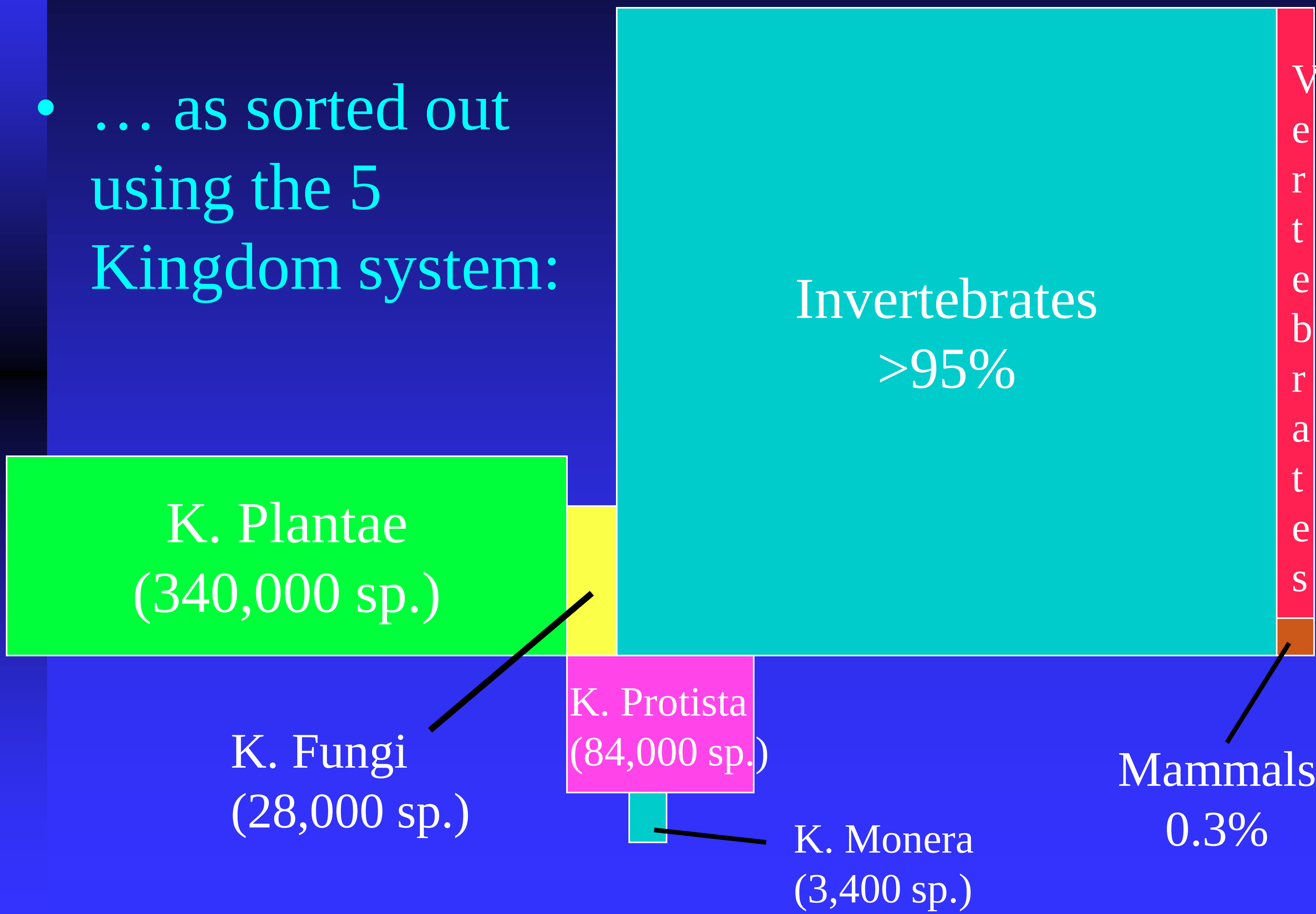
# 7 Basic Requirements of Animal Life

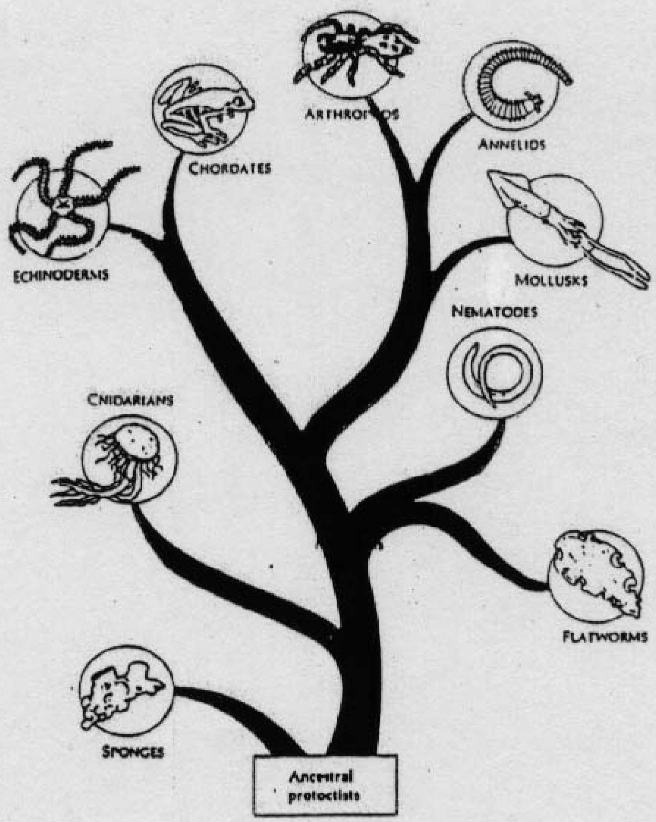
- 1. Gas exchange
- 2. Nutrition
- 3. Distribution and transport
- 4. Disposal of cellular wastes
- 5. Internal water and salt balance
- 6. Reproduction and development
- 7. Support and movement

# The Diversity of Living Species…

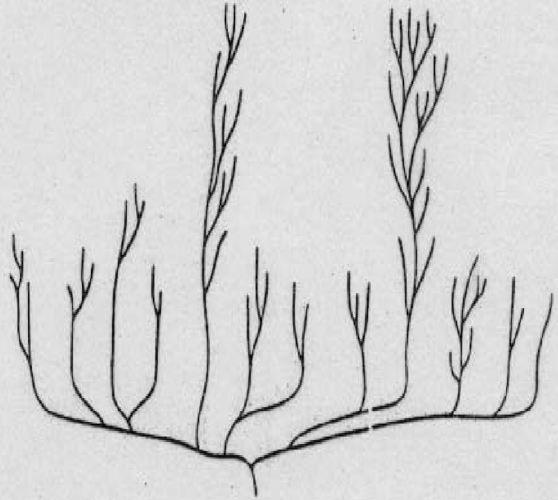
- … as sorted out using the 5 Kingdom system:



# Patterns of Evolution: The cone of increasing diversity vs. the revised model of decimation and diversification




Phylogenetic tree of the animal kingdom. Not all phyla are represented.

