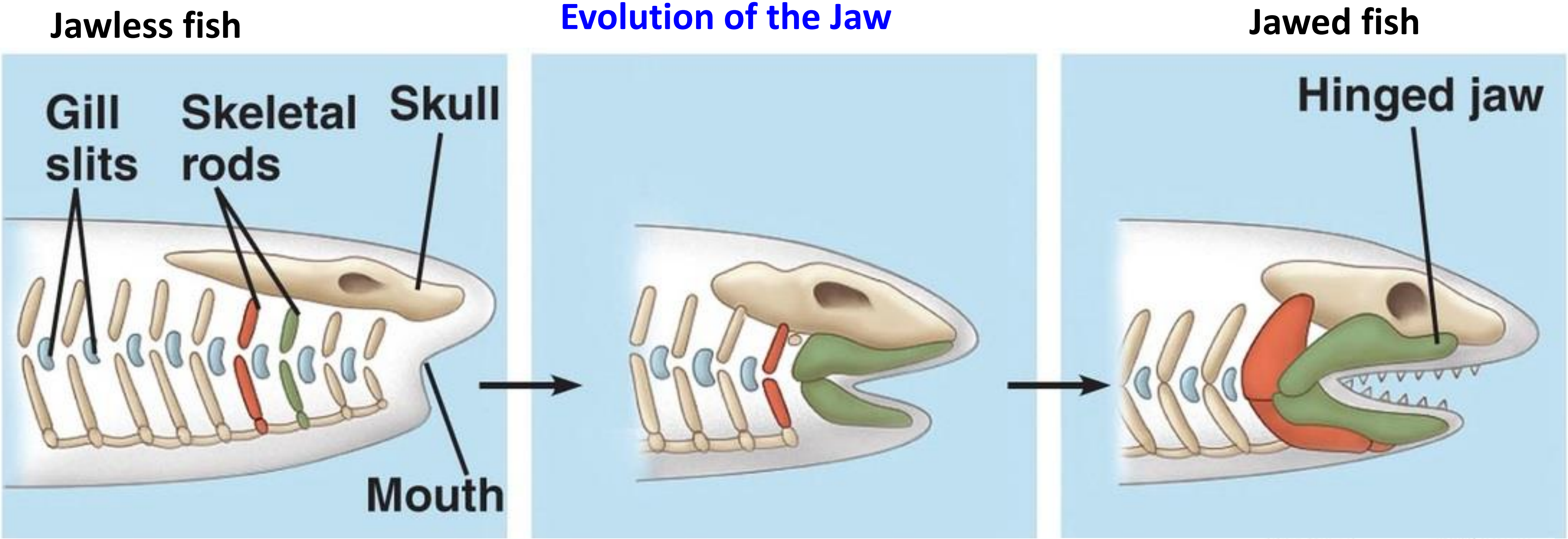
# Jaws

Almost all vertebrates are jawed, first evolving some 425 million years ago and distinguished by teeth.

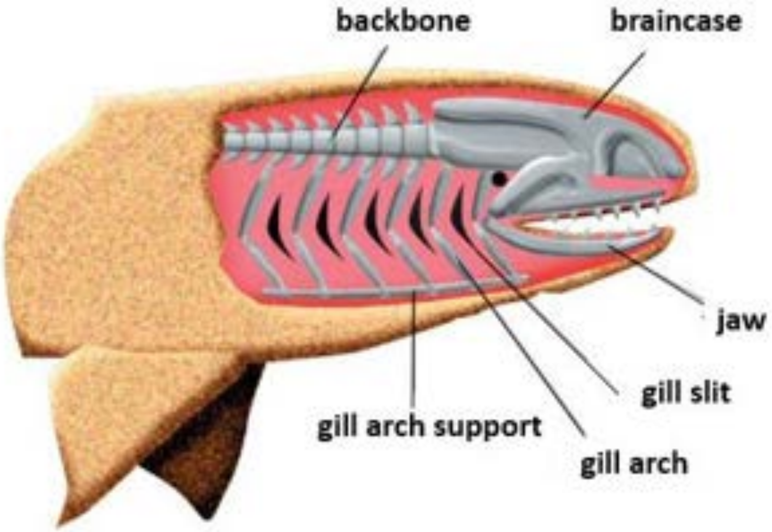
Humans owe their evolutionary success to the evolution of jaws in fish, which allowed animals to process a wider variety of foods.

**Almost all creatures that have jaws, use them in the same way – to grab food and process it.**

# Evolution of the Jaw



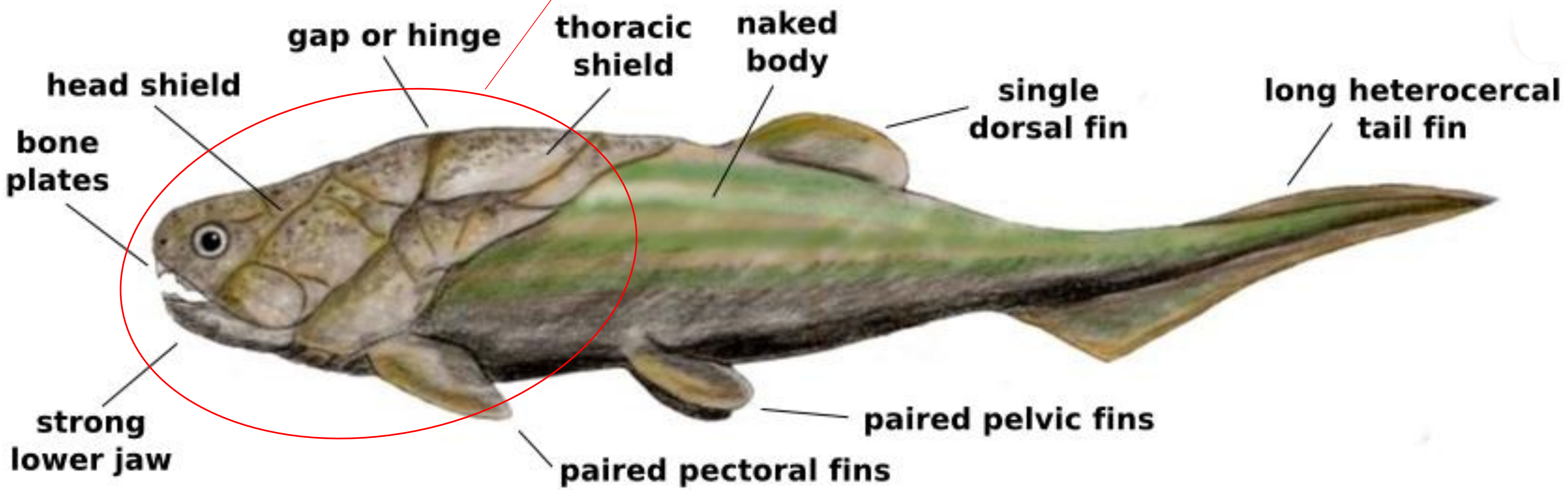

The skeletal rods (gill arch support) are early ribs



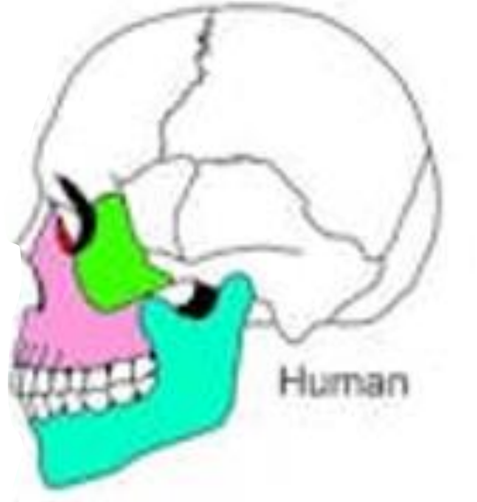

We can think of our jaw bones as modified front ribs of jawless fish

The first jawed fish (and ancestor to all others) were the placoderms.

Note the continuity of the head shield of the precursor jawless fish. Protection against the fearsome predators of that time.

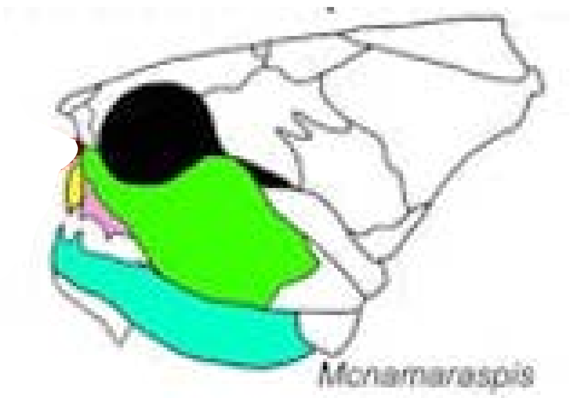



They possessed two sets of paired fins, which increased their ability to manoeuver accurately.



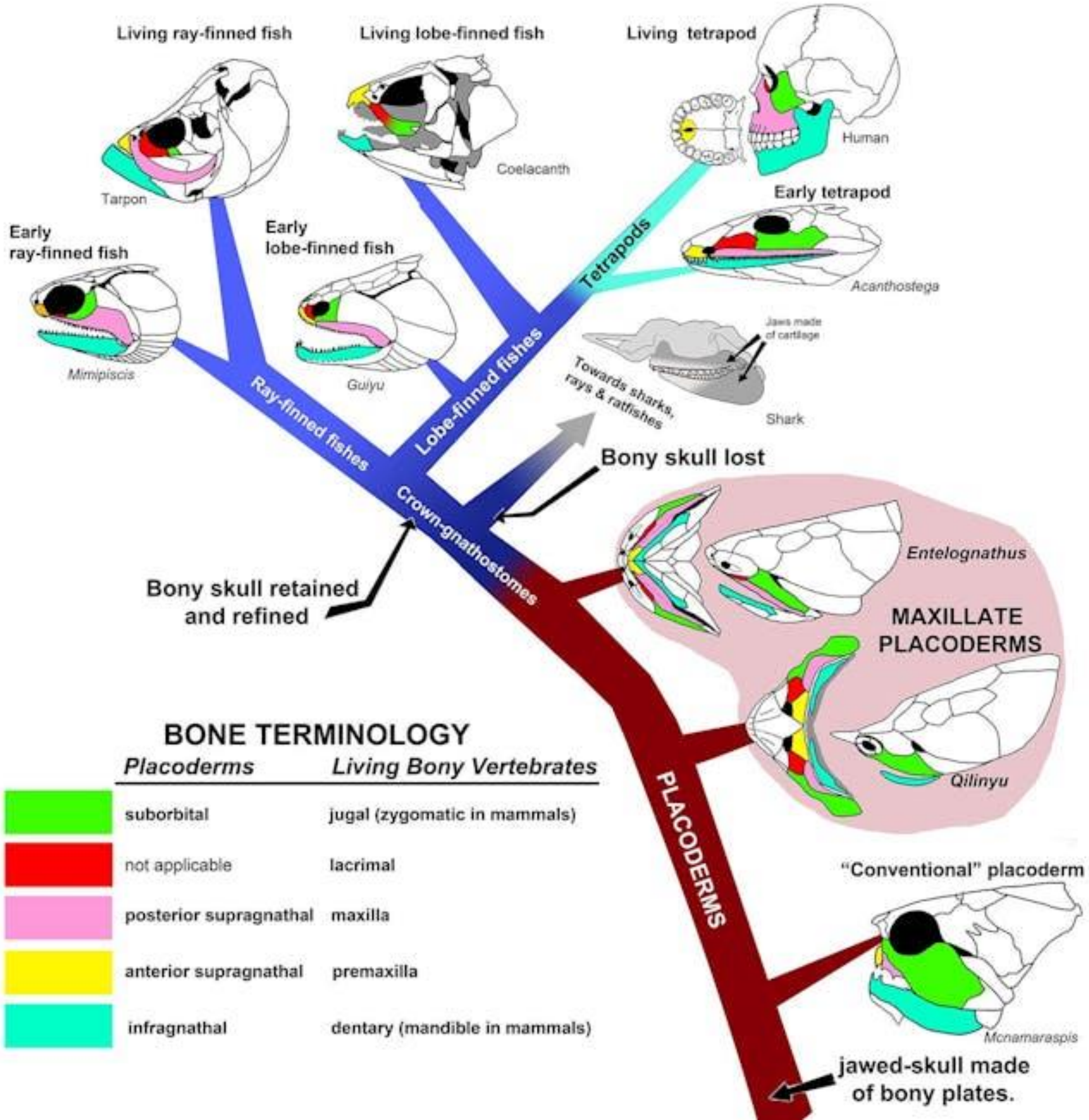

Showing off his *jawless-fish* modified front ribs.

