CHORDATA

SK.M.BASHA

Phylum Chordata

Vertebrates, sea squirts or tunicates, lancelets such as *Amphioxus*.
Name: "Chord" means "string", referring to the nerve cord and/or notochord.
Chief characteristics: Chordates have the following features at some point in their life (although in some cases, these features may be present only in the embryo):

1. **Bilateral symmetry.**
2. **Gill slits**. These slits are a series of openings that connect the inside of the throat to the outside of the "neck".
3. **Dorsal nerve cord** (sometimes called a spinal cord). The nerve cord runs down the "back", connecting the brain with the muscles and other organs.
4. **Notochord**. A stiff cartilaginous rod which supports the nerve cord.
5. **Post-anal tail**. This is an extension of the body past the anal opening.
6. Blood that circulates forward in a main ventral vessel and backward in a dorsal vessel.

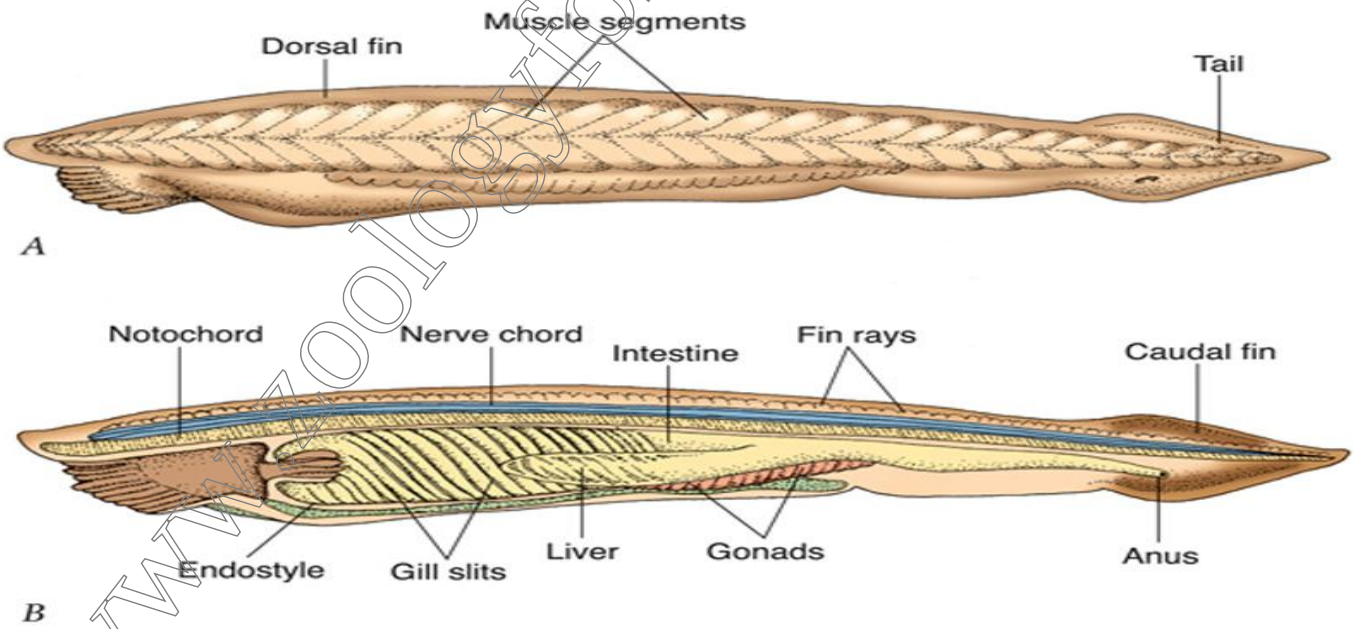
Geologic range: Cambrian to Recent.
Mode of life: Varied. Among the vertebrates alone, various members are land dwellers, swimmers, or fliers. Paleozoic vertebrates were initially in the sea, but later colonized freshwater and land.

Subphylum Urochordata

Primitive chordates. Sea squirts, ascidians, or tunicates. Larval forms have notochord in tail region.
Chief characteristics: Adults have sac-like bodies, ranging in size from less than 1 mm to a few cm. Larval form resembles a tadpole and has a notochord, dorsal tubular nerve cord, gill slits, and post-anal tail.
Geologic range: not known
Mode of life: Inhabit overhangs or shaded areas in the low intertidal and subtidal zone. Most live attached as adults. Filter feeders. Behavior resembles that of a sponge. Body contracts abruptly expelling water, giving them the name "sea squirts".

Subphylum Cephalochordata

Primitive chordates. Lancelets, *Branchiostoma*, *Amphioxus*. Small marine animals with fish-like bodies and notochord.



***Branchiostoma**, a non-vertebrate chordate. Length 3 - 5 cm.*
Chief characteristics: Lancelets resemble a small, colorless anchovy fillet, without obvious eyes or lateral fins. Worm-like. Has segmented axial muscles, gill slits, a dorsal hollow nerve cord, a notochord, and a post-anal tail. There is nothing resembling a vertebral column. No solid skeleton.

Geologic range: Cambrian to Recent.
Mode of life: Bottom dwellers. Lancelets spend much of their time burrowing in the sand in warm, coastal, marine environments. Filter feeders. Relatively sessile but capable of swimming.
Significance: An ancestor to the vertebrates resembled a lancelet-like creature.