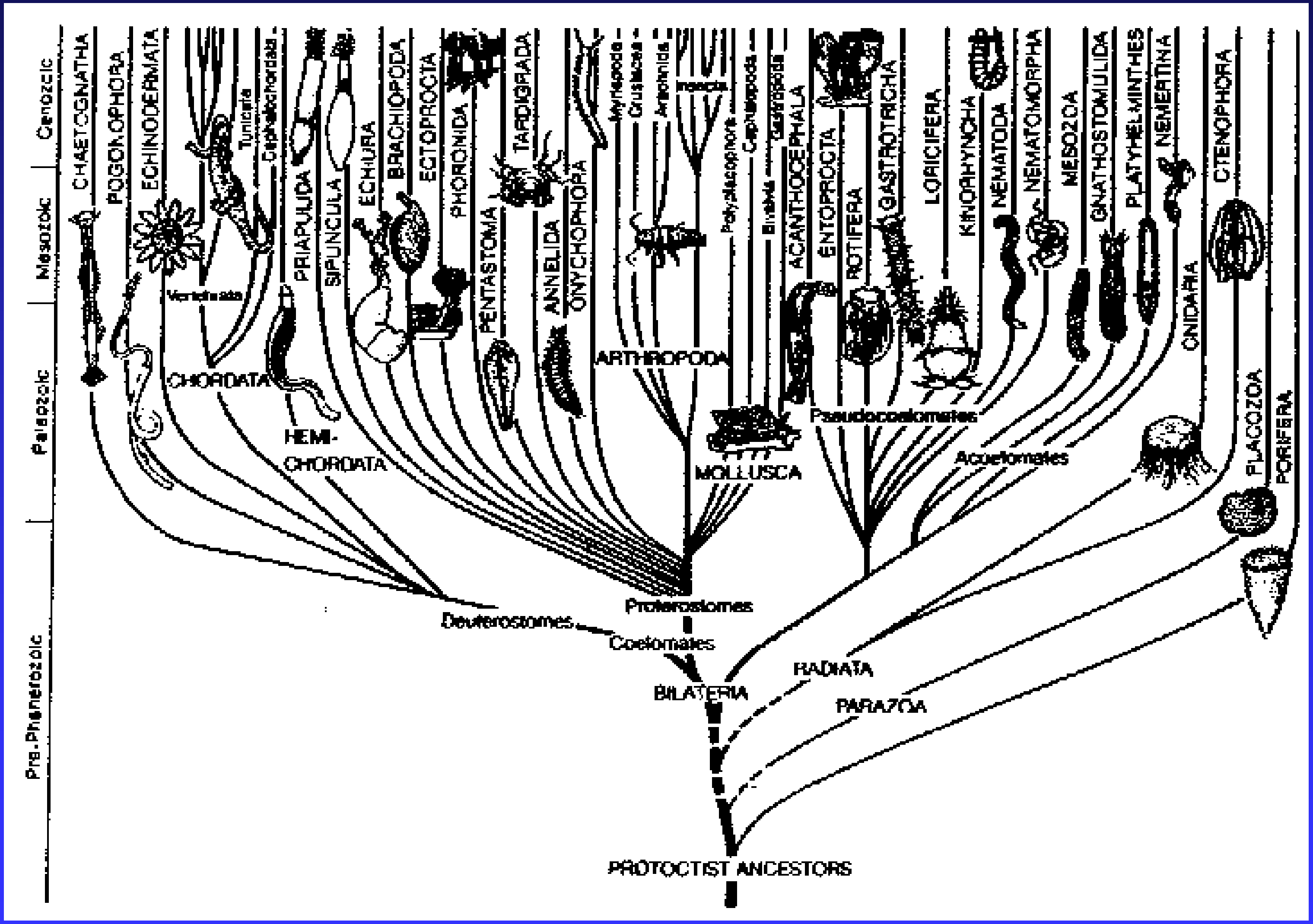


1.17. The false but still conventional iconography of the cone of increasing diversity, and the revised model of diversification and