**Same bones, modified**



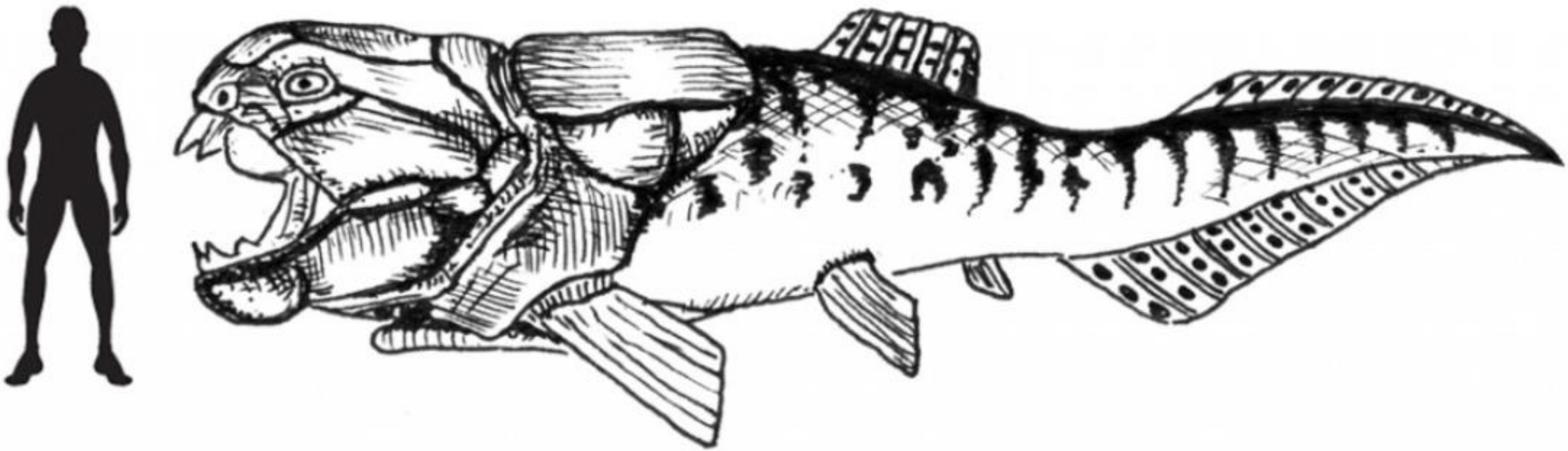

# Jaws in defence as well as attack

## The role of the same facial bones can be traced through evolution.




Placoderms

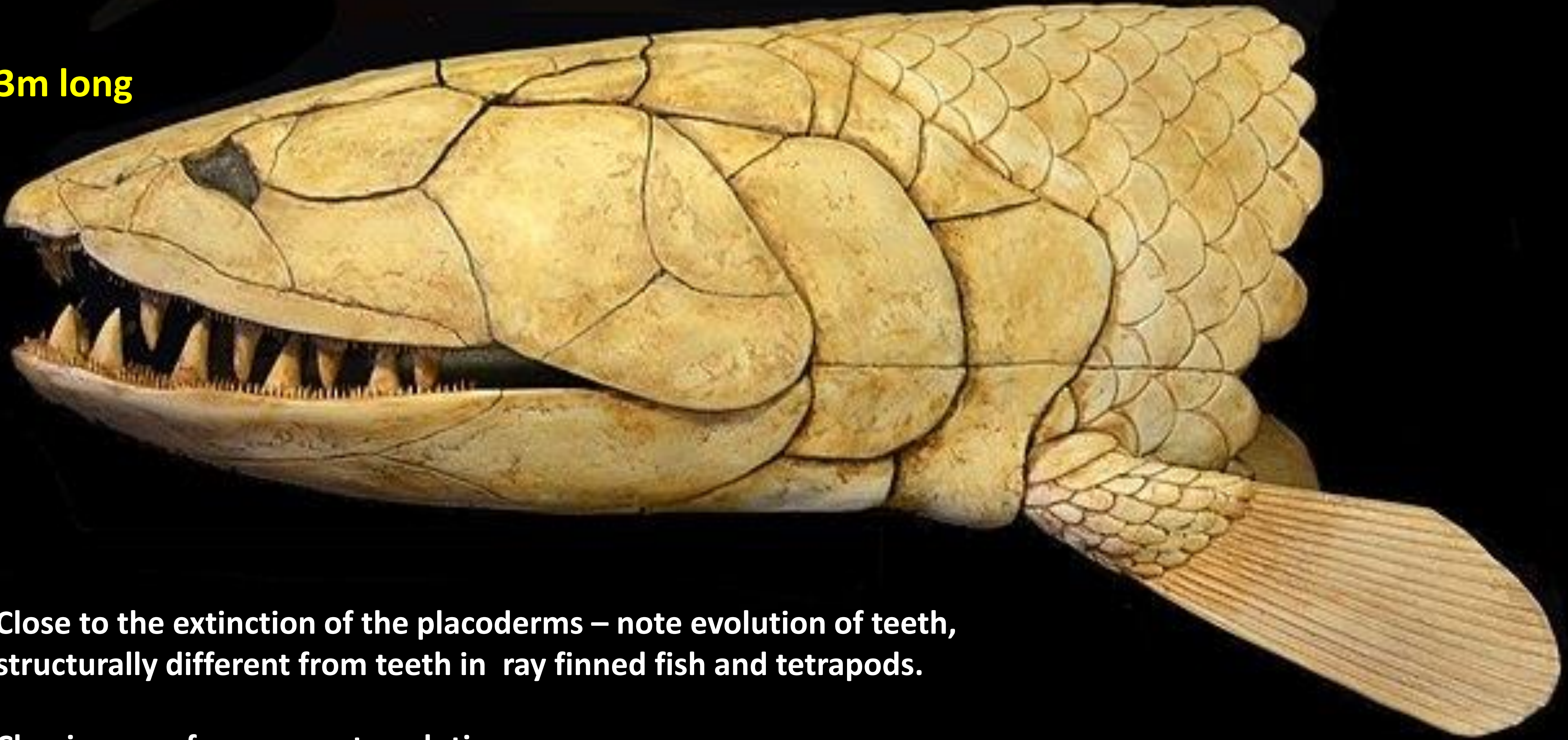
Placoderms became a serious presence in Devonian seas, including dominating as apex predators.



The ‘teeth’ were bony plates modified for slicing and chopping.

## Including late Devonian *Edenopteron*, discovered near Eden in 2008

**3m long**



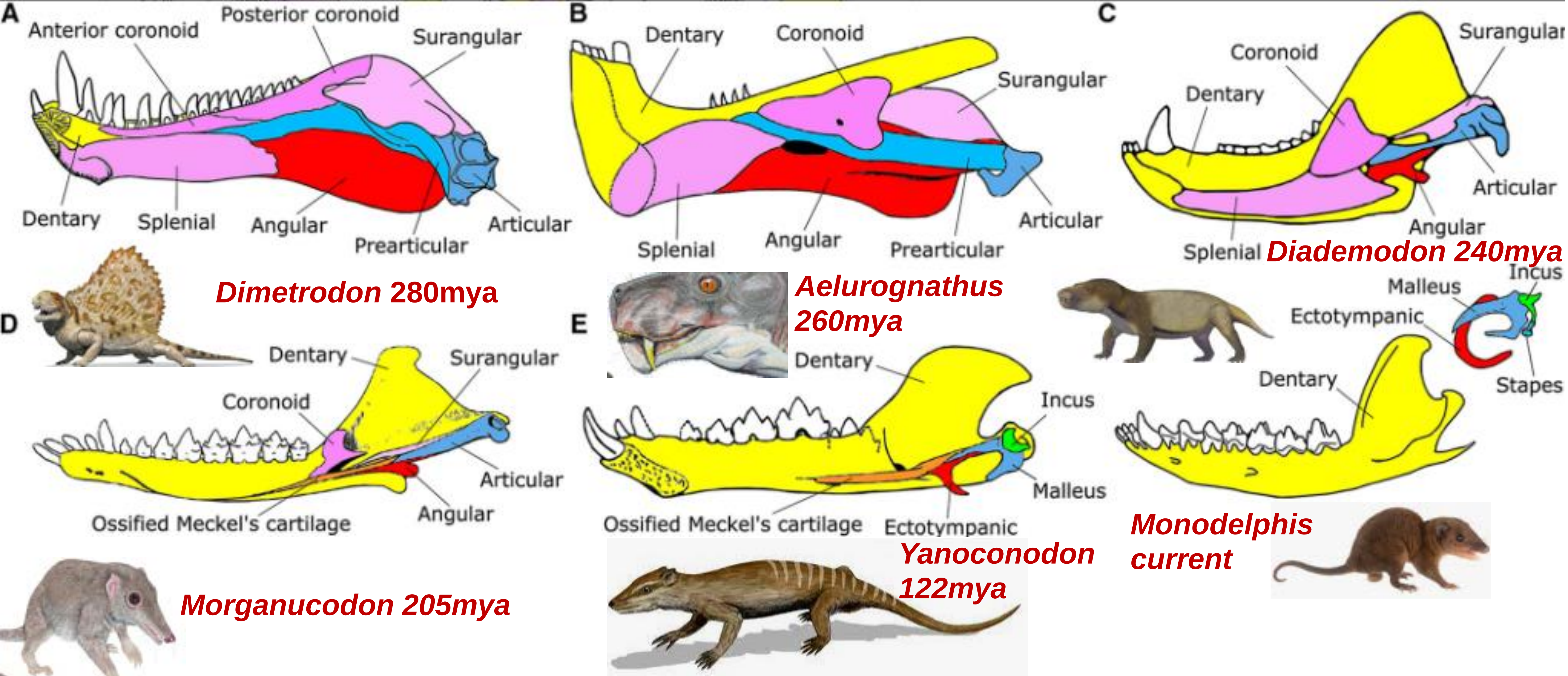
**Close to the extinction of the placoderms – note evolution of teeth, structurally different from teeth in ray finned fish and tetrapods.**

**Classic case of convergent evolution.**

# Hearing -

## From a jaw bone to an ear

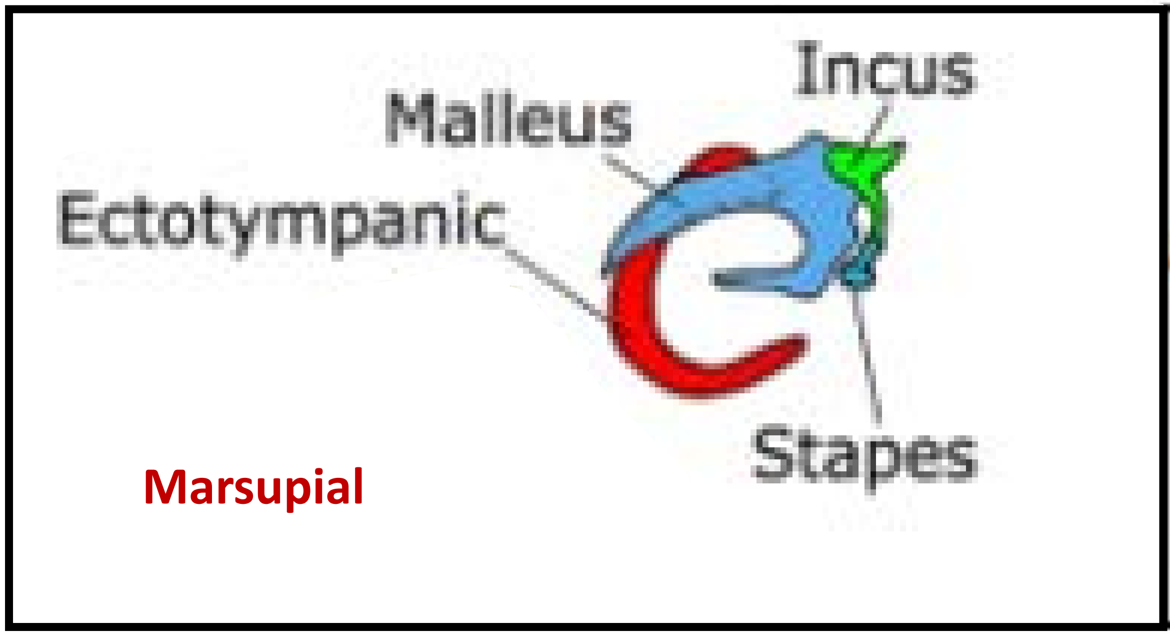
**Being able to hear became a crucial matter of survival.**

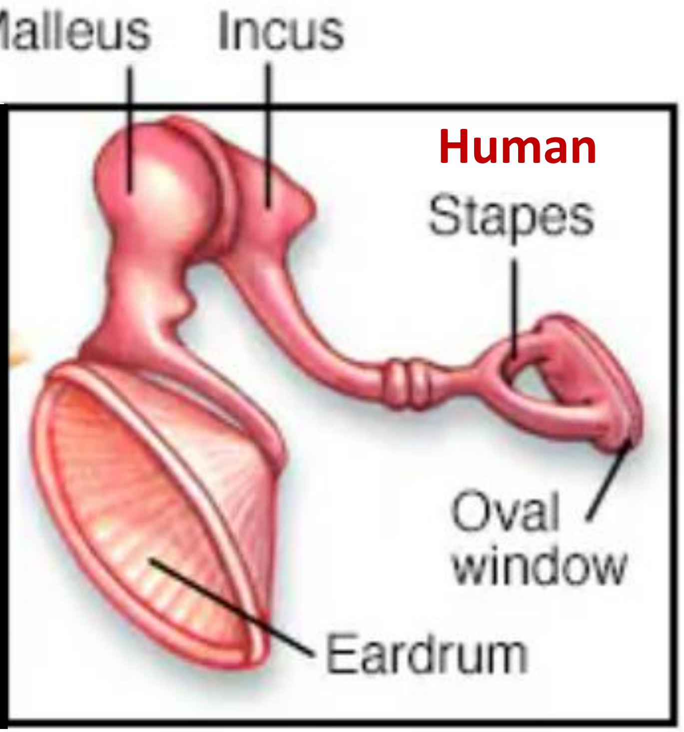



**The ear - from a migrating fish jaw bone**

Primitive synapsid *Dimetrodon* (B) gorgonopsian therapsid *Aelurognathus*. (C) cynognathian cynodont *Diademodon*. (D) mammaliaform *Morganucodon*. (E) eutriconodont mammal *Yanoconodon* .(F) marsupial *Monodelphis*

**Interesting to see the similarity between a marsupial and a human.**




**Mammals and marsupials diverged 160 million years ago**

# Heart

Bichir

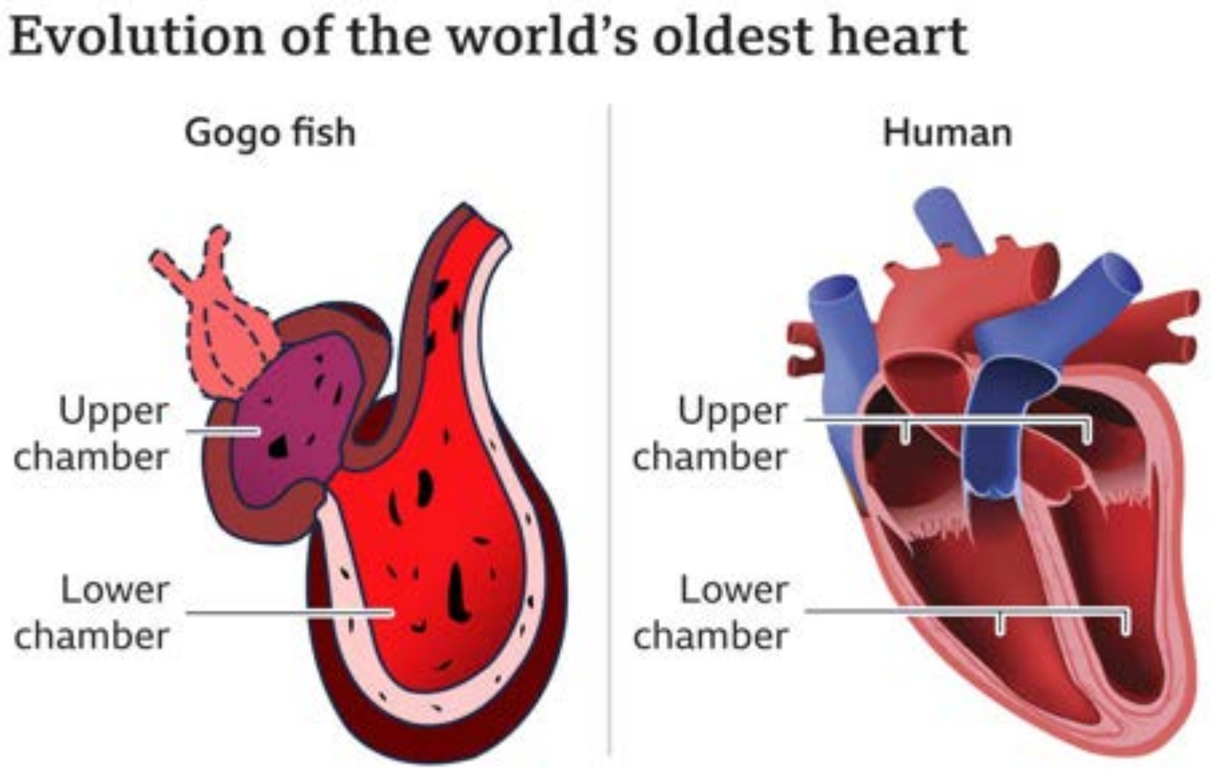
Birchir belong to an archaic sister group with ray-finned fishes. They likely diverged at least 330 million years ago (Mid Devonian). They retain the primitive ancestral lungs lost by ray finned fishes.

Primitive fish and humans share a common and critical function in the cardio-respiratory system: The *conus arteriosus*, a structure in the right ventricle of our heart which might allow the heart to efficiently deliver the oxygen to the whole body, and which is also found in the bichir.