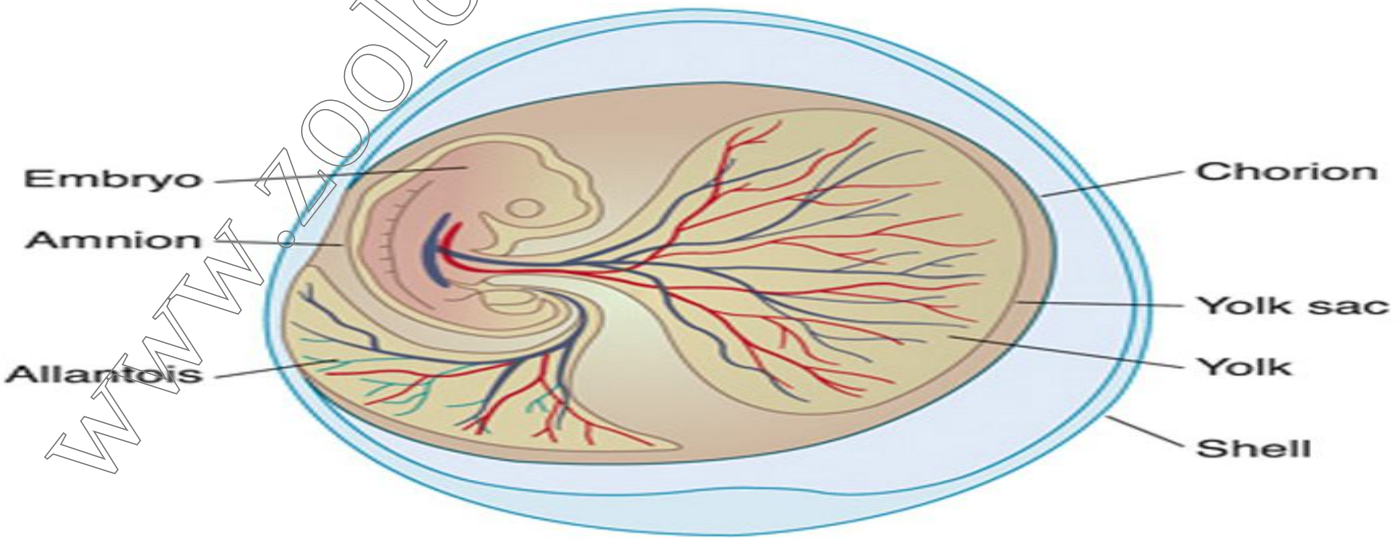
***Pikaia**, an early chordate, pre-vertebrate cephalochordate from the Cambrian Burgess Shale, has a notochord, seen near the top of the body in this picture. Also note the segmented muscles.*

Subphylum Vertebrata - The Vertebrates

The vertebrates are animals with a segmented backbone consisting of vertebrae, a definite head with a skull that encloses a brain, a ventrally-located heart, and well-developed sense organs. The notochord is supplemented or replaced by cartilaginous or bony vertebrae. Arches of the vertebrae encircle and protect a hollow spinal cord.
Mode of Life: Includes both water-dwelling and land-dwelling tetrapods (from the Latin, meaning four feet). Some walk on four legs and some walk only on the hind legs (bipedal). In some, forelimbs are modified into wings. In some, the limbs have been modified into flippers.
Geologic range: Cambrian to Recent.
Two major groups of vertebrates:

1. **Non-amniotic vertebrates** - Egg lacks a covering and must be fertilized externally. Must be wet or in water to reproduce.
    a. **Fish**
    b. **Amphibians**
2. **Amniotic vertebrates** - Amniotes. **Internal fertilization** and an **amniotic egg** (enclosed egg). Water is not required for reproduction.
    a. **Reptiles**
    b. **Birds**
    c. **Mammals**

Amniotic egg:

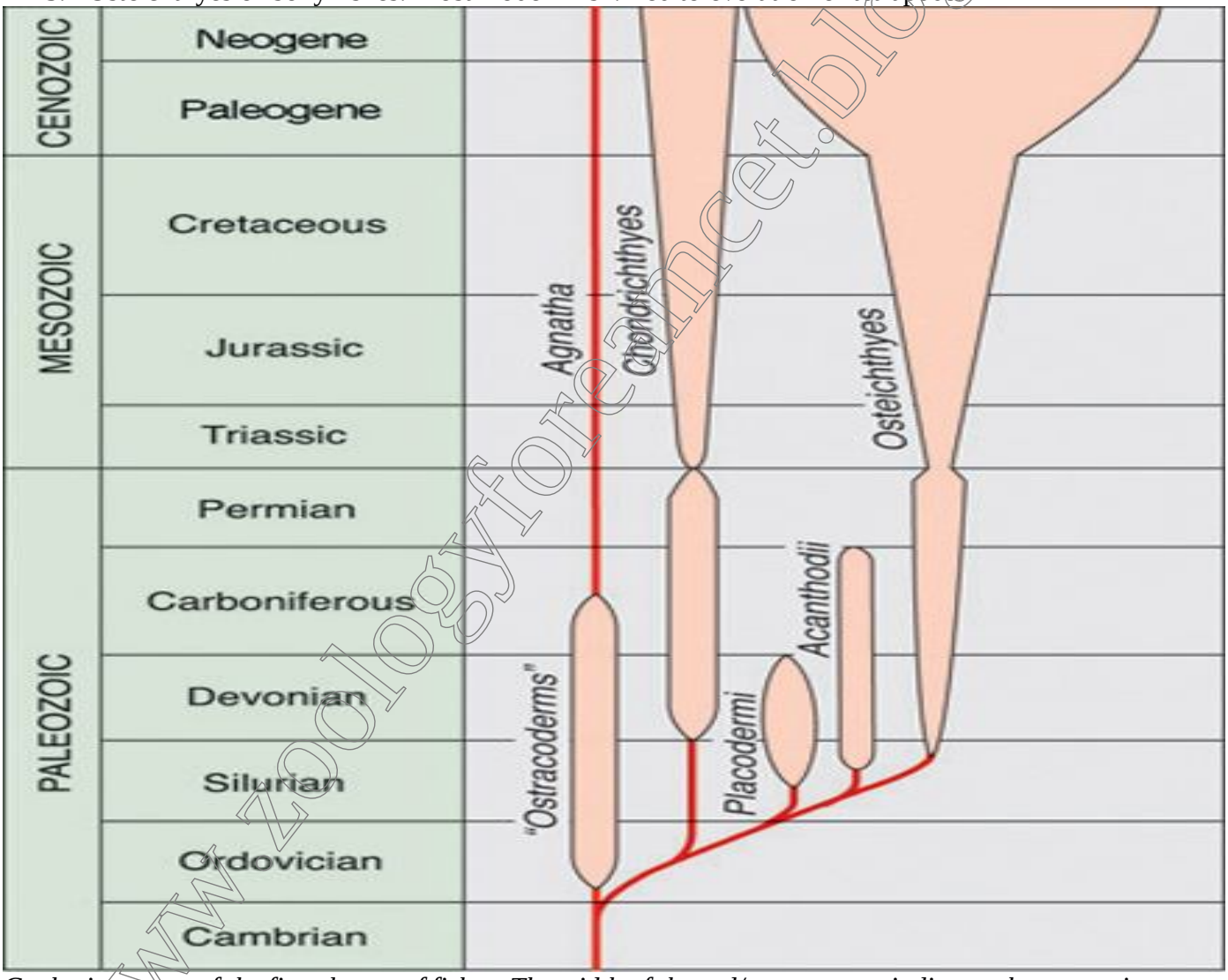


Amnion (or amniotic membrane) encloses the embryo in water (amniotic fluid).
Allantois is a reservoir for waste and provides for gas diffusion. It becomes the urinary bladder in the adult.
Chorion provides a protective membrane around the egg.
Yolk is a storage area for fats, proteins, and other nutrients - food for the embryo.
The amniotic egg provided **freedom from dependency on water bodies**, and helped the vertebrates live in diverse types of terrestrial environments. It is an important milestone in the evolution of vertebrates.