decimation, suggested by the proper reconstruction of the Burgess Shale.

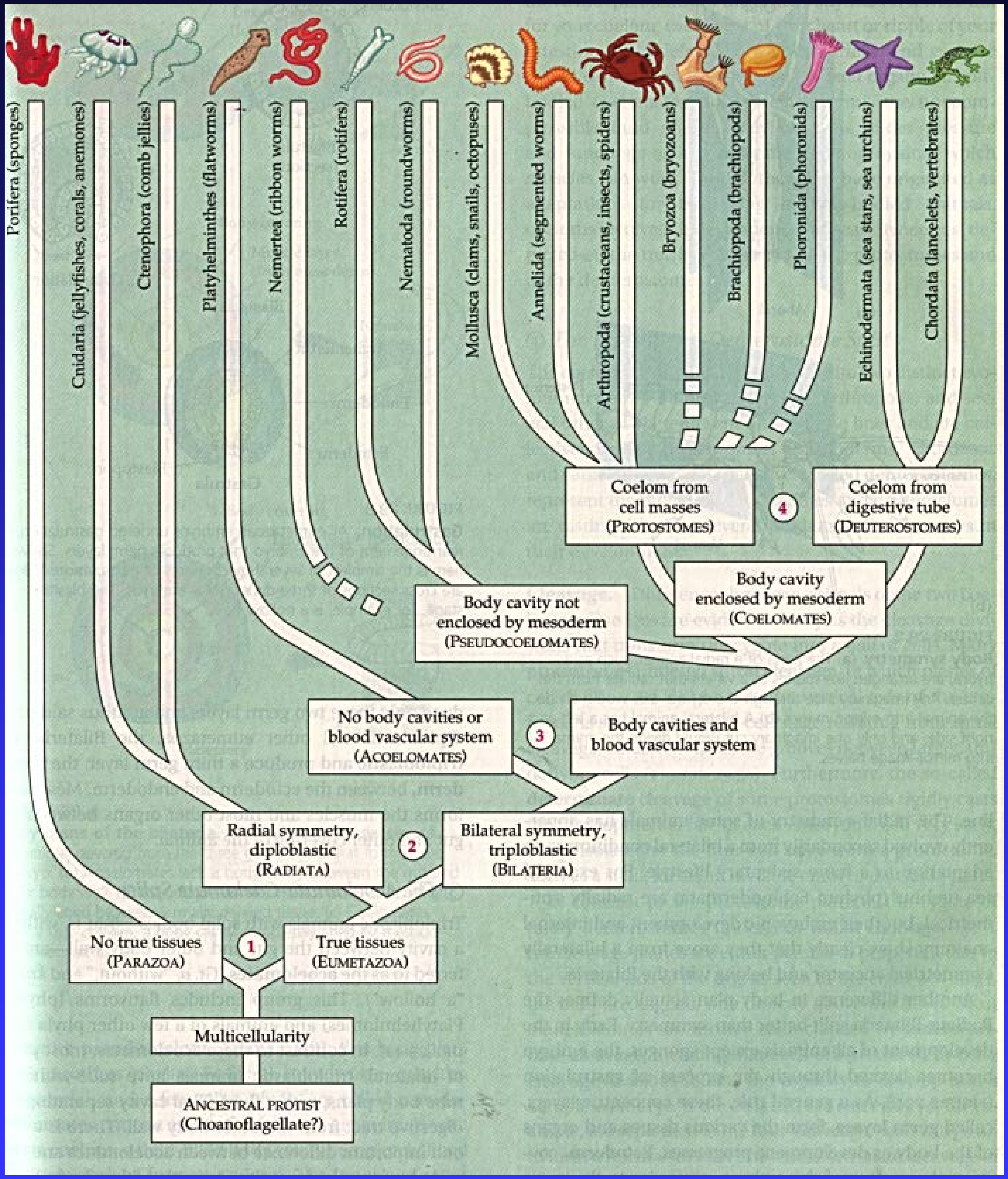
# The Cambrian Explosion: How do we explain this surge of biodiversity?