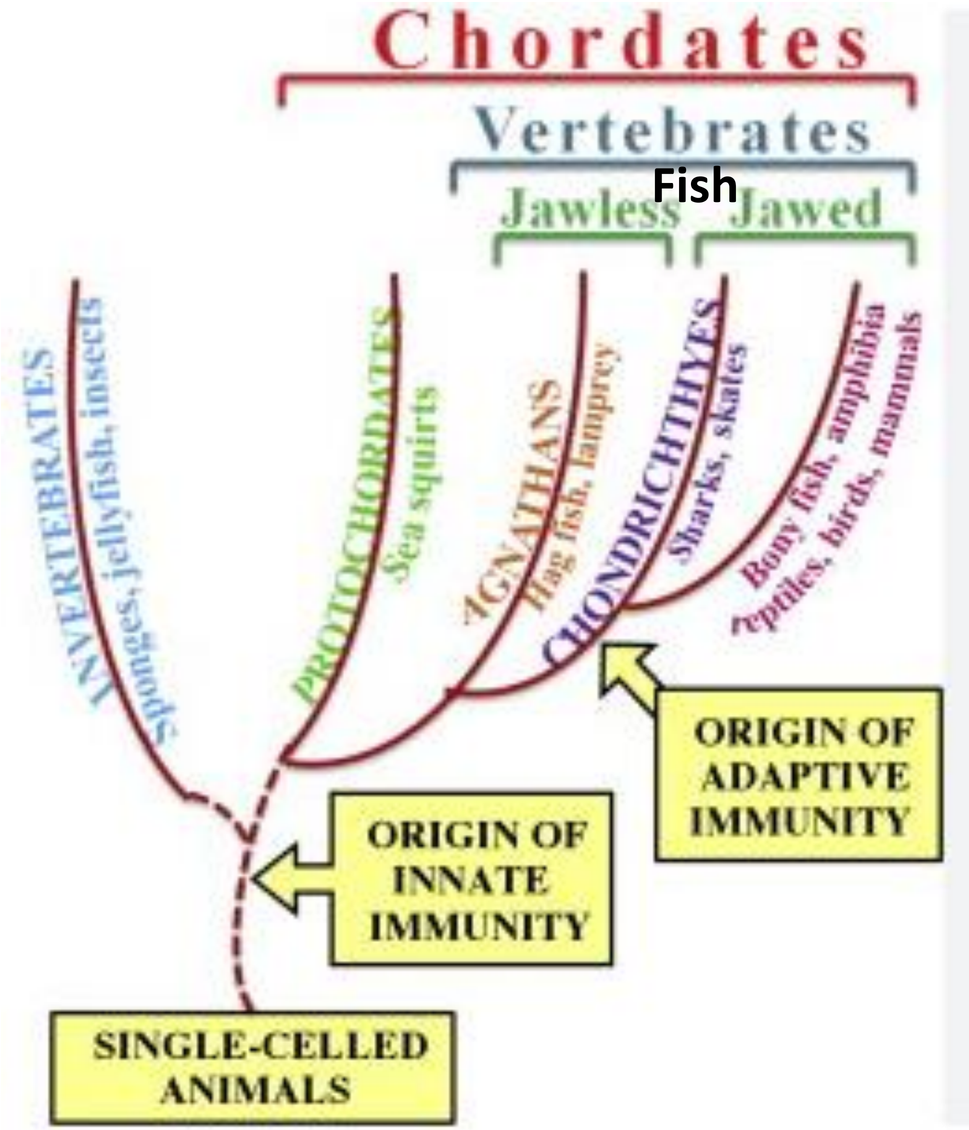
However, the vast majority of bony fish have lost this structure. Researchers discovered a genetic element that appears to control the development of the *conus arteriosus*.

Experiments with mice showed that when researchers removed this genetic element, the mutated mice died due to thinner, smaller right ventricles, which lead to congenital heart defects and compromised heart function.

# A 380 million year old placoderm from the Gogo fossil site in The Kimberley, WA



# Immune System




**Bacteria and viruses have been at war with each other since life first arose some 4.1 billion years ago. A war that would have included the emergence of eukaryotes (cells with a nucleus) 2.7 billion years ago.**

**The evolution of an immune system would have been essential for survival from the outset of life on earth. Single celled life needed to defend against infective invasion (innate immunity).**

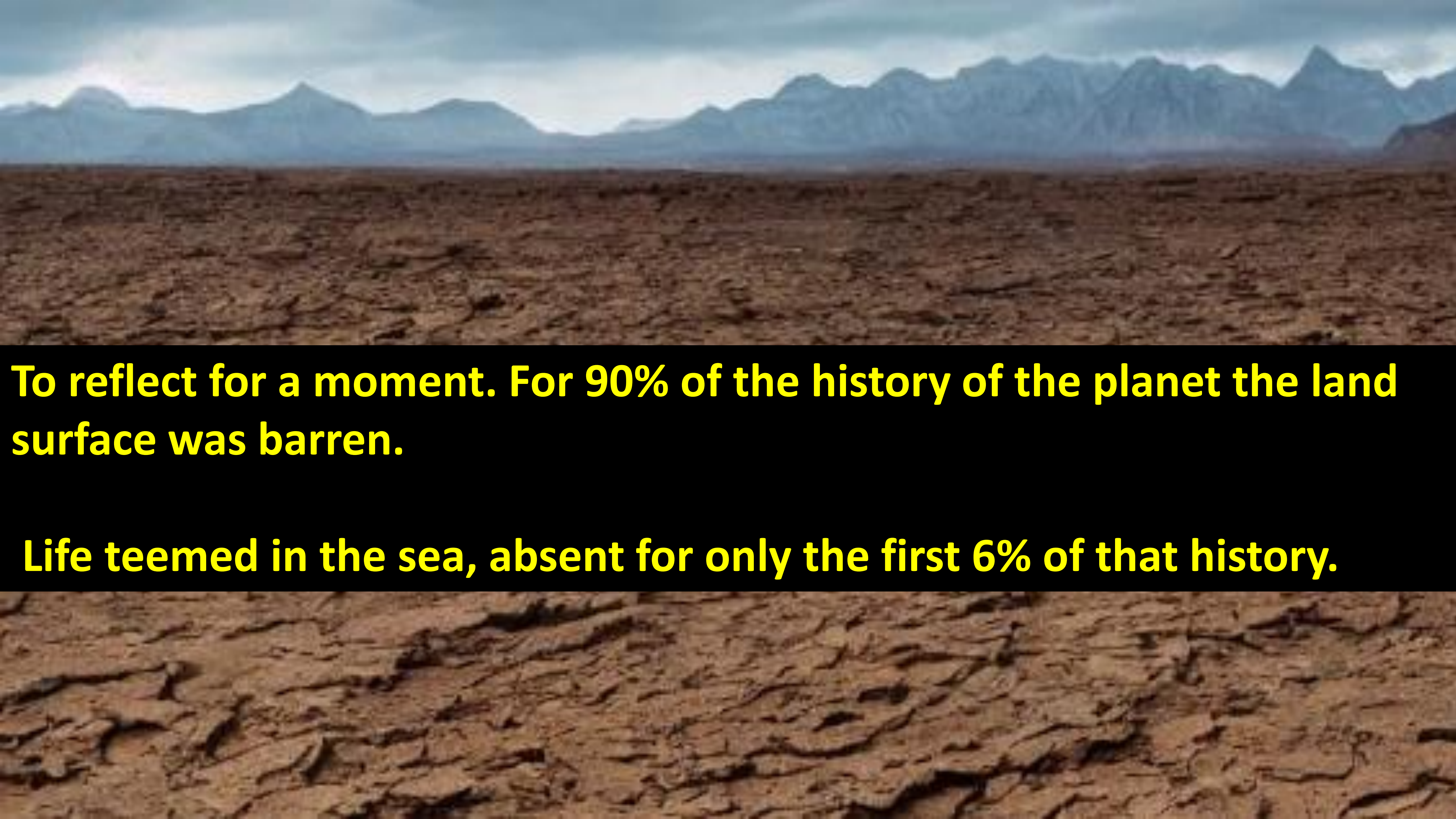
**The emergence of multicellular life in the '*boring billion*' just meant the battlefield diversified. New predatory organisms, within the Protista and Fungi, added to the deadly infection soup.**

**The addition of 'adaptive immunity' to the defence arsenal meant the immune system can remember previous infections and call up tailored killer cells to destroy the invasion. The basis for our vaccines.**

**Our *adaptive immunity* first arose in the early jawed fishes before the separation of cartilage and bony fishes. This was in the Late Silurian, 425 million years ago.**

# Greening of the land

**Plants first appeared on land about 460 million years ago, in the middle of a 45-million-year-long geologic period known as the Ordovician.**

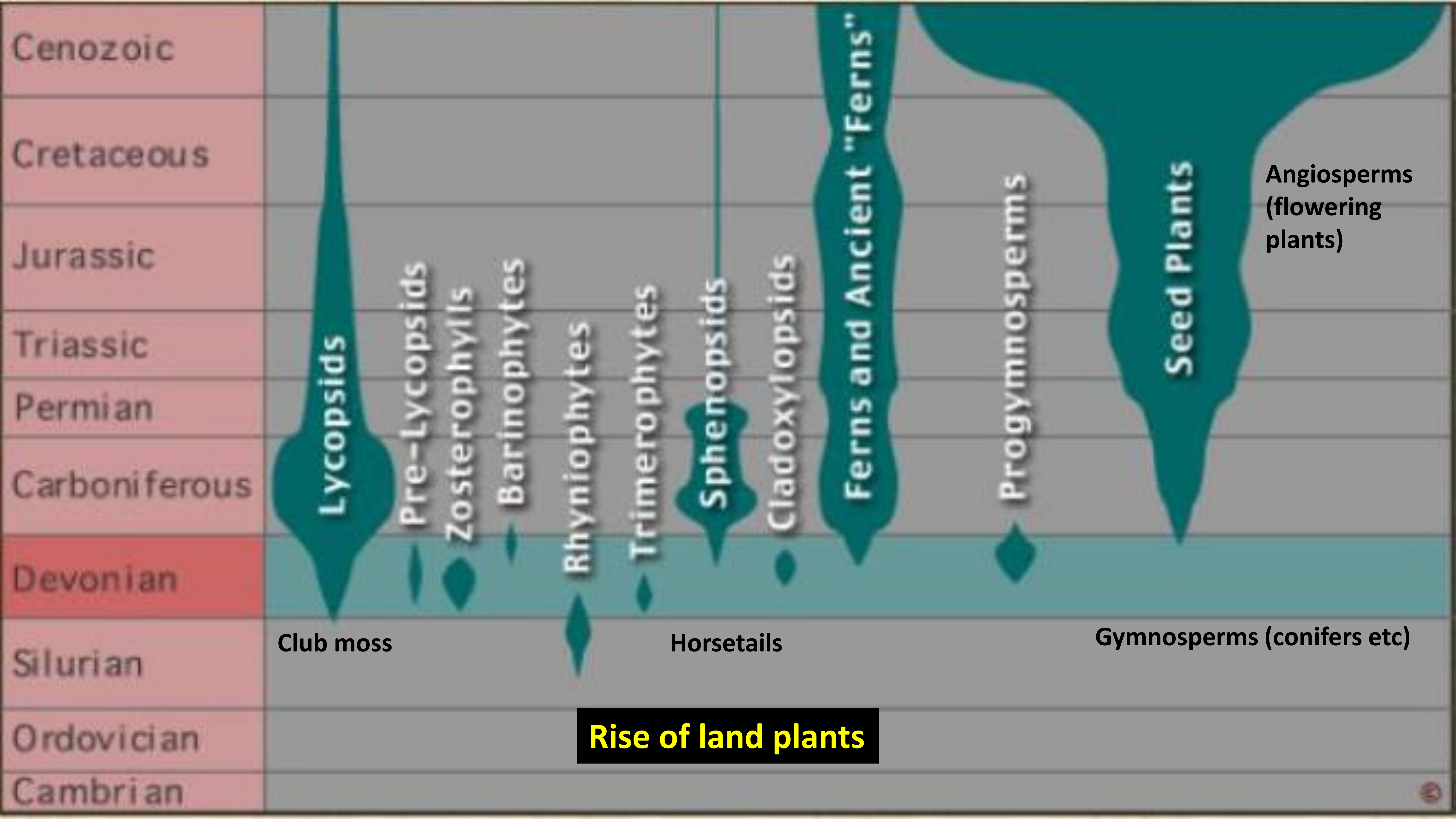

To reflect for a moment. For 90% of the history of the planet the land surface was barren.
Life teemed in the sea, absent for only the first 6% of that history.


The land surface was like Mars today.

*Cooksonia* is one of the earliest land plants to have evolved – late Silurian.

The real change came when plants began rooting themselves into the earth. In pushing their roots down into sediments.  Plants caused increased rock  weathering including release of minerals.

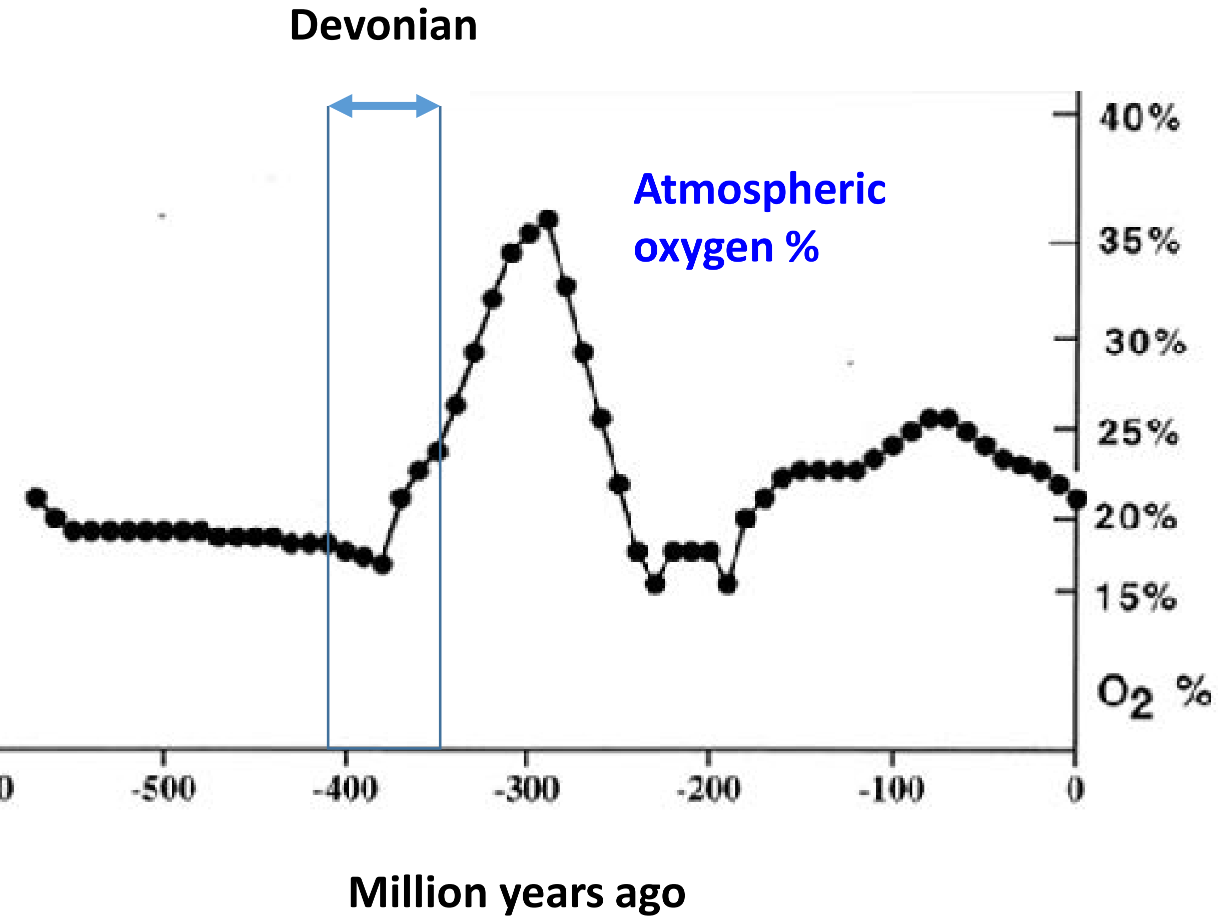
Roots not only increase the connectivity between subsurface geology and the atmosphere, they also secrete substances like organic acids and form symbiotic relationships with cyanobacteria and fungi that accelerated the weathering process.