The Fishes

The oldest known fish is from the Cambrian of China (about 535 m.y. old), found in the Chengjiang fossil site in Yunnan Province,
There are five classes of fishes.

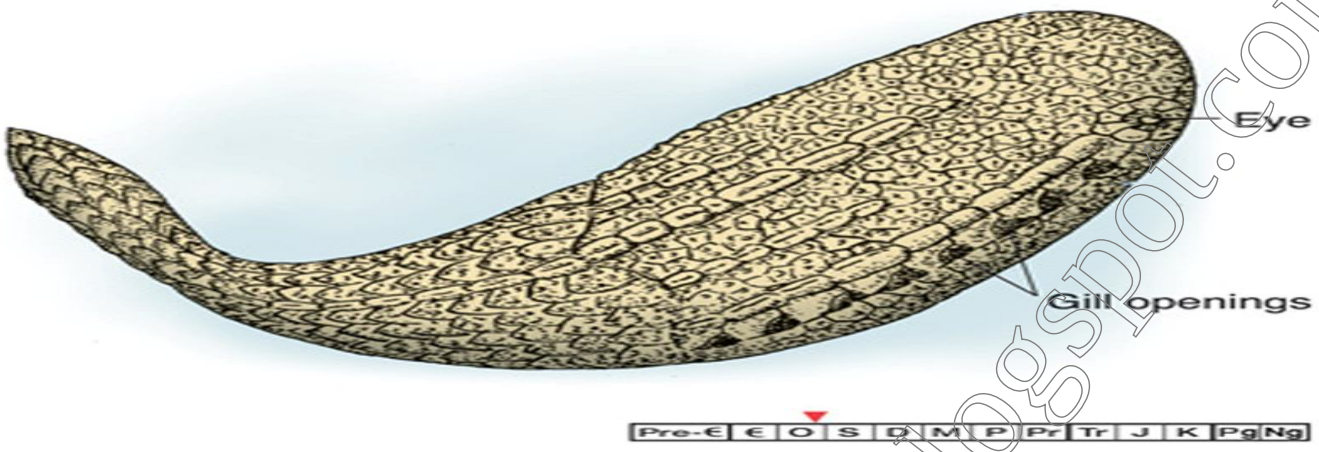
1. Agnathids or jawless fish
2. Acanthodians or spiny fish with jaws. Extinct.
3. Placoderms or plate skinned fish with jaws. Extinct.
4. Chondrichthyes or fish with cartilaginous skeletons, including sharks, rays, and skates.
5. Osteichthyes or bony fishes. Most modern fish. Led to evolution of tetrapods.



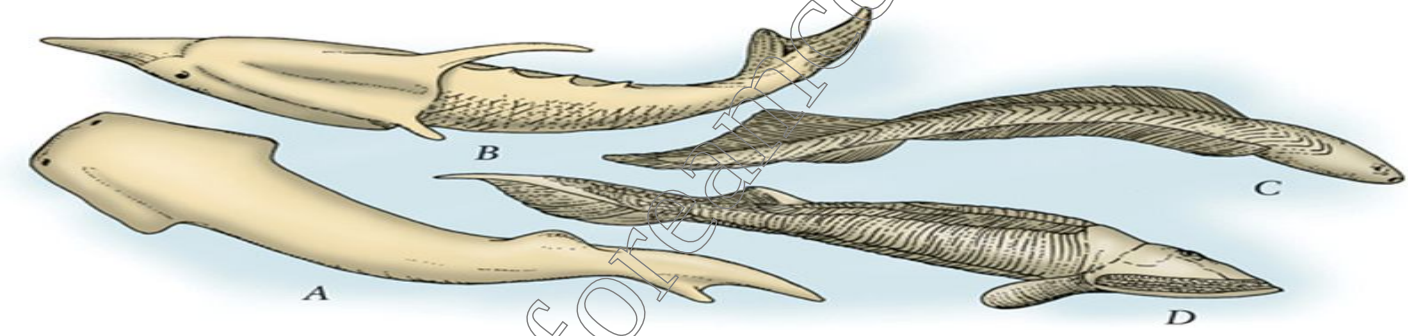
Geologic ranges of the five classes of fishes. The width of the red/orange area indicates the approximate relative abundance of each class.

1. CLASS AGNATHA (jawless fishes, including the living lampreys and hagfishes as well as extinct **ostracoderms**)
Name: "A-" means "without", and "gnatha" means "jaws".

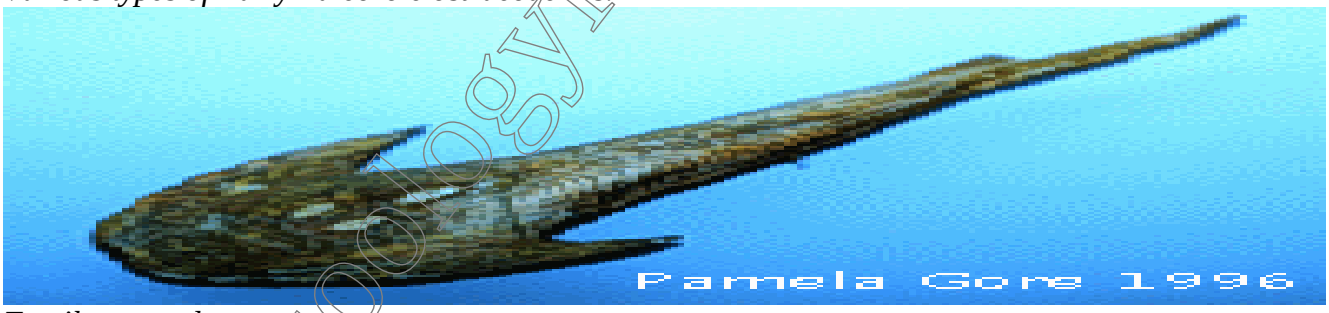
Chief characteristics: Fish without jaws.
Geologic range: Cambrian to Recent. **Ostracoderms** were Ordovician to Devonian.
Mode of life: Swimmers.
Jawless fishes are present in the Harding Sandstone (Lower Ordovician) of Colorado. Also found in Lower Ordovician rocks in Australia and Bolivia. Includes ***Astraspis***.