- 1. Food - The evolution of plants into all habitats provided abundant sources of food.
- 2. Motility - The ability to move enables a rapid adaptive radiation.
- 3. Predator-prey relationship - Active prey capture creates high selective pressure.
- 4. Sexual reproduction - The gametic life cycle allows for ample genetic variation.
- 5. Developmental features that enable diverse potential.
- 6. Genetic platform includes the potential for almost limitless re-engineering.
- 7. Global environmental changes lit the fuse.

# A modern view of animal diversity: The 33 Extant Animal Phyla



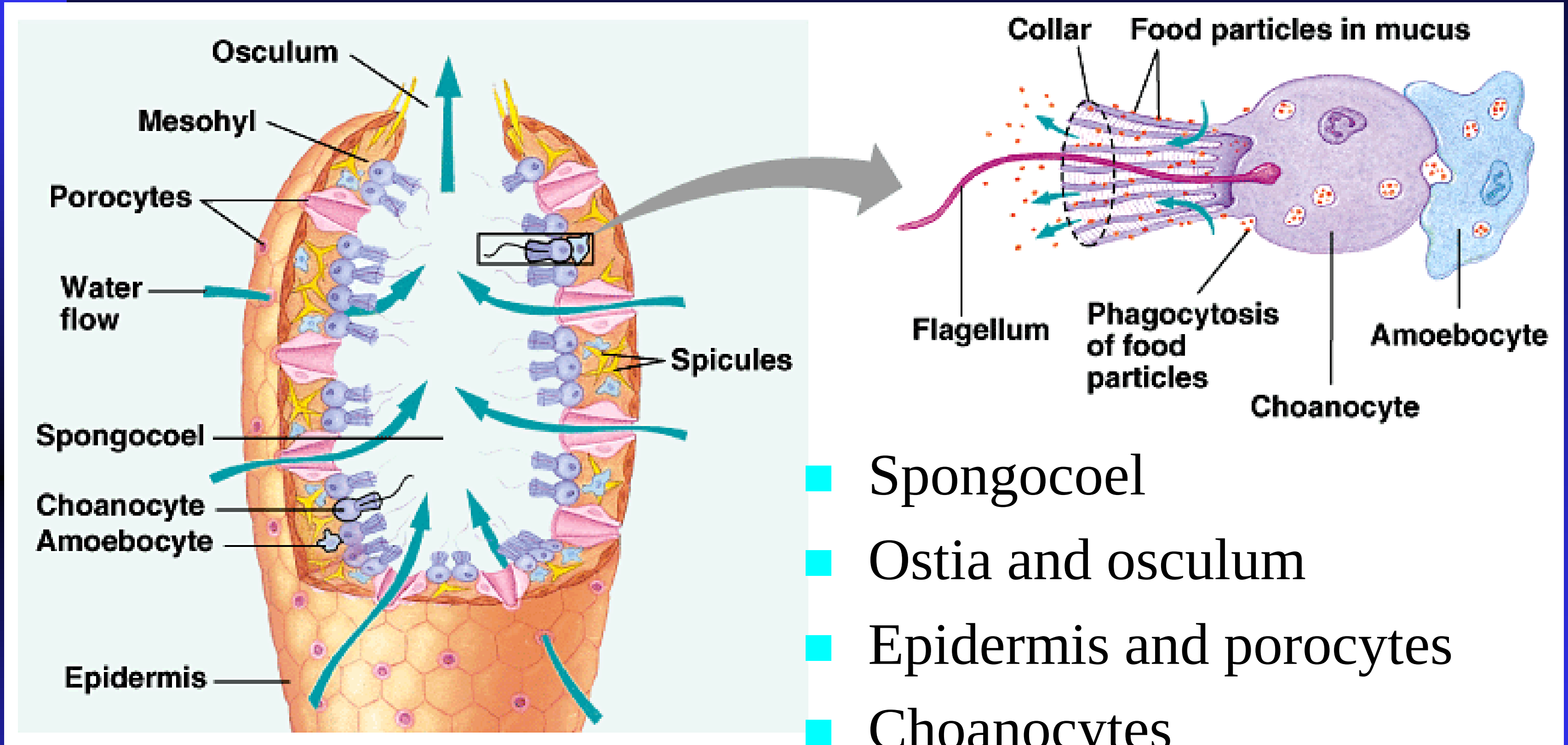
# A Hypothetical Phylogeny of Animals



# Phylum Porifera

- Approx. 9000 species
- Cellular level of organization
- Suspension/filter feeders
- Diffusion, diffusion, diffusion
- Osmoconformers

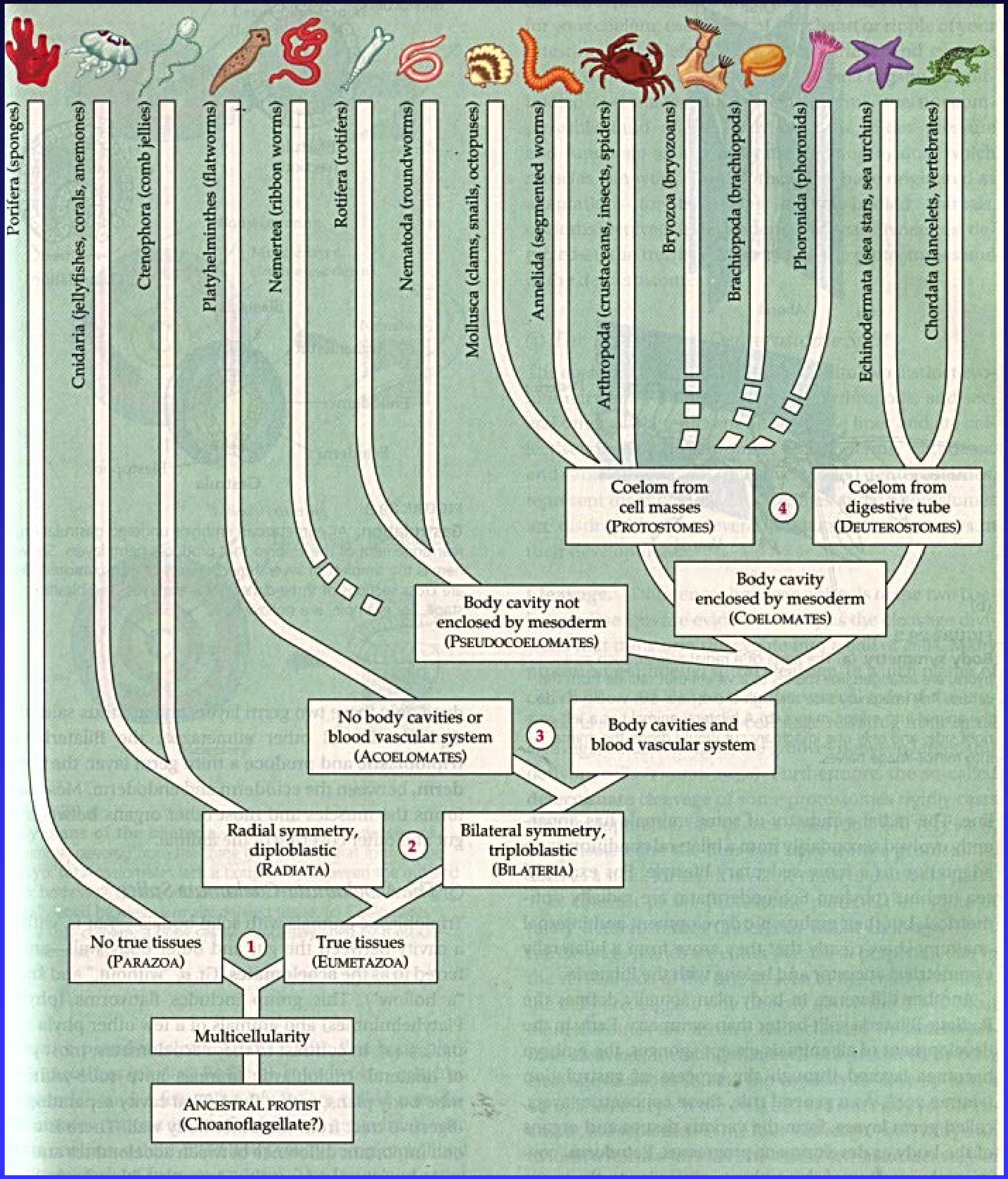
# Sponge Morphology:






- Spongocoel
- Ostia and osculum
- Epidermis and porocytes
- Choanocytes
- Mesohyl
- Amoebocytes
- Skeletal:spicules or spongin
- reproduction

# A Hypothetical Phylogeny of Animals

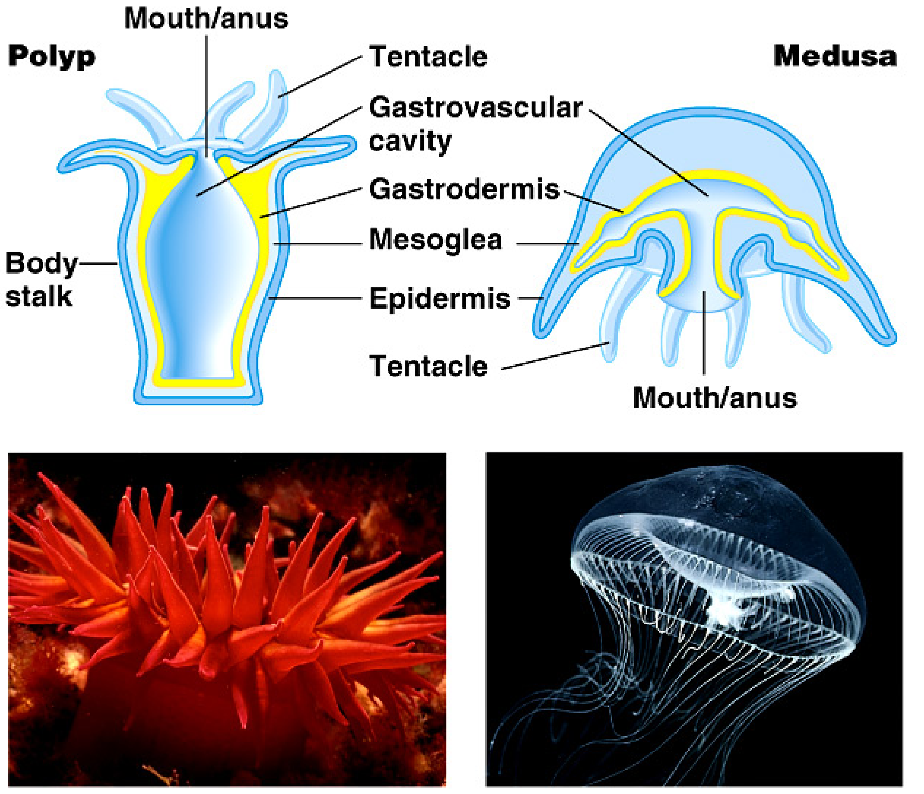


# Phylum Cnidaria:
## hydras, jellfish, sea anemones and corals

- *Ediacara* fossils
- Radial Symmetry
- Diploblastic: Tissue level of organization
    - Ectoderm: outer layer, epidermis
    - Endoderm: inner layer, gastrodermis

# Cnidarian Body Plan