Cenozoic
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
Lycopsids
Pre-Lycopsids
Zosterophylls
Barinophytes
Rhyniophytes
Trimerophytes
Sphenopsids
Cladoxylopsids
Ferns and Ancient "Ferns"
Progymnosperms
Seed Plants
Angiosperms (flowering plants)
Club moss
Horsetails
Gymnosperms (conifers etc)
Rise of land plants


Prototaxites - a fungus
Late Silurian 430 Myo

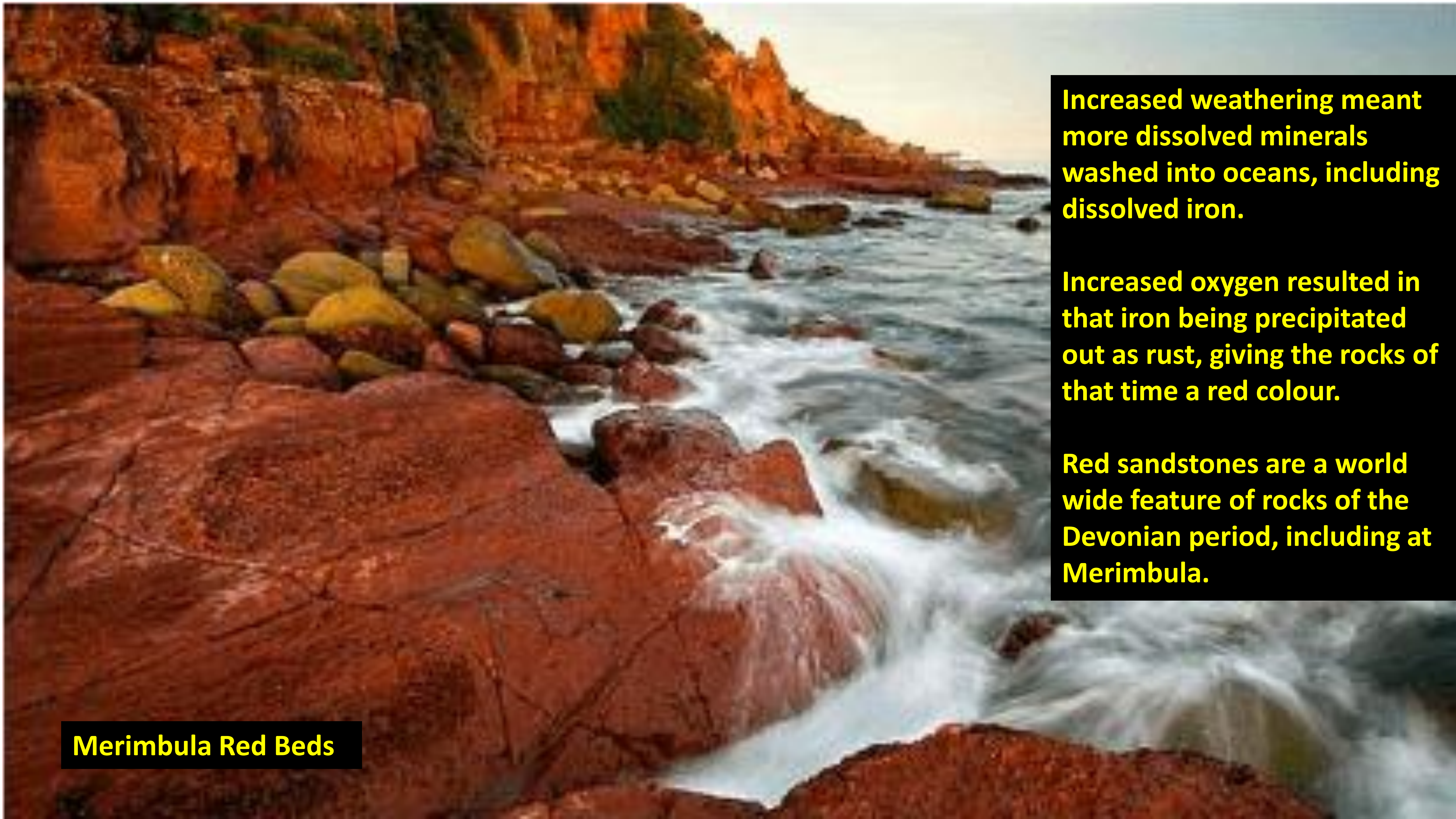
# Atmospheric oxygen




There was a major rise in Devonian atmospheric oxygen levels caused by plant expansion and a resultant increase in organic carbon burial.

The timing of this oxygenation rise is consistent with late Silurian through Early Devonian plant diversification and, in particular, the shift from smaller to larger plants along with their spread into a wider array of environments. This triggered increased photosynthesis, organic carbon burial, and atmospheric oxygen build up.

This oxygen increase then tipped the oceans into a more oxygenated state characteristic of the post-Middle Devonian to today.



Merimbula Red Beds

Increased weathering meant more dissolved minerals washed into oceans, including dissolved iron.

Increased oxygen resulted in that iron being precipitated out as rust, giving the rocks of that time a red colour.

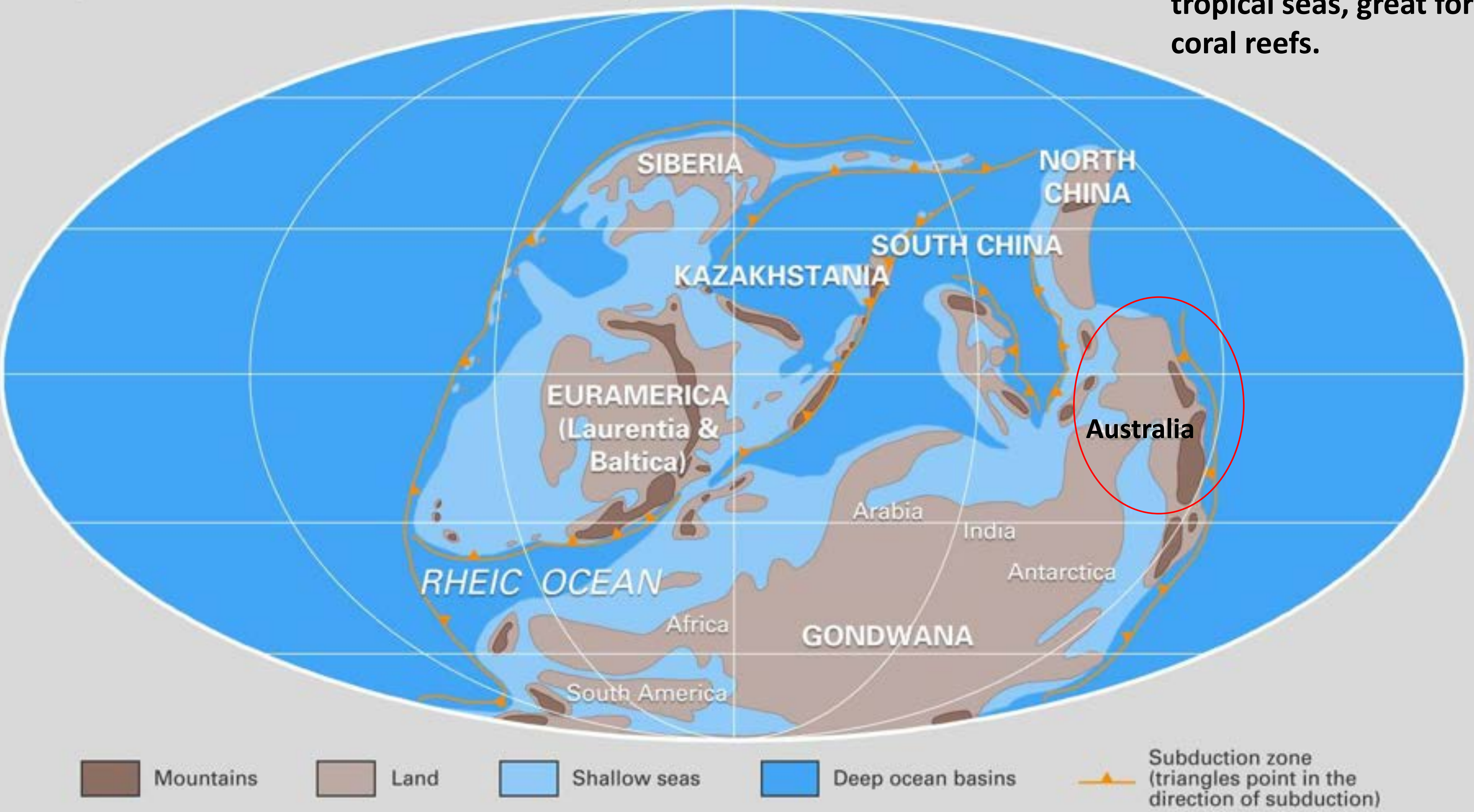
Red sandstones are a world wide feature of rocks of the Devonian period, including at Merimbula.


‘Redwall’ – Devonian, Grand Canyon


Devonian red beds – Penbrokeshire, Wales

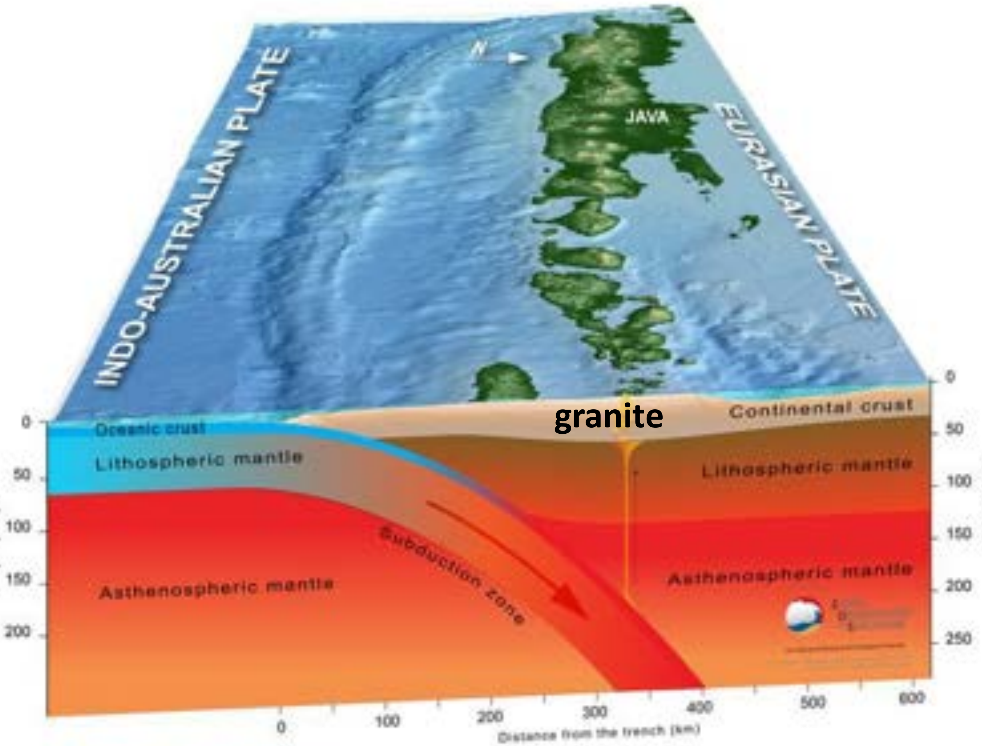
# Early Devonian 390 million years ago

**Note extent of shallow tropical seas, great for coral reefs.**




The east coast of Australia then was like Indonesia today, shallow tropical seas with copious reefs. An off-shore subduction zone and a chain of island arc volcanoes.

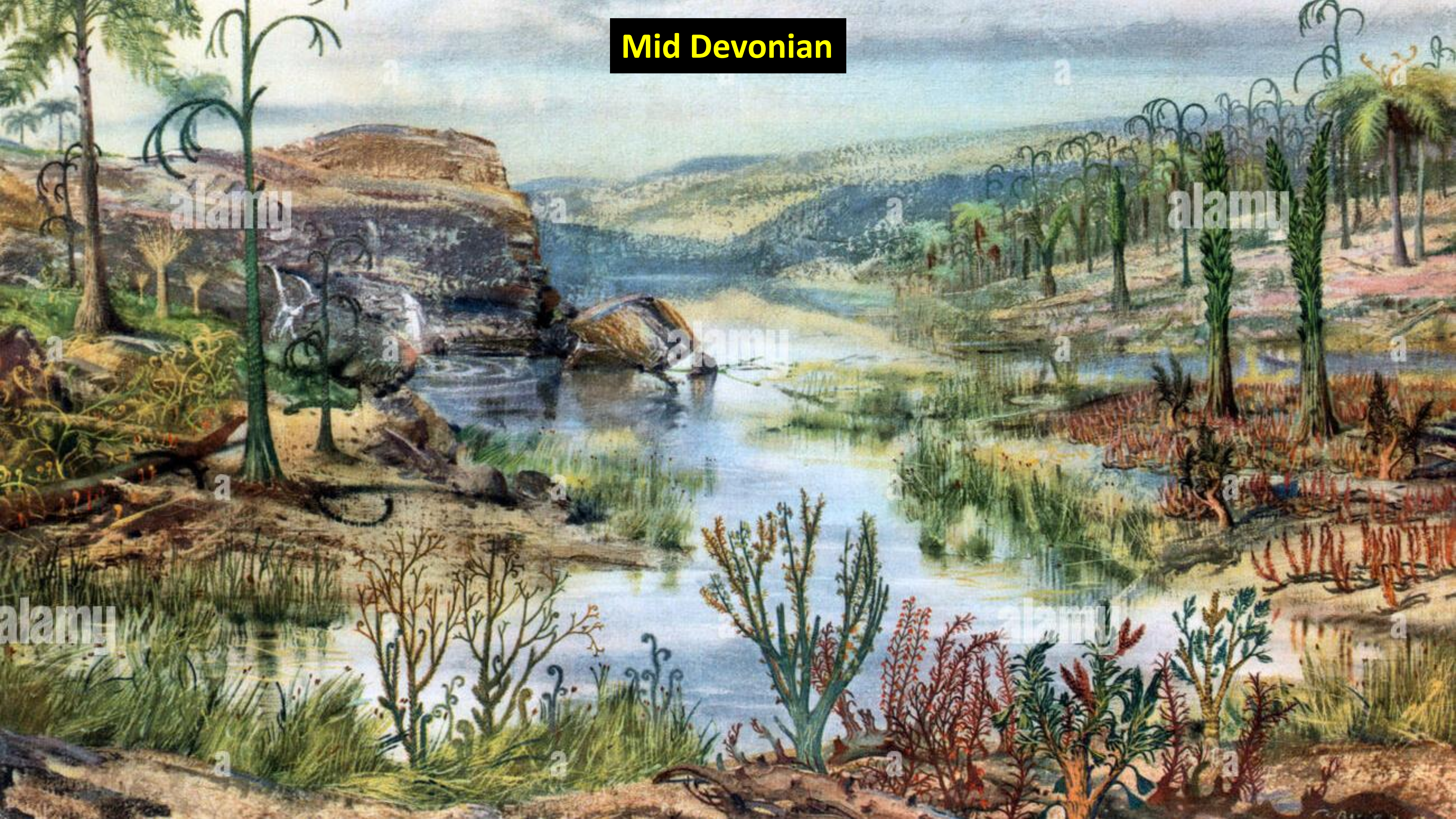
These are granite factories (hence the Bega-Kosciuszko Granites).



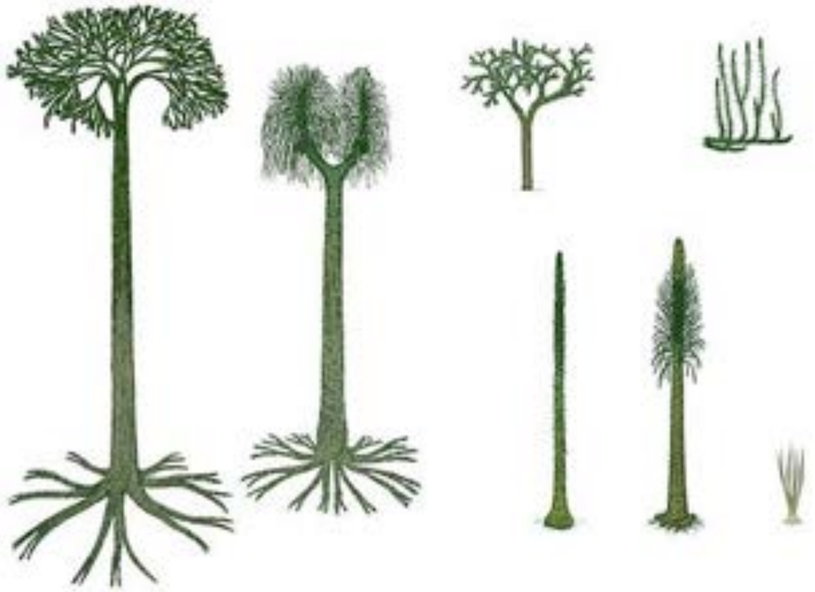

In the new vegetation driven ecosystems  animals, mainly arthropods, became established. Providing tasty morsels for any that strayed near the edge of water.