***Astraspis**, an Ordovician jawless fish from the Harding Sandstone of Colorado.*
A group of *armored* jawless fishes called the **ostracoderms** (name means "shell skin") lived in the Early Paleozoic. The armor was made of bony material, and served as protection from predators or for storing seasonally available phosphorous. Bone is made of apatite, which contains phosphorous. Ostracoderms were mainly small, sluggish fish that were filter feeders or "mud strainers".



Various types of Early Paleozoic ostracoderms.



Fossil ostracoderm.
Photo courtesy of Pamela Gore.

Evolution of Jaws

The evolution of the jaw expanded the adaptive range of vertebrates.
Used for biting and grasping.
Led to more varied and active ways of life, and to new sources of food.
Origin of jaws - two hypotheses:

1. Modification of a front pair of bone or cartilage **gill supports**.
2. More recent hypothesis: Modification of the **velum**, a structure used in respiration and feeding in lamprey larvae.

Both hypotheses are based on anatomy and embryology of living fishes.
The first fish with jaws appeared in nonmarine rocks in the **Late Silurian**.

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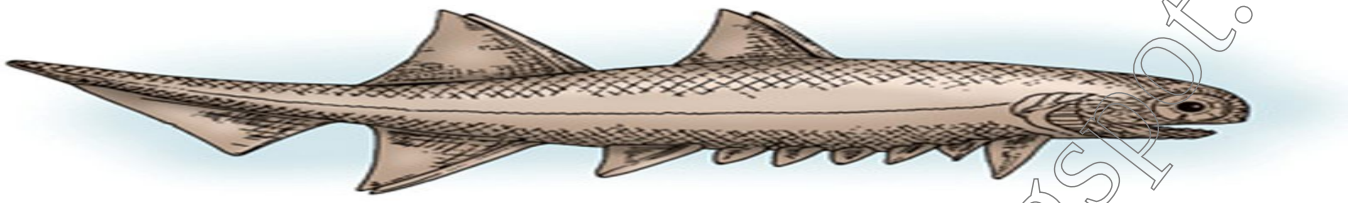
2. CLASS ACANTHODII (the acanthodians or spiny fishes)
Significance: These were the **first fishes to have jaws**.
Name: "Acanthos" means "spiny".
Chief characteristics: Primitive spiny fishes with jaws.
Geologic range: Late Silurian to Permian. Most numerous during the Devonian. Extinct.
Mode of life: Swimmers. Nonmarine.



Acanthodian fish from the Early Devonian.

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3. CLASS PLACODERMI (placoderms)
Name: "Placo-" means plate and "derm" means "skin". These are the "plate-skinned" fishes.
Chief characteristics: Fish with jaws and armor plating.
Geologic range: Late Silurian to Late Devonian. Extinct.
Mode of life: Swimmers. Some were large carnivorous predators, such as *Dunkleosteus*, which grew to about 9 meters long

*Skull of **Dunkleosteus**, a Late Devonian placoderm fish. The skull is about 1 m high and 1 m wide. Photo courtesy of Pamela Gore.*

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4. CLASS CHONDRICHTHYES (sharks, rays, and skates)
Name: From "chondros", meaning "cartilage", and "icthyes" meaning "fish".
Chief characteristics: Cartilaginous fishes. Skeleton is made of cartilage and not bone, and so is rarely preserved.
Geologic range: Middle Paleozoic (Late Silurian to Devonian) to Recent.
Mode of life: Swimmers. Marine, except one genus that inhabited freshwater in the Late Carboniferous.
The genus ***Cladoselache***, is found in Devonian shales on the southern shore of Lake Erie.

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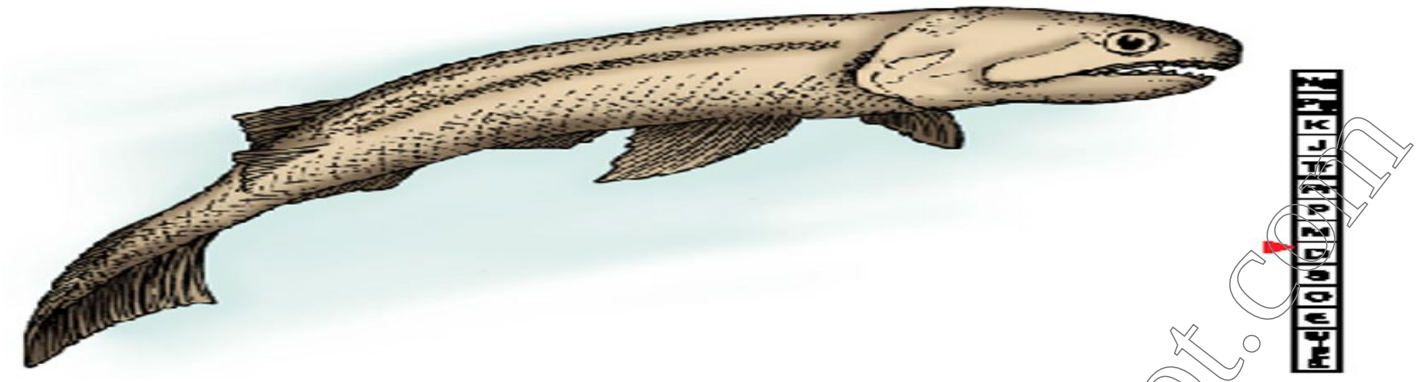
5. CLASS OSTEICHTHYES (bony fishes)
Name: "Osteo" means "bone" and "ichthyes" means "fish".
Chief characteristics: Skeleton of bone, not cartilage. Modern bony fishes are of this type. The most numerous, varied, and successful of all aquatic vertebrates.
Geologic range: Devonian to Recent. Well known in Devonian rocks.
Mode of life: Swimmers. Marine and freshwater. **The earliest lived in freshwater**.