# Early Devonian

# Mid Devonian




Late Devonian 380 Myo
Club moss (Lycophytes), horsetails and ferns grew to large sizes and formed the first forests.

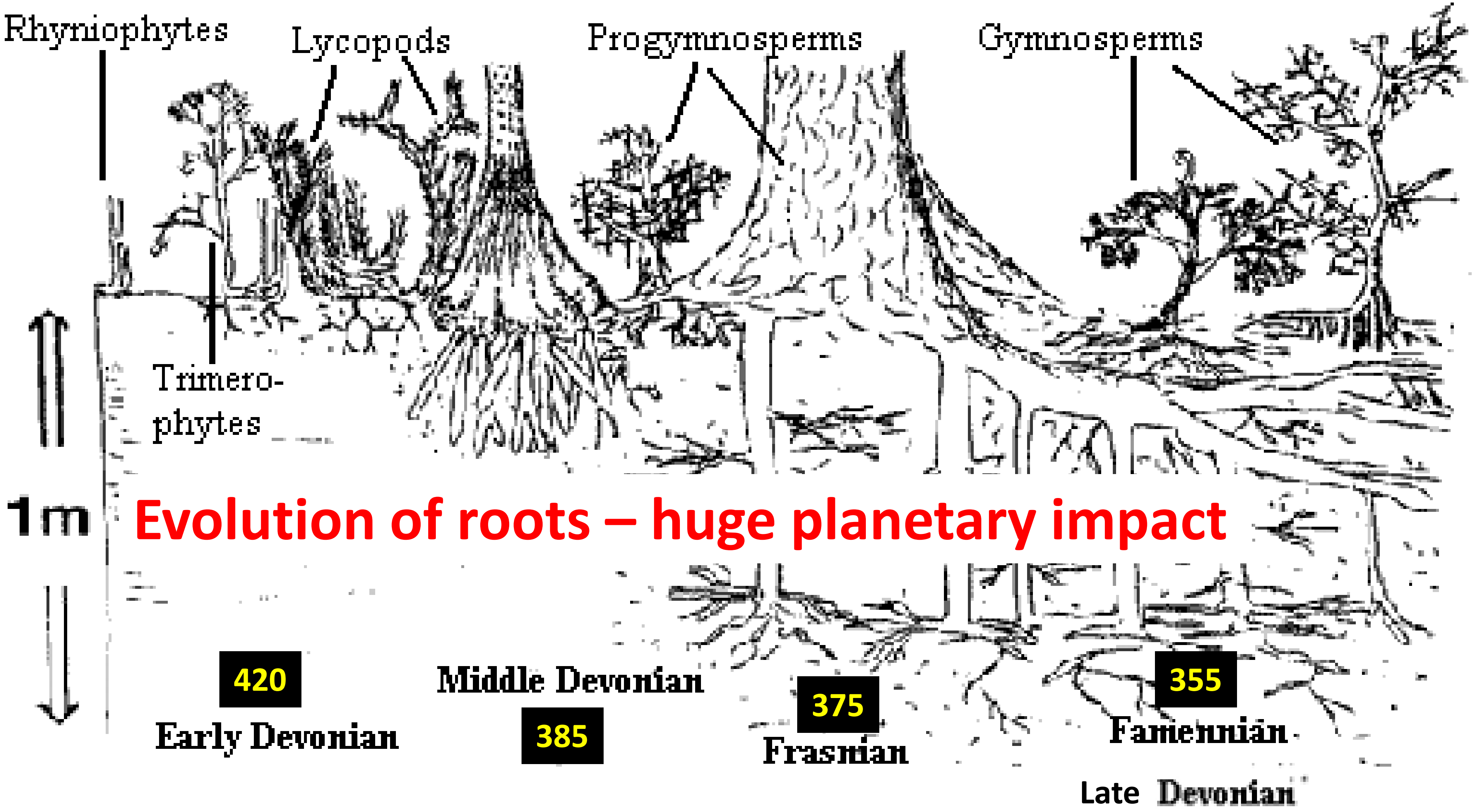


Club moss
(Lycophytes)

Devonian plant fossils can be found in the Bunga Head area

The red sandstone wall in the car park behind the Merimbula Wharf restaurant has plentiful Devonian fossil roots.

# Evolution of roots – huge planetary impact




The evolution of roots led to deep soils, breakdown of rock and mobilisation of nutrients that flowed into the ocean, stimulating bacterial and algal photosynthesis.

# Lungs

In addition to altering land and water habitats in ways that encouraged limb development in fish, the rise of more advanced plants also changed the oxygen balance.

The oxygen scenario, combined with the newfound ability to stick their heads out of the water encouraged the evolution of lungs in fish.

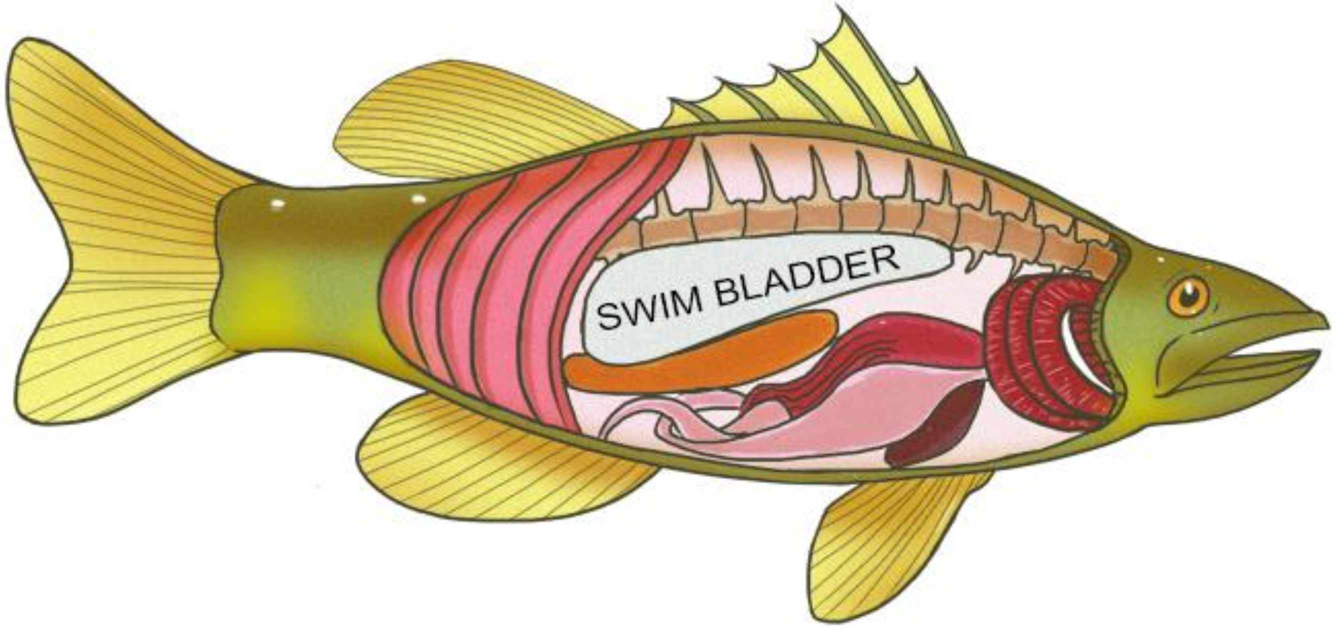
Streams full of toothy carnivorous fish — some with joints in their skulls to increase the size of their bites — inspired tetrapods to take their head-propping, muck-stomping skills to the smorgasbord on higher ground.

The water in the rotting vegetation choked wetlands was oxygen depleted.

Survival would favour a fish that could gulp oxygen from the air above the waterline.

Early bony fish ancestors had primitive functional lungs. Through evolution, one branch of fish preserved the lung functions that are more adapted to air breathing and ultimately led to the evolution of tetrapods.

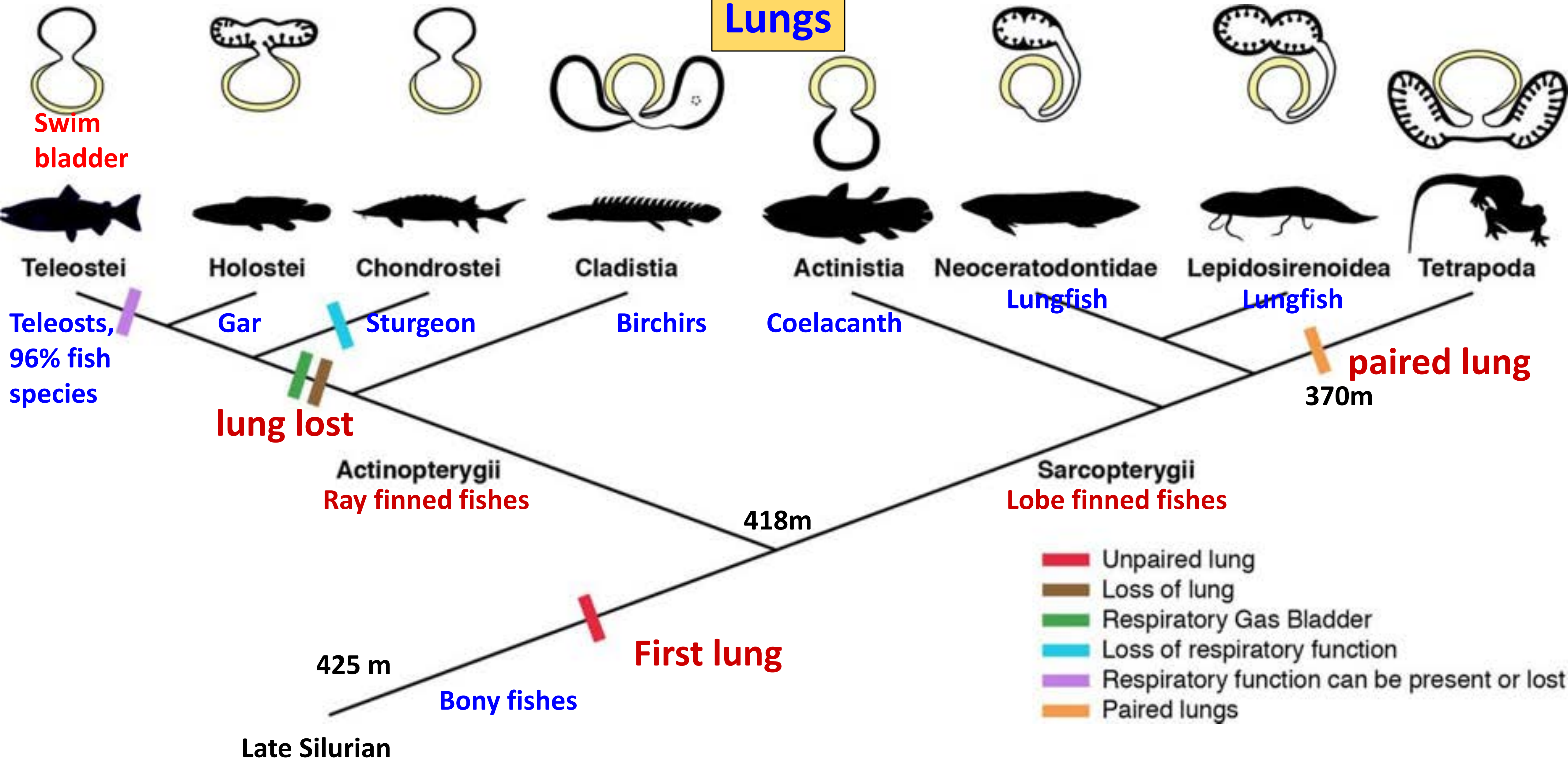
With the newly oxygenated seas air gulping was no so critical.

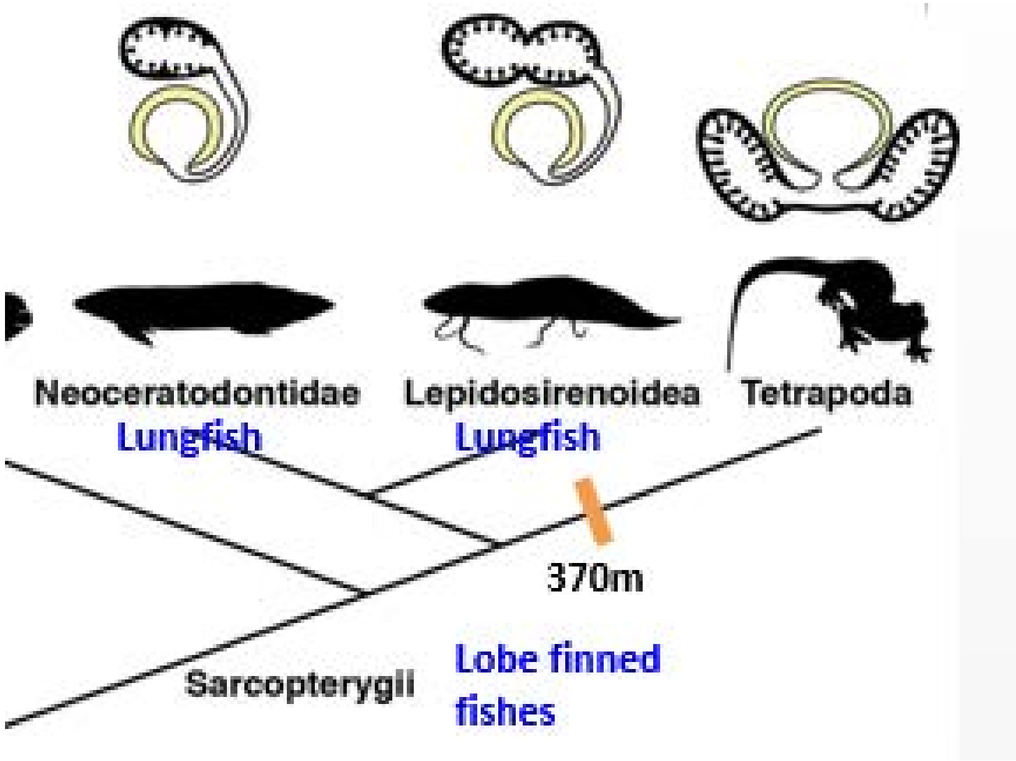



The other branch of fishes modified the lung structure and evolved with swim bladders, leading the evolution of ray-fin fishes (teleosts). The swim bladders allow these fishes to maintain buoyancy and perceive pressure, thus better survive under water.