***Cheirolepis**, the Devonian ancestral bony fish.*

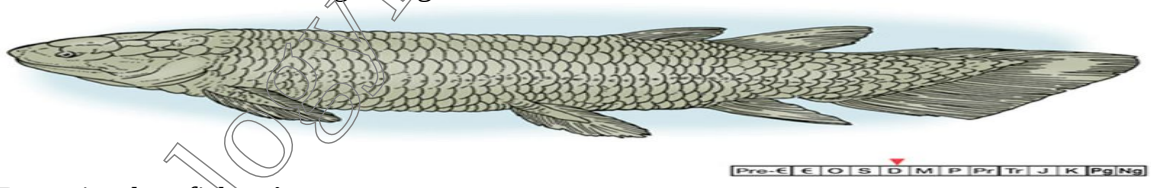
Bony fishes played a key role in the evolution of tetrapods (four-legged animals).

Two types of bony fish are significant:

A. **Subclass Actinopterygii - the ray-finned fish.**
Dominant fishes in the world today. No muscular base to the paired fins. Fins are thin structures supported by radiating rods or rays. First appeared in Devonian freshwater lakes and streams, and then expanded their geographic range to the sea.

B. **Subclass Sarcopterygii - the lobe-finned fish or lungfish.**
The lobe-finned fishes appeared in the Late Devonian.
Leg-like fins:
Fishes with sturdy, fleshy lobe fins.
These were leg-like muscular fins which they used to "walk" about on pond or stream bottoms.
Lungs:
They had a pair of openings in the roof of the mouth that led to **nostrils**.
They were able to rise to the surface and breathe air with **lungs** when the water became foul or stagnant.
Some had both lungs and gills.
This group gave rise to the amphibians and other tetrapods (four-legged animals).
Types of Devonian sarcopterygians or lungfish:

1. **Order Dipnoi** or dipnoans (meaning "double breather") -
This group did not lead to tetrapods, but includes interesting freshwater lungfish living today in Australia, Africa and South America. They can breathe with lungs during the dry season, and can burrow into the mud during droughts.



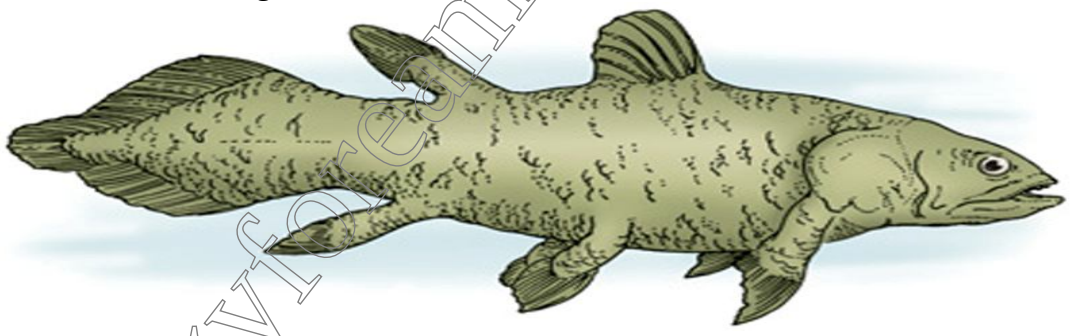
*Devonian lungfish, **Dipterus**.*

2. **Order Crossopterygii** or crossopterygians -
The **ancestors of the amphibians**.
This group is considered to be ancestral to the amphibians because of the *arrangement of bones in their fins, the pattern of bones of the skull, and the structure of their teeth*.
Short, muscular, paired fins. Had a single basal limb bone called the **humerus**, followed by the **radius** and **ulna** in front fins, and followed by the tibia and fibula in hind fins. (Same bones as in humans, chickens, and other vertebrates with four limbs.)
The adaptation assisted movement in shallow water, and allowed the animal to move from a body of water that became too shallow or stagnant, to search for another body of water.
Eusthenopteron belongs to this group.

*The Late Devonian crossopterygian lungfish, **Eusthenopteron** (365 m.y., Escuminac Formation, Quebec, Canada) had sturdy fins. It is structurally similar to amphibians and is considered to be transitional to the amphibians.*
Photos courtesy of Pamela Gore.

There are two types of crossopterygian fish:

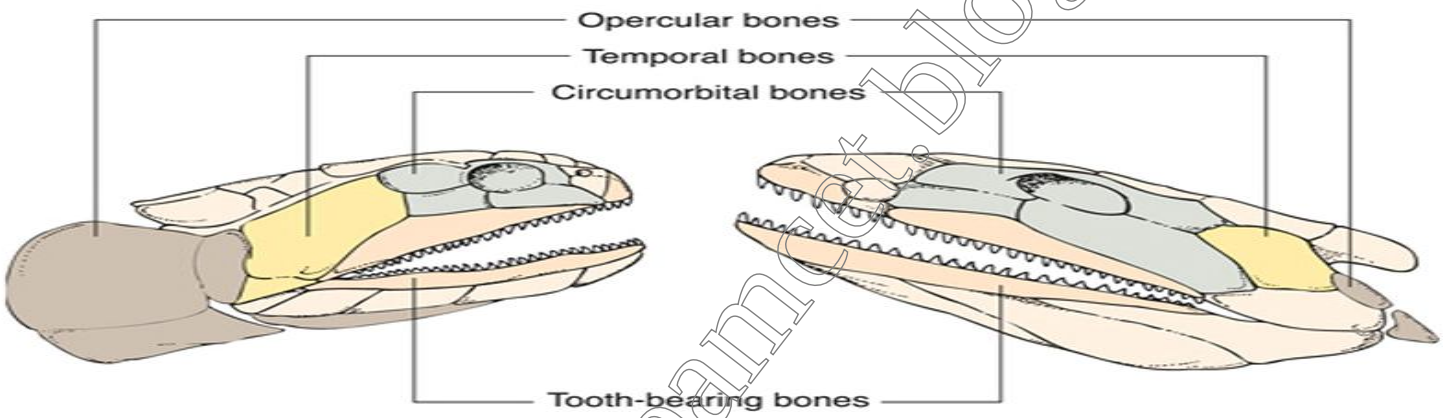
a. **Rhipidistians - this group led to the amphibians**
b. **Coelacanths** - Another group of lobe-finned crossopterygian fish invaded the sea and gave rise to the coelacanths. The coelacanths are considered to be **living fossils** because they were long-believed to be extinct, but one was caught in 1938 near Madagascar. More have been caught since.