# Lung fish

# Lungs

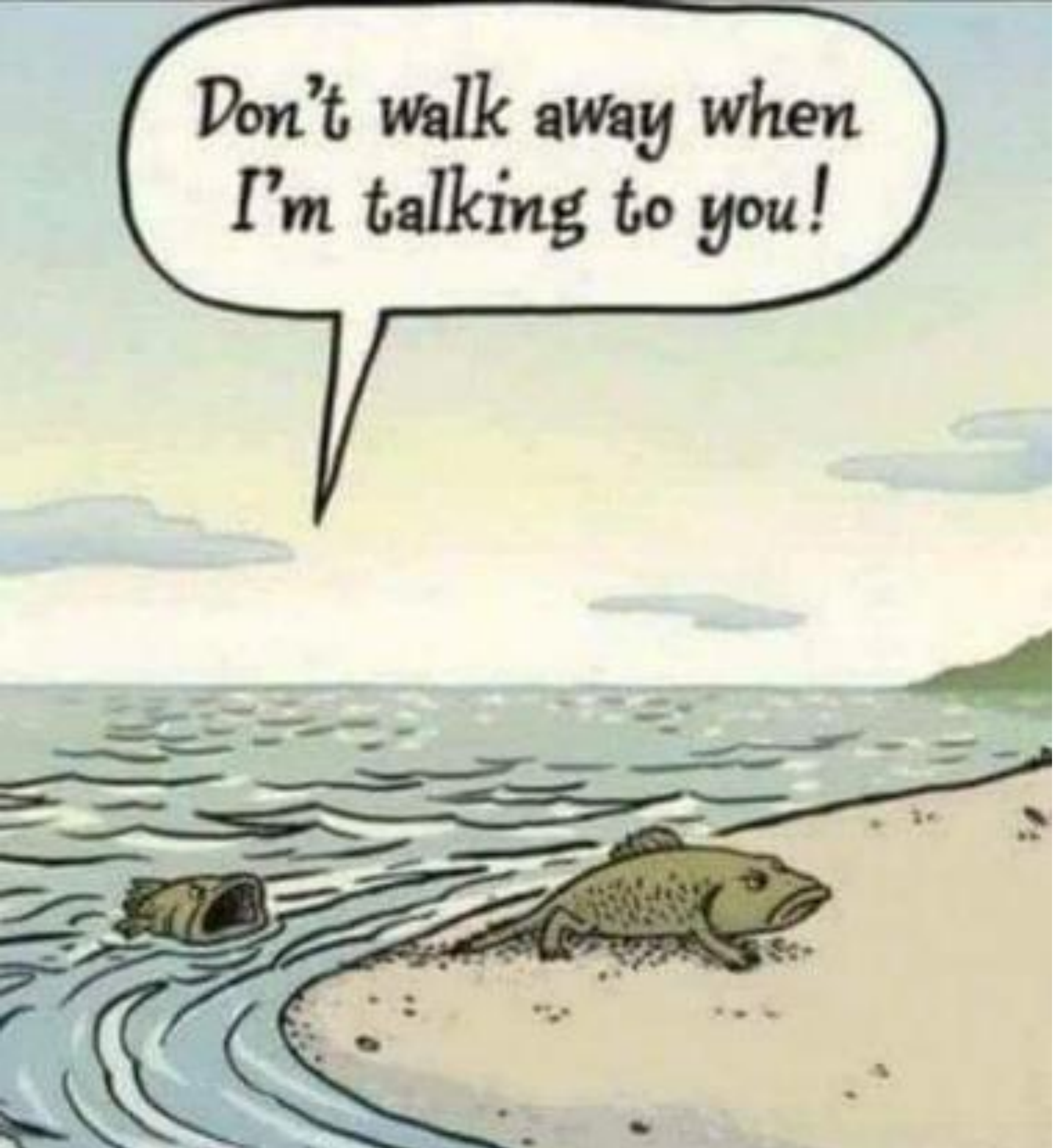

Swim bladder
Teleostei
Holostei
Chondrostei
Cladistia
Actinistia
Neoceratodontidae
Lepidosirenoidea
Tetrapoda
Teleosts, 96% fish species
Gar
Sturgeon
Birchirs
Coelacanth
Lungfish
Lungfish
paired lung
370m
lung lost
Actinopterygii
Ray finned fishes
Sarcopterygii
Lobe finned fishes
418m
First lung
425 m
Bony fishes
Late Silurian
Unpaired lung
Loss of lung
Respiratory Gas Bladder
Loss of respiratory function
Respiratory function can be present or lost
Paired lungs




The primitive state of vertebrate lungs were **unpaired,** evolving to be truly paired in the lineage towards the tetrapods.

The water-to-land transition confronted profound physiological challenges and **paired lungs** were decisive for increasing the surface area and the pulmonary effectiveness and volume, especially during air-breathing on land.

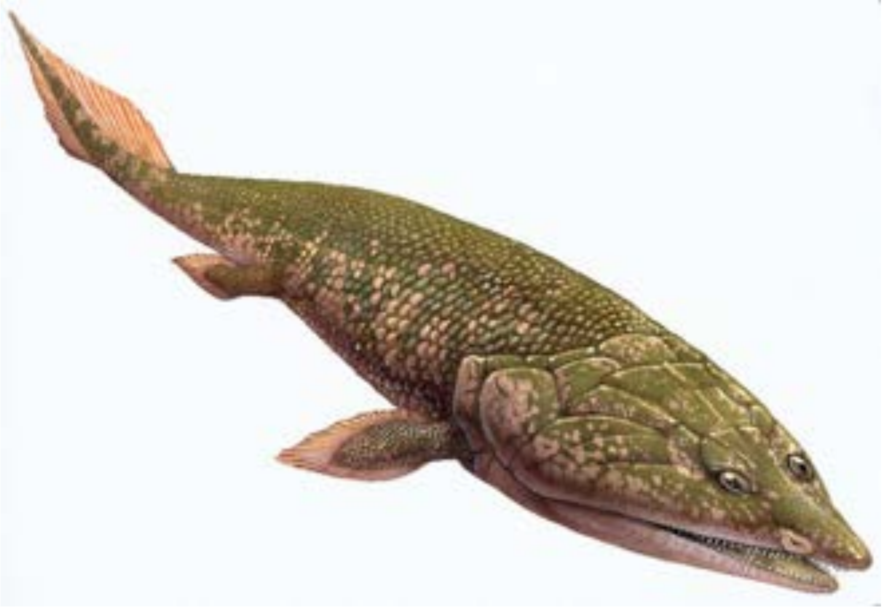
**Exercising her 370 million year old *Lobe Finned Fish* paired lungs.**




**The move onto land.**

# Devonian debris-choked water ways


RavePaleoArt



Panderichthys 380 Mya

Tiktaalik 375 Mya

Plants with stems, roots and leaves colonized shallow rivers and changed the nature of many aquatic environments and nearby shores.

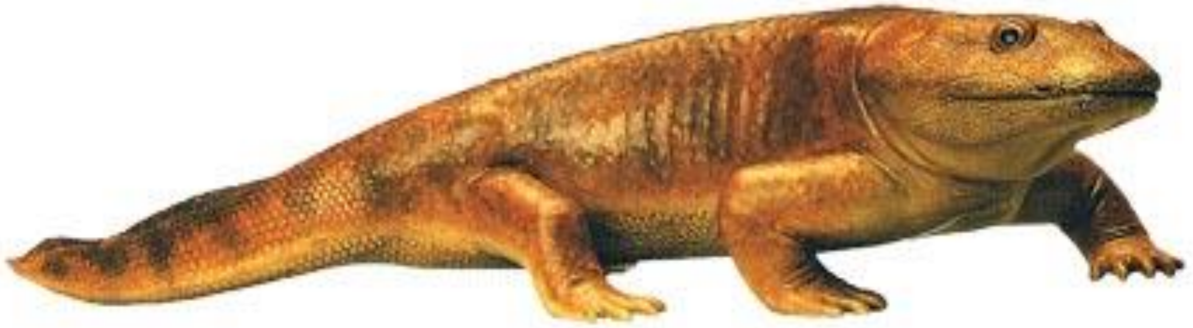
The evolution of limbs from fins, one of the key transitions in the history of life, took place gradually and largely separate from the water-to-land transition.

Plants grew thick in streams and rivers, their roots stabilized ecosystems, and their decomposing biomass generated organic muck. Plant-clogged waterways made weight-bearing fins, and eventually limbs, useful for getting around.

Scientists conclude that many of the limb and muscle developments needed for walking on land developed before fish and limbed-animals split.

# Tiktaalik 375 Mya

Tetrapod shoulders changed the direction they face in order to adapt to life in a plant-tangled, aquatic environment. With shoulders facing sideways, tetrapod's arms projected out from its trunk at a right angle, similar to the limb arrangement of a crocodile.



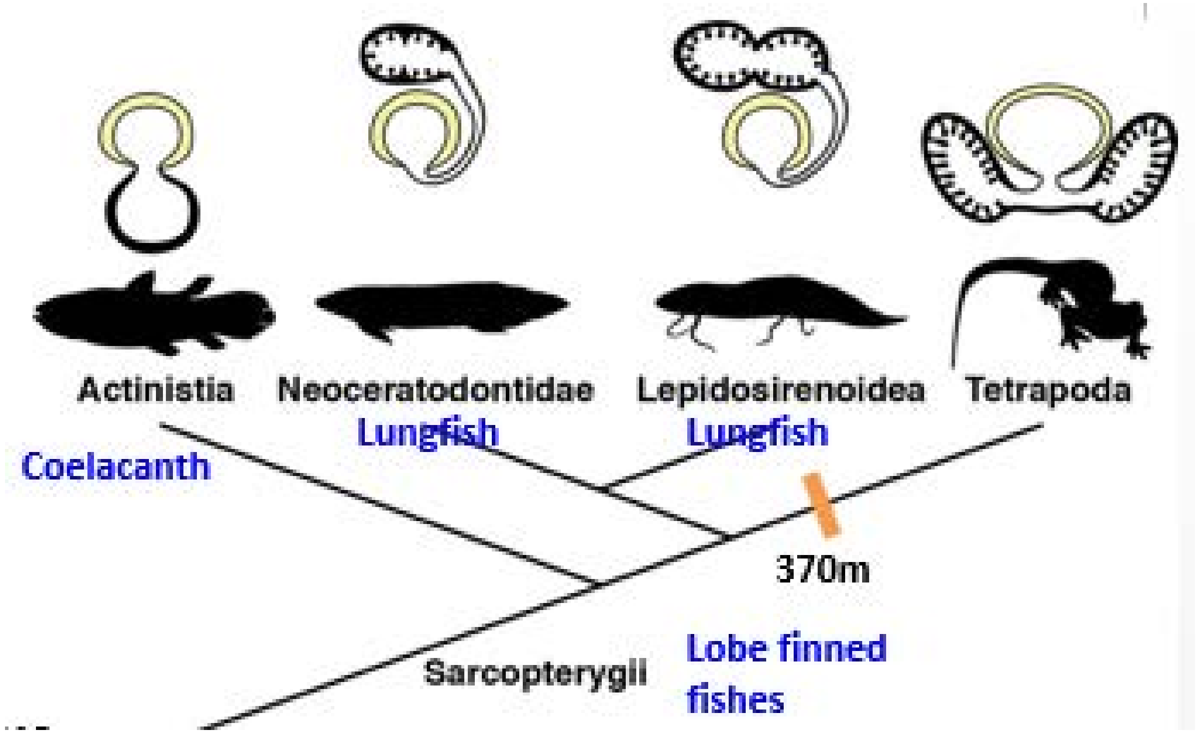
Ichthyostega 365Mya

This shoulder and arm orientation would have made the front limbs more useful as weight-bearing limbs than paddles.

Ichthyostega is regarded as the first amphibian.


Ichthyostega 365Mya

## Summary





Tetrapods evolved from marine environments during times of higher oxygen levels. The change in environmental conditions played a major role in their evolution.

This idea is supported by various environmental factors such as sea levels and oxygen rate, and biotic factors such as biodiversity of arthropods and coral reefs.

The molecular data strongly supports lungfish as the tetrapods closest living relative.

Coelacanths were well known from the fossil record dating back over 360 million years, with a peak in abundance about 240 million years ago.

On 23 December 1938, the first living specimen was found off the east coast of South Africa. A Museum curator  discovered the fish among the catch of a local fisherman.

Her astonishment was like discovering a living T Rex.

Preserved museum specimen

In the wild

**Flexing his Lobe Finned Fish pectoral fins**

# An adapted pelvic fin

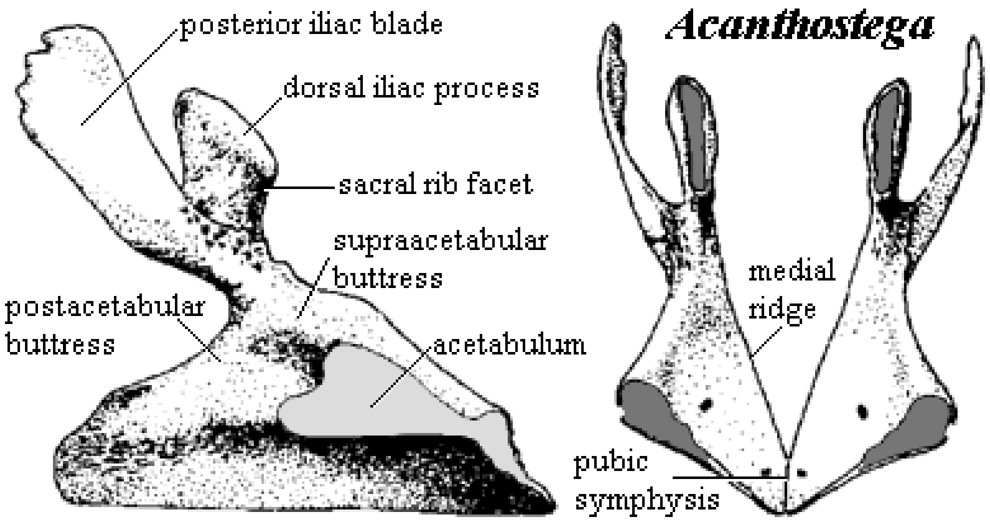
# The Pelvis

The connection between the pelvis and hind limbs in early tetrapods is a prime example of exaptation. This fused connection is the sacrum.

The earliest form of this connection (as seen in *Acanthostega*) evolved while these tetrapod precursors were still living in the water. The later usefulness for terrestrial locomotion was a lucky fluke (*exaptation* in evolution). Evolution does not have plans only memories.

Only later, as tetrapod ancestors moved onto land, was this trait co-opted for terrestrial support — and as it was, additional vertebrae were fused in the same way, providing further limb support.

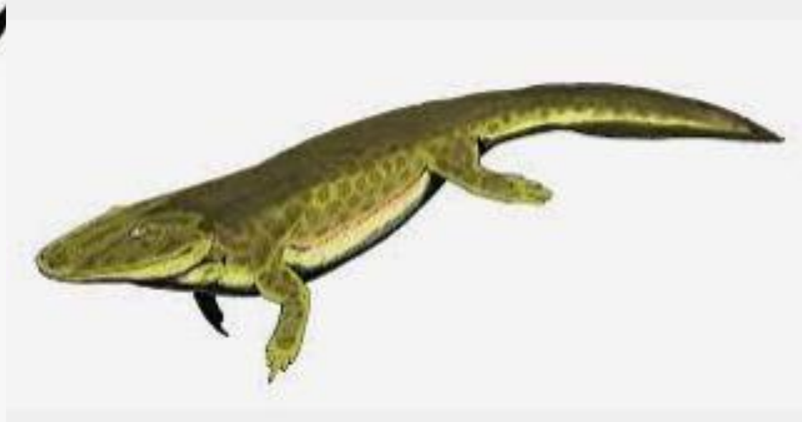
Early fused 'pelvis'.