***Latimeria**, a modern coelacanth about 2 m long, living near Madagascar. Note the similarity of the tail to that of **Eusthenopteron** fossils, above. The tail is very different from that of the ray-finned fishes.*

There are many similarities between crossopterygian fish and amphibians. The illustrations below show comparisons of limb structure and skull structure. The same bones are present in the limbs of each, and the same bones are present in the skulls of each. The shape and size of the bones is slightly different. Amphibians will be discussed on the next page.

Comparison of the limb bones of a crossopterygian fish (right) and the limb bones of an early amphibian (left). The major limb bones are coded r, u and h.
r = radius
u = ulna
h = humerus



*Comparison of skulls and lower jaws of a crossopterygian fish (left) and the Devonian amphibian, **Ichthyostega**.*

Modern walking, air-breathing fish in the U.S.

Some fish today have lungs and can walk on land.
The **snakehead fish**, *Channa argus*, native to parts of Asia and Africa, made news in 2002 when they were found in a pond in Maryland, and subsequently in the Potomac River near Washington, D.C. They were originally purchased live in a fish market in New York's Chinatown, and later released into the wild, where they began to reproduce rapidly as a non-native species with no natural predators. They are capable of breathing air using an air bladder that works like a primitive lung. They are also capable of moving short distances on land using their pectoral fins. These fish can live out of water for 3 to 7 days. They can hibernate in cracks during cold weather, and become dormant in burrows in the mud during droughts. Snakeheads are predators at the top of the food chain.
Florida also has "walking catfish", *Clarias batrachus*, that can breathe air. They are also non-native fish, and were accidentally introduced in the 1960's when they walked away from a fish farm.
Both of these fish are in Class Actinopterygii. They are not closely related to the Devonian lungfish.

Phylum Chordata
The Advent of Tetrapods

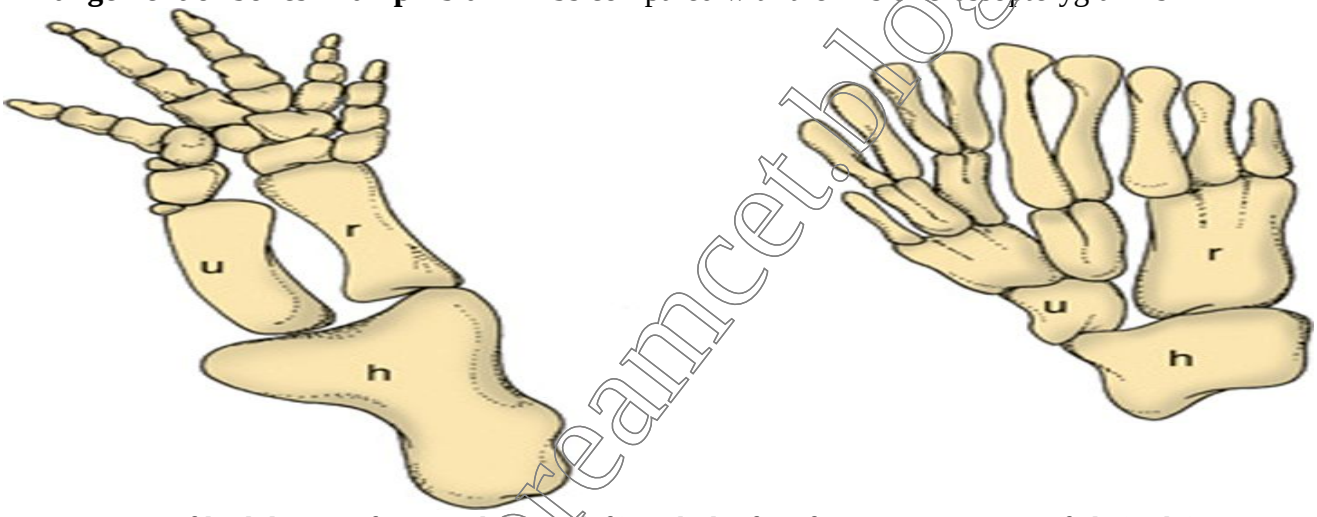
Tens of millions of generations passed before crossopterygian fish evolved into animals that could live entirely on land. The early tetrapods (four-legged animals) continued to return to water to lay their fish-like, naked eggs. Fish-like tadpoles hatched from these eggs, which used gills for respiration.

Anatomical changes associated with the shift from water to land:

1. Three-chambered heart developed and functioned to pump blood more efficiently to the lungs
2. Limb and girdle bones altered to support the body above the ground
3. Spinal column changed to become sturdy but flexible
4. Bones of the ear changed to function better in air than in water (modification of hyomandibular bone that propped fish braincase and upper jaw together, into an ear ossicle called the stapes)
5. Fish spiracle (vestigial gill slit) became amphibian eustachian tube and middle ear
6. Eardrum (tympanic membrane) formed across a notch in the skull

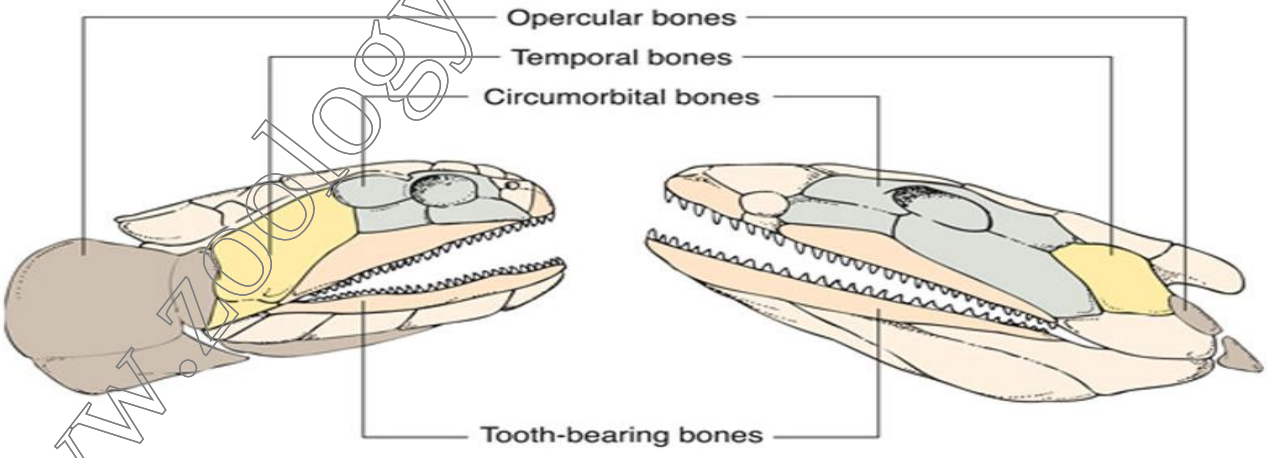
Amphibians are interpreted to be descended from crossopterygian fishes because of:

1. **Arrangement of bones in amphibian limbs** compared with the fins of crossopterygian fish



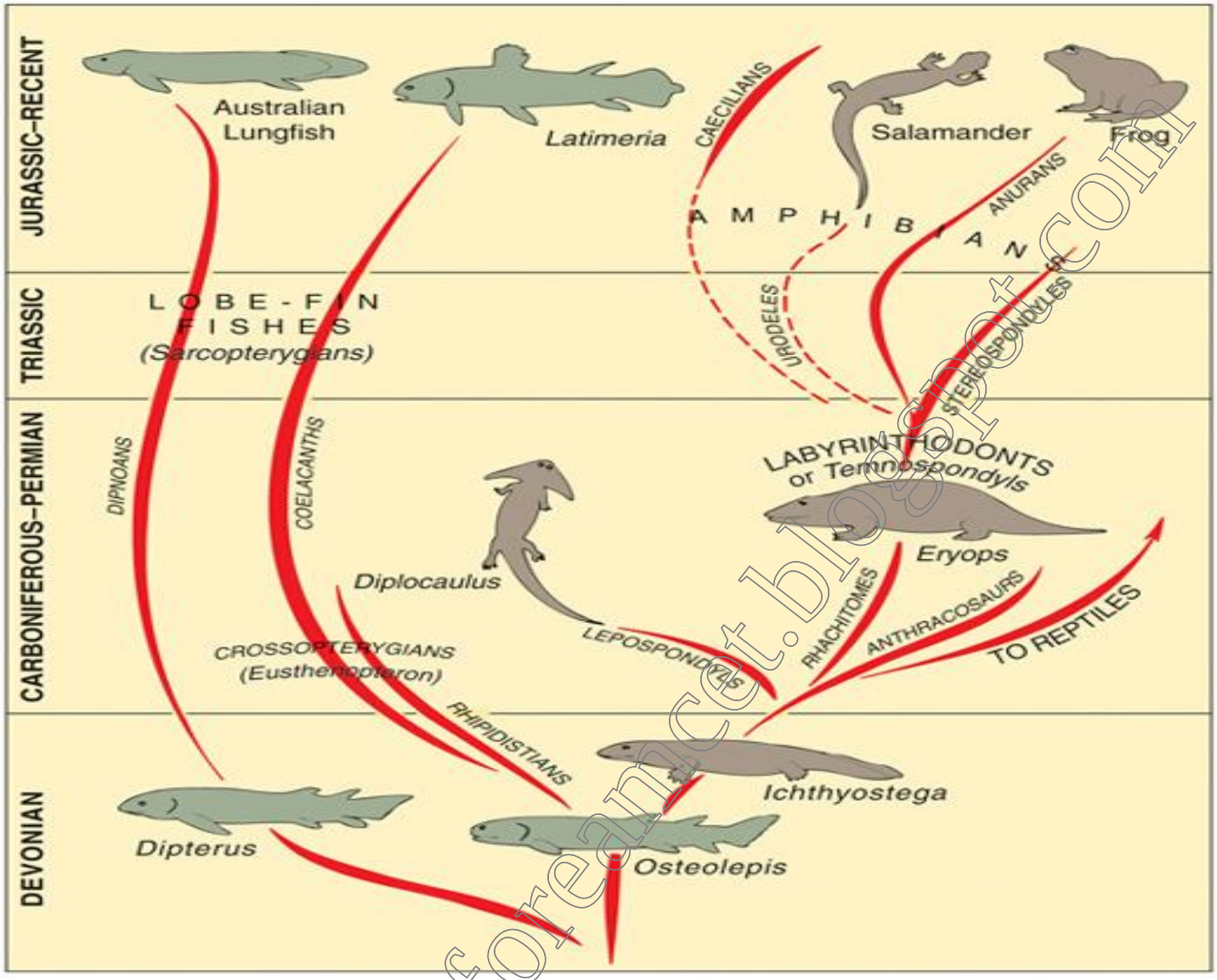
Comparison of limb bones of an amphibian (left) with the fin of a crossopterygian fish (right). The major limb bones are coded r, u and h. r = radius u = ulna h = humurus

2. **Pattern of bones of the skull**



*Comparison of skulls and lower jaws of a crossopterygian fish (left) and the Devonian amphibian, **Ichthyostega**.*

3. **Structure of the teeth** - highly infolded like a maze (or labyrinth), and called **labyrinthodont teeth**.
4. Bones of the spinal column in early forms.



The Amphibians

CLASS AMPHIBIA

Name: "Amphi" means "both" or "double", and "bios" means "life". "Amphibios" means living a double life, referring to living in water and on the land.

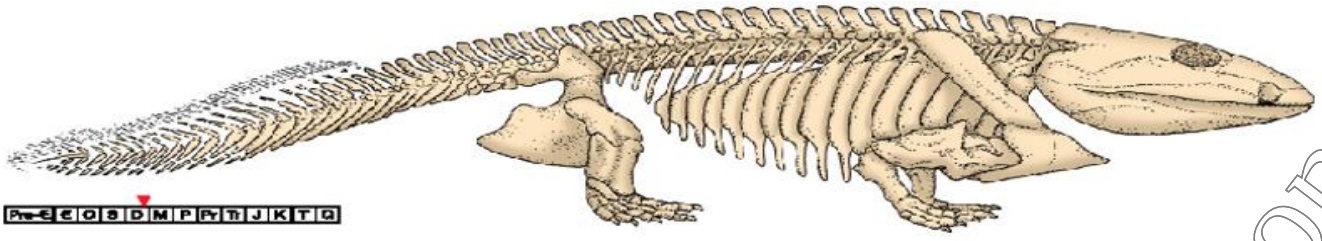
Chief characteristics and mode of life: Amphibians can live on the land as adults, but they lay their eggs in water. Young amphibians live in the water and are fish-like (tadpoles).