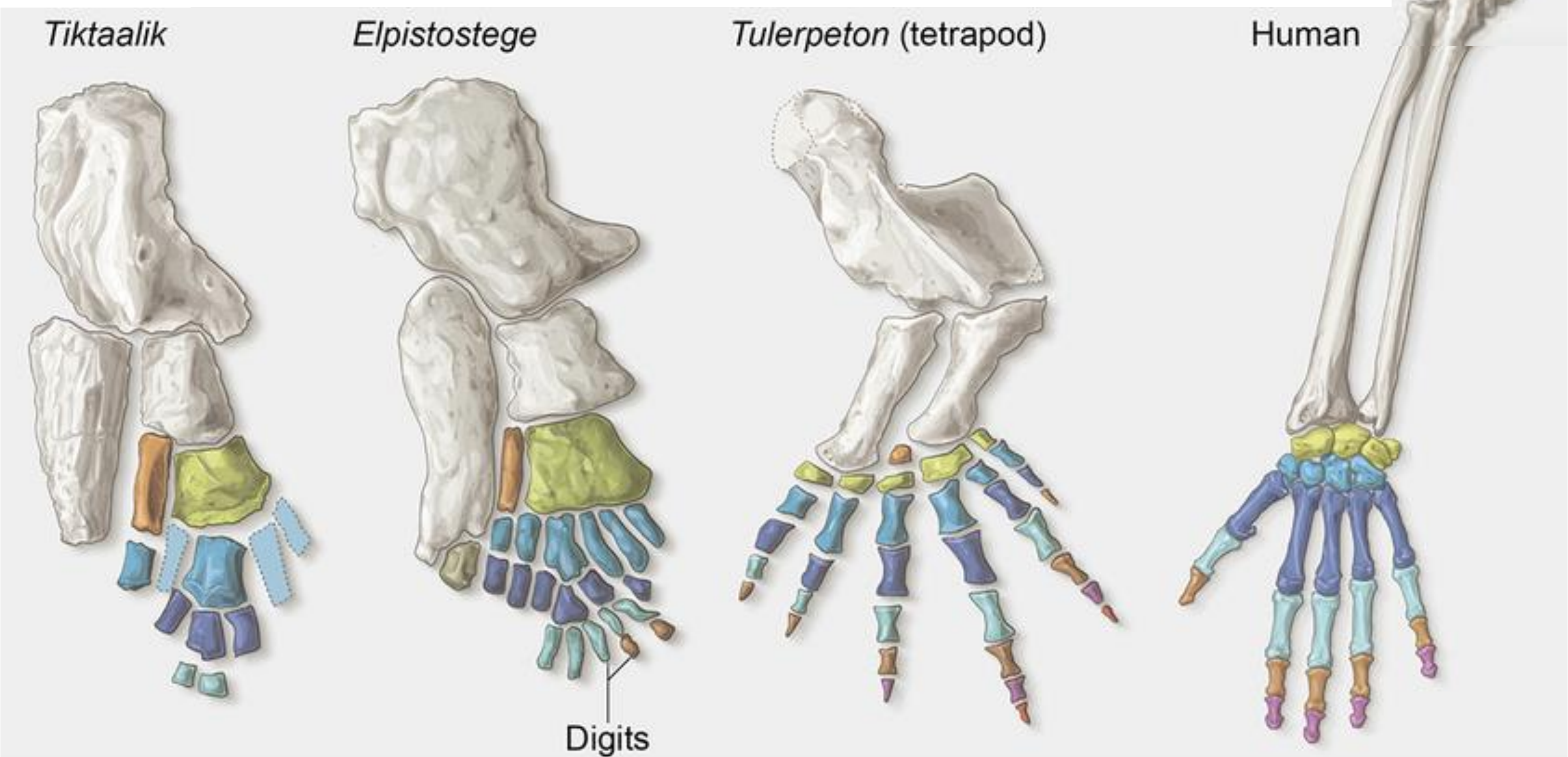



Pelvic girdle in right lateral and anterior views. Coates (1996).

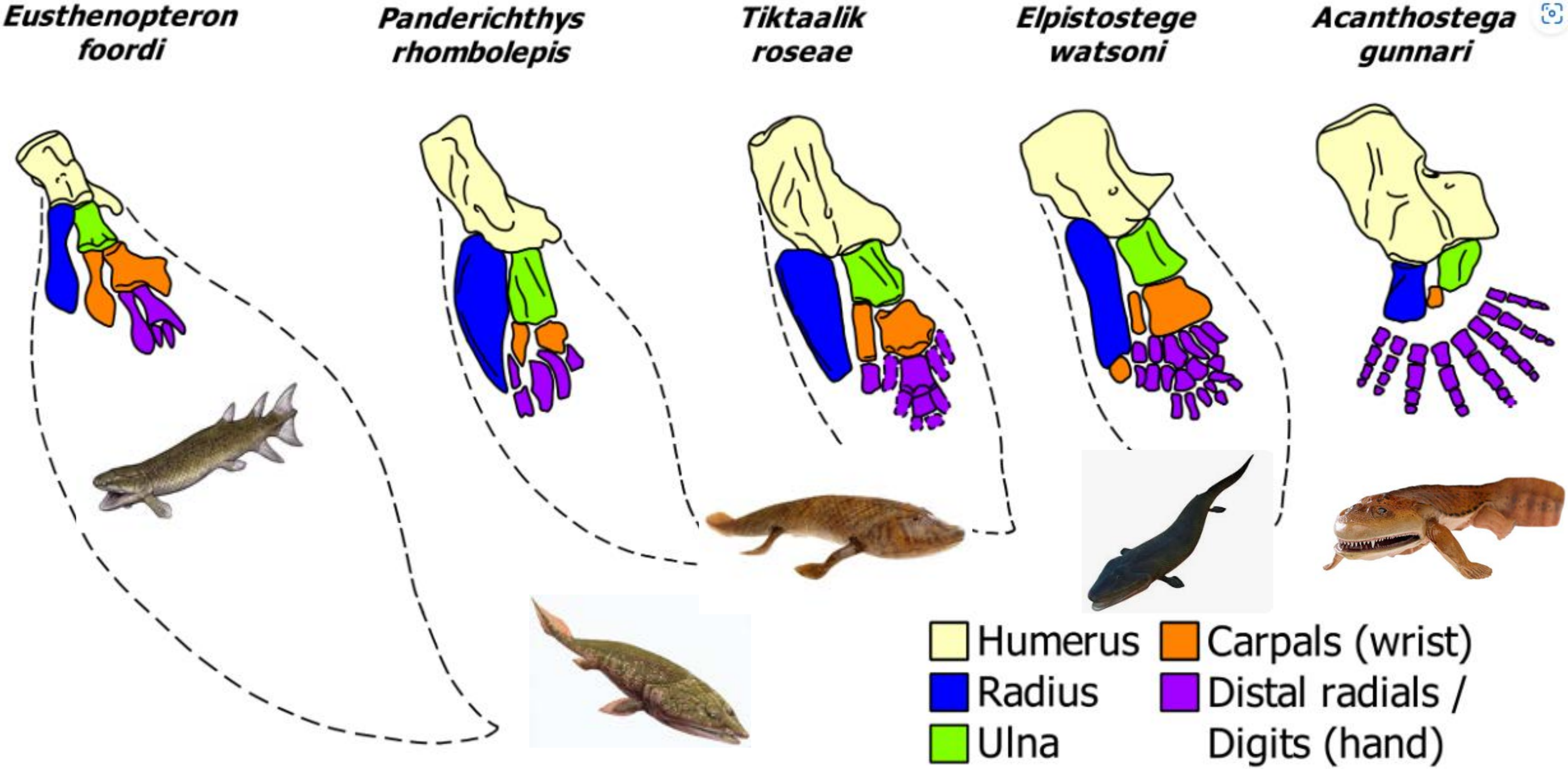
Acanthostega

# Limbs

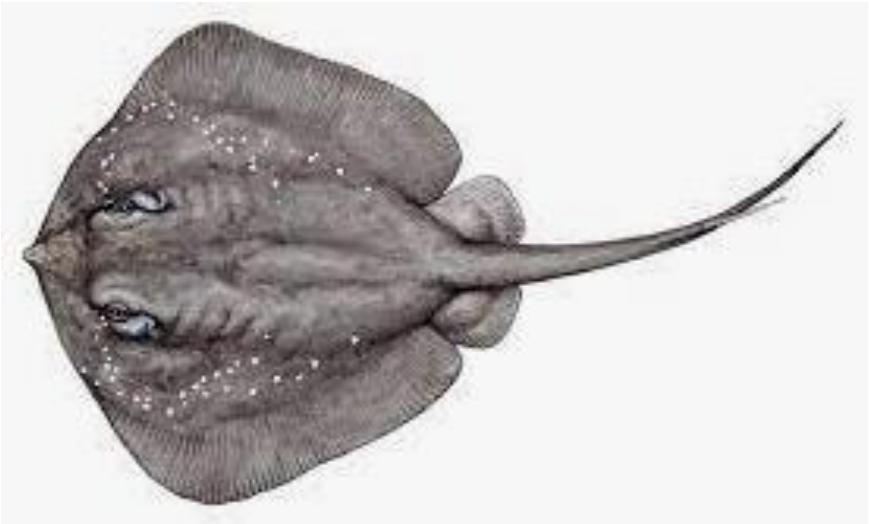



Tiktaalik
Elpistostege
Tulerpeton (tetrapod)
Human
Digits


***Elpistostege***

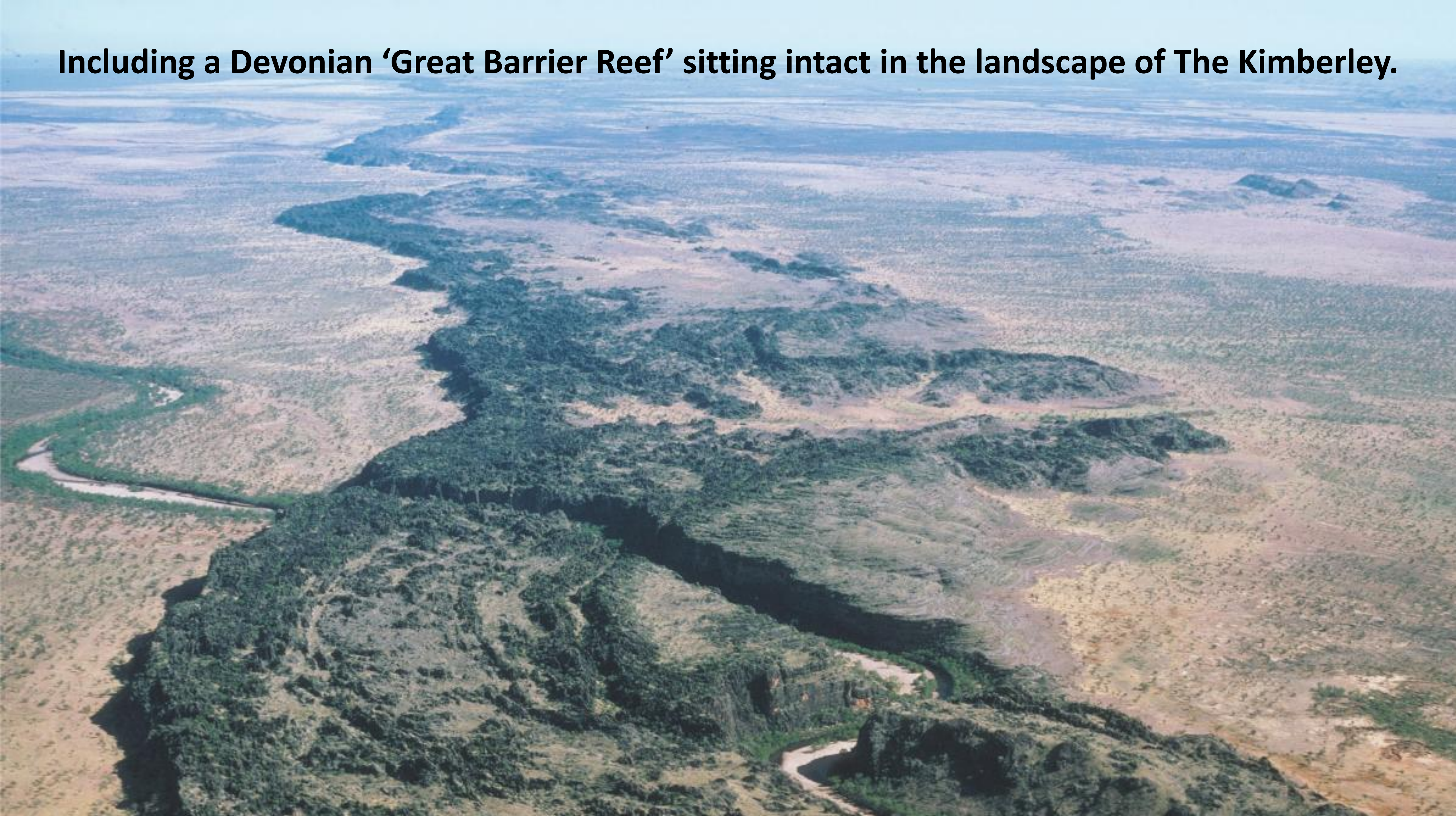

Eusthenopteron foordi
Panderichthys rhombolepis
Tiktaalik roseae
Elpistostege watsoni
Acanthostega gunnari
Humerus
Radius
Ulna
Carpals (wrist)
Distal radials / Digits (hand)


**A footnote on flat heads – whether it is 450 million years ago or today, having a flat head says shallow 'bottom dwelling' and eyes placed for looking up to avoid being somebody's lunch.**

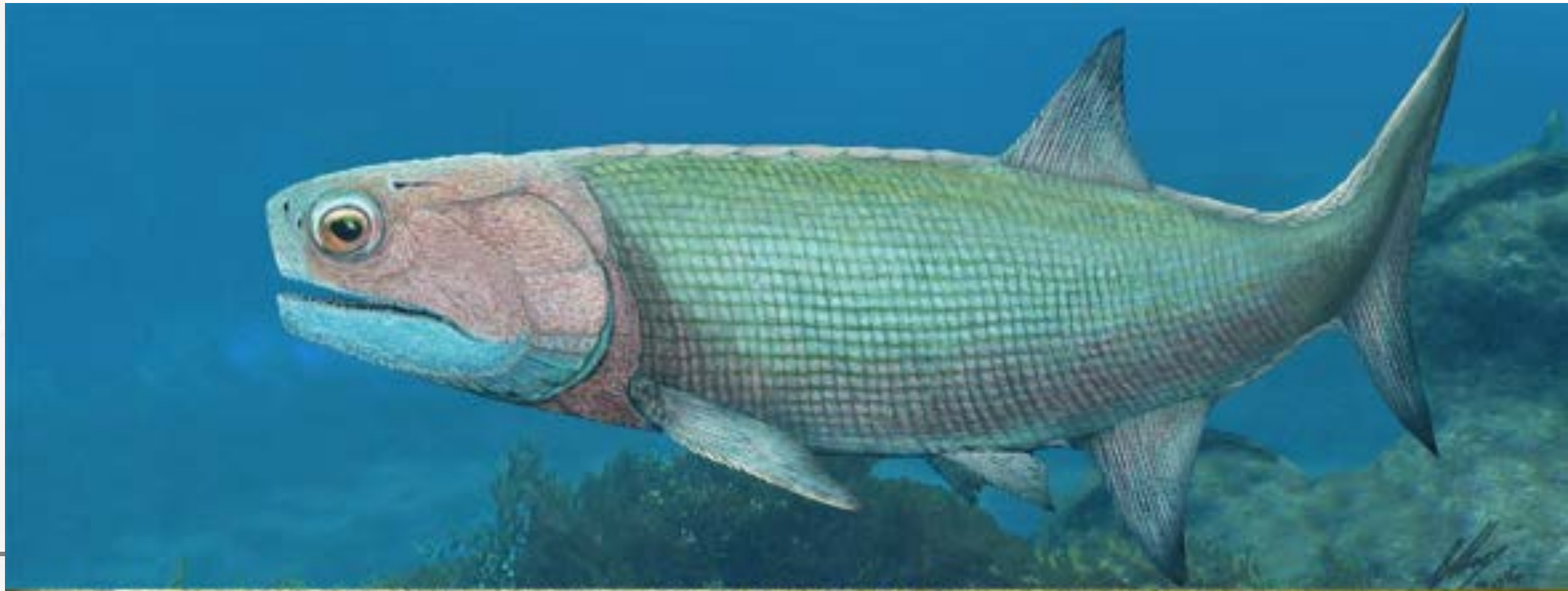



This talk has focussed on the tetrapods and swampy and estuary environments.
The Devonian also had very rich ocean and coral reef ecosystems

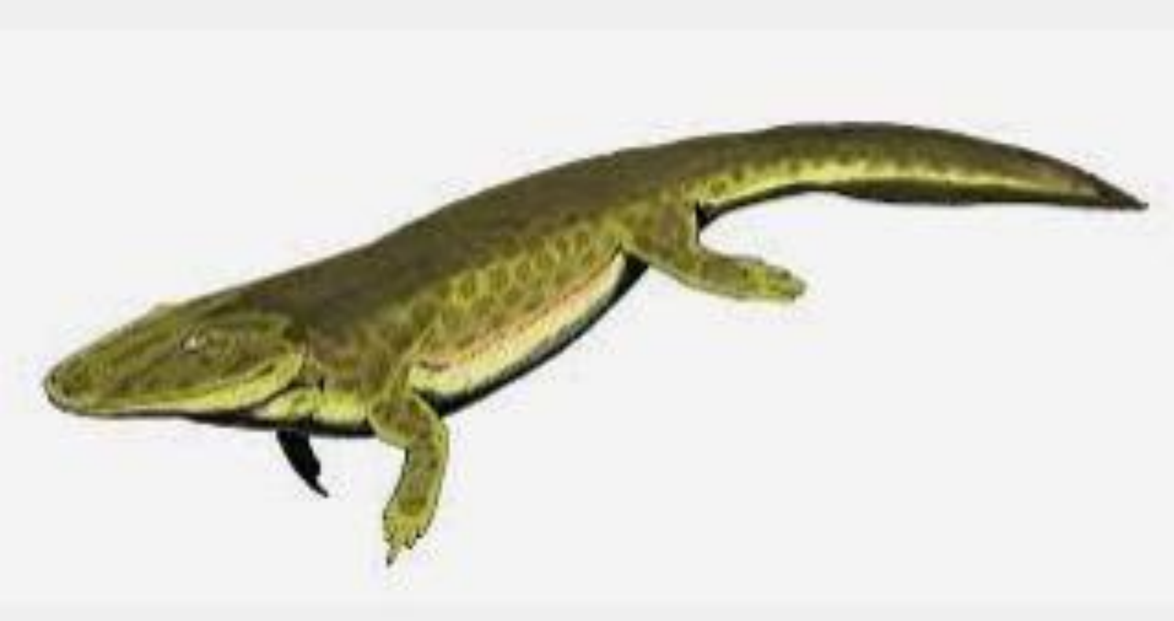
# Including a Devonian ‘Great Barrier Reef’ sitting intact in the landscape of The Kimberley.

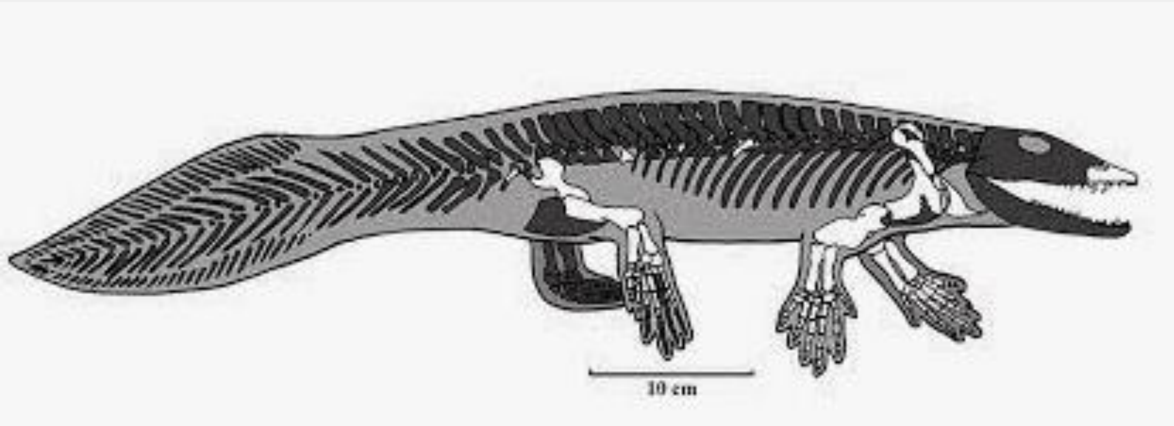



# Gogo Devonian fish fossil site



As this session is about our inner fish the terrestrial tetrapods are a subject for another day






*Tulerpeton* is one of the early transition tetrapods – a marine animal capable of living on land. The separation of the pectoral-shoulder girdle from the head allowed the head to move up and down, and the strengthening of the legs and arms allowed the early tetrapods to propel themselves on land.


2 m
long
Eryops
270 Myo
Predator amphibian

# U3A – Term 3 Crawling out the swamp, the Carboniferous Period

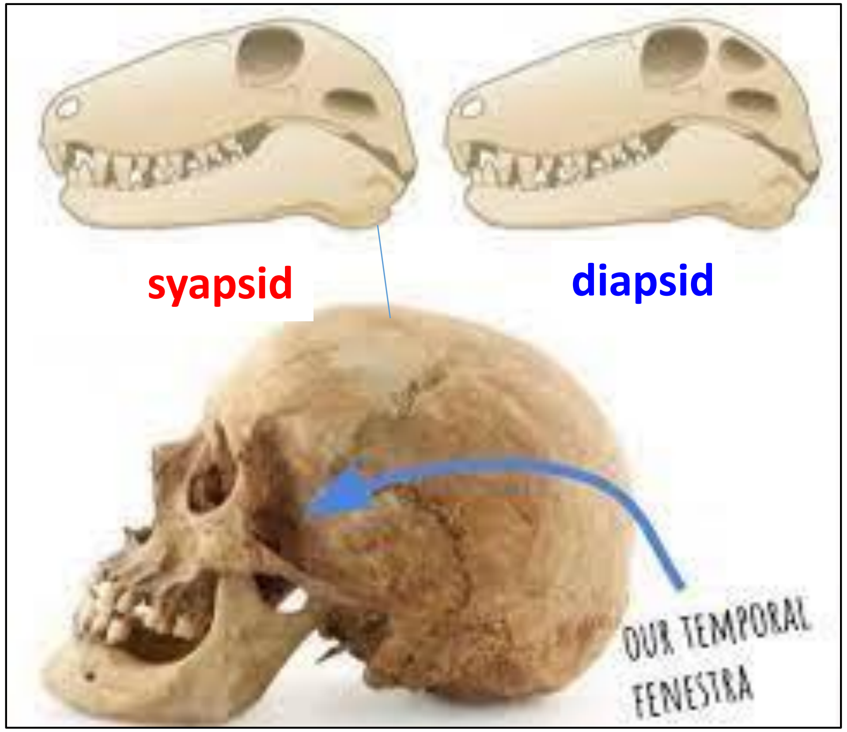
# You will again learn about your ancestry

Archaeothyris was a very early synapsid 306 Mya

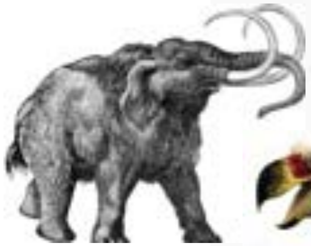
later mammals

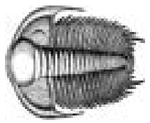
Petrolacosaurus, the first diapsid 302 Mya

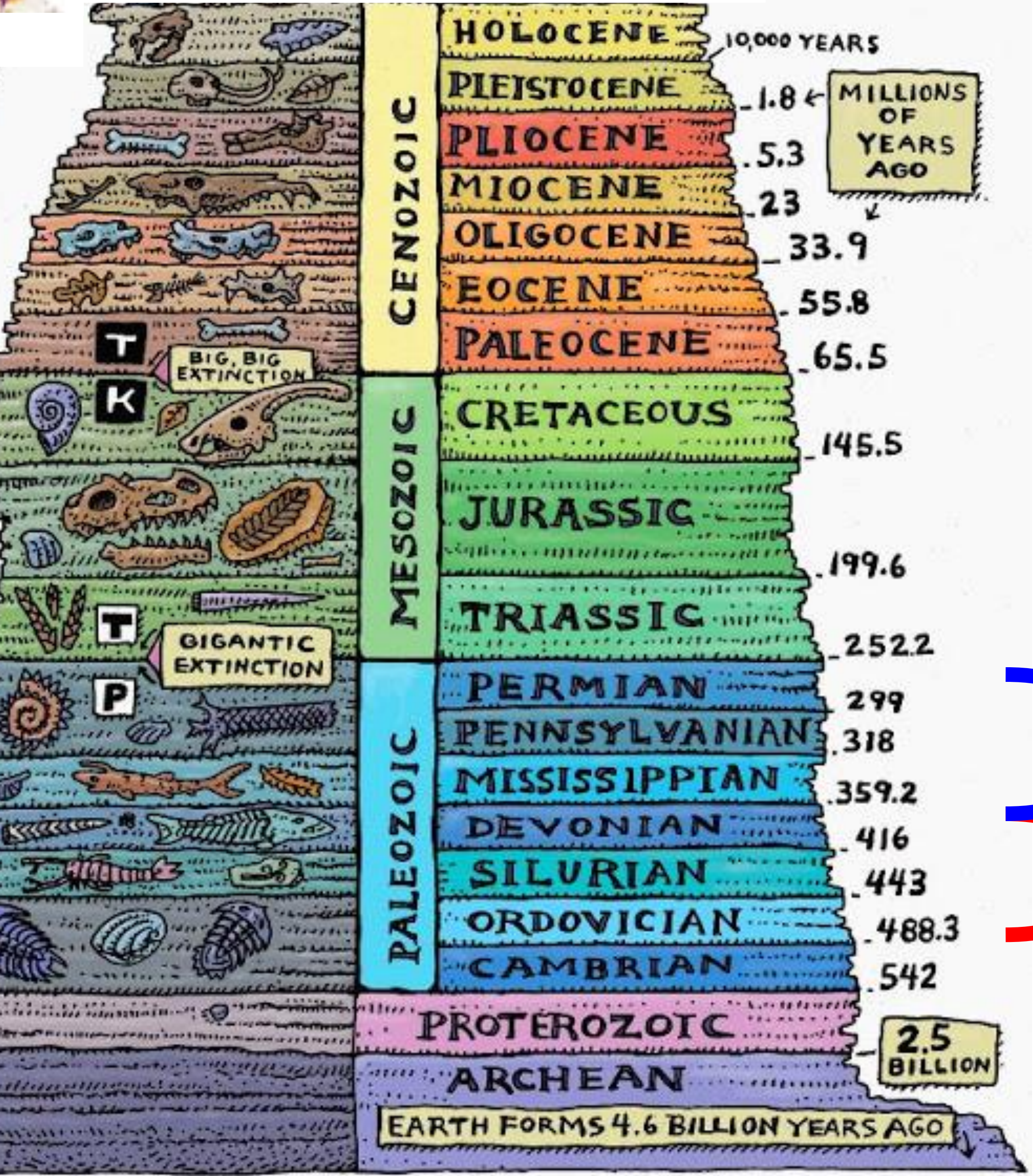
later dinosaurs, pterosaurs, birds,  lizards and snakes



# Term 3 Crawling out the swamp







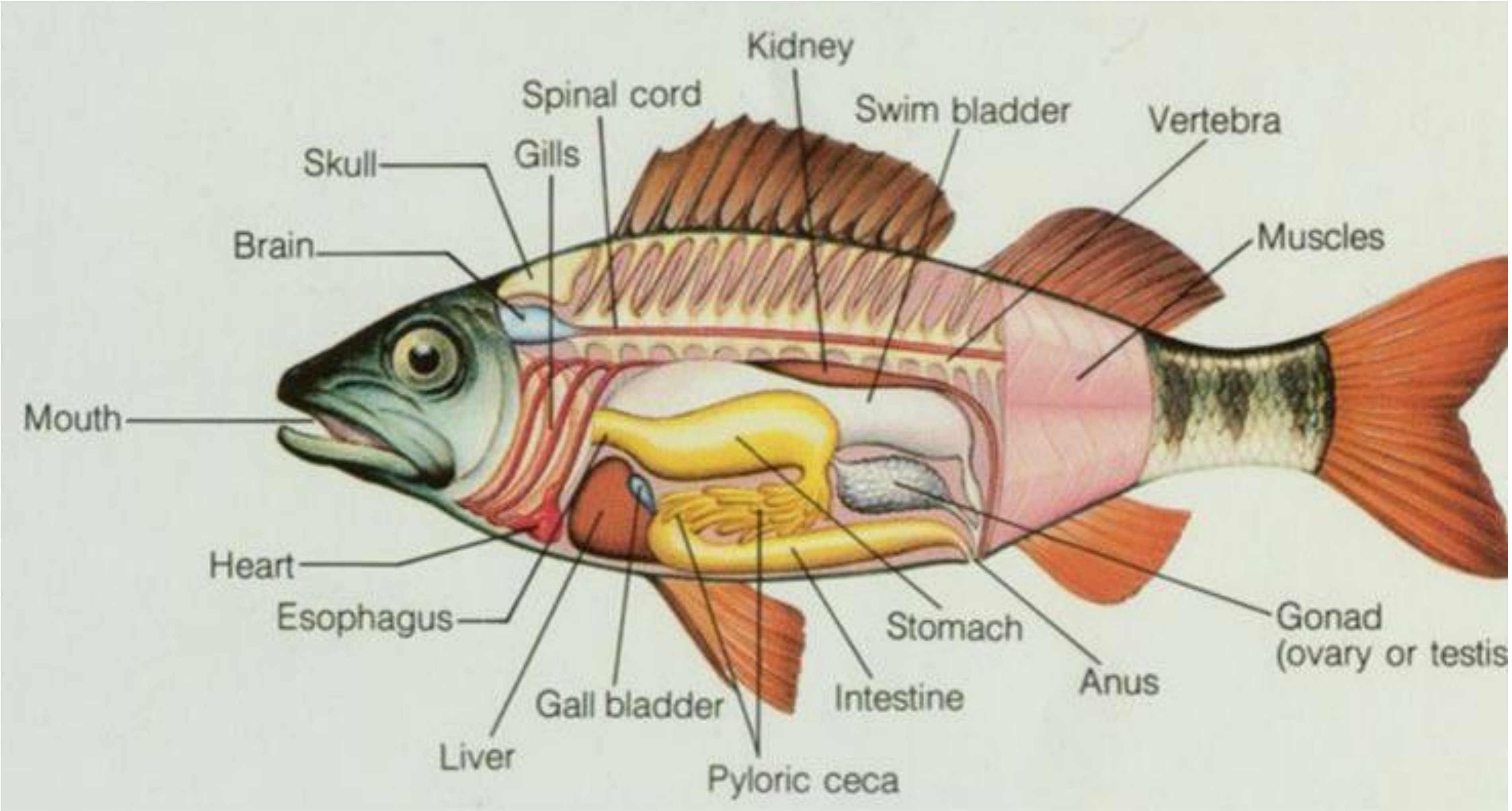

Term 3 session

This session

Your Inner Fish

## Concluding comments

**We have covered some, but not all, the stuff we inherited from fish. The diagram shows many other elements that are in common with humans (and all vertebrates).**



# The last word from the Zebra Fish

The zebra fish is a favourite of genetics researchers. It is easy to breed and it's embryo is transparent, enabling study of the development of organs.  It's genome was recently fully sequenced, allowing a comparison with the genetic data from the *Human Genome Project.*

**71.4% of the human genome have a least one obvious zebrafish *same function* genetic equivalent.**

**Your Inner Fish – how much?     71.4%**

# Their Inner Fish

This talk was about us, it equally applies to any of the other 78,533 existing species of tetrapods plus their extinct ancestors.








We are the chance result of climate related events in East Africa over 2 million years ago.
Evolution could have had quite a different outcome from our fish ancestry.

# Questions?


C'MON OUT, FOLKS! IT LOOKS LIKE WE'RE THE FIRST ONES HERE.
FIRST ONES HERE? PLEASE! WE'VE BEEN HERE FOR SIXTY MILLION YEARS!
I...I...I WONDER WHAT THEY EAT?