Geologic range: Late Devonian to Recent.

For 50 million years, from the Late Devonian to the Middle Carboniferous, amphibians were the only vertebrates to inhabit the land. Some adult amphibians reverted to an aquatic mode of life, while others retained a terrestrial lifestyle.

In the Late Devonian (about 375 m.y. ago), the first terrestrial vertebrate, ***Ichthyostega***, appeared. These amphibian fossils are found in freshwater deposits.

"Ichthyo" means "fish" and "stega" means "roof" or "cover" (probably referring to the bones in the roof of the skull).



*The skeleton of **Ichthyostega**, the first amphibian.*

Ichthyostega retained many features of its fish ancestors, such as:

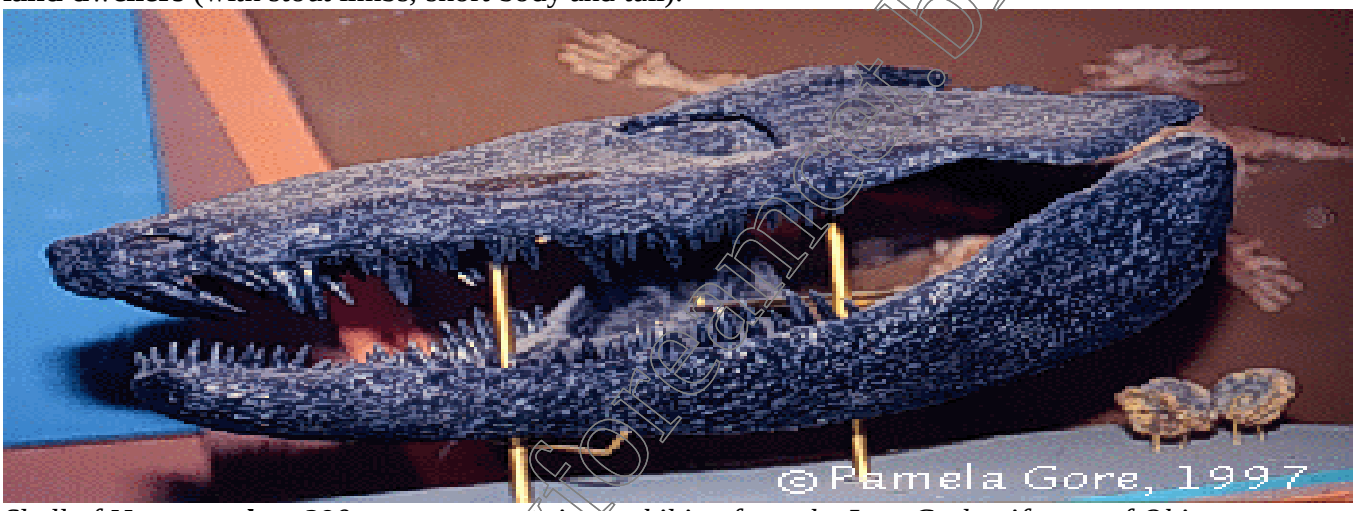
1. Scales
2. Similar skull structure, including arrangement of nostrils
3. Loosely connected fish-like spinal column

It also had a number of unique traits such as:

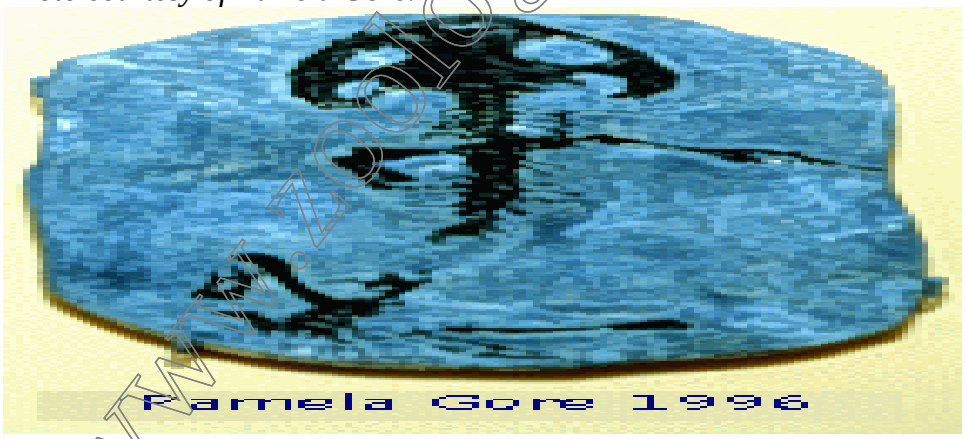
1. Five-toed limbs
2. Pelvic and pectoral girdles, allowing it to walk on land

Amphibians inhabited the **Carboniferous coal swamps**, and were abundant and varied.

They had several different modes of life, including some with an **aquatic lifestyle** (as suggested by features such as a flattened body and skull, reduced limbs, and a slender snake-like body), and some that were clearly **land dwellers** (with stout limbs, short body and tail).



*Skull of **Neopteroplax**, 290 m.y. ago, aquatic amphibian from the Late Carboniferous of Ohio.*
Features suggesting an aquatic lifestyle include a flattened body and skull, reduced limbs, and a slender snake-like body.
Photo courtesy of Pamela Gore.



***Amphibamus lyelli**, Middle Pennsylvanian, North America*
Photo courtesy of Pamela Gore.

Some Carboniferous amphibians were quite large, ranging up to 20 feet (about 6-7 meters) in length.
In contrast, most living amphibians are small.

Eryops is a typical Permian amphibian, with short, powerful limbs, which suggest that it was primarily a land dweller.

***Eryops**, large amphibian (about 5 feet or nearly 2 m in length) from the Permian, on display at the Pratt Museum, Amherst College, Amherst, Massachusetts.*
Photo courtesy of Pamela Gore.

Some Permian amphibians, such as ***Seymouria***, exhibit a combination of amphibian and reptilian features.

***Seymouria**, a land-dwelling amphibian from the Lower Permian of Texas, 260 m.y. ago, was less than 3 feet long.*
*Note stout limbs, short body and tail. A primitive amphibian similar to **Seymouria** was probably ancestral to the reptiles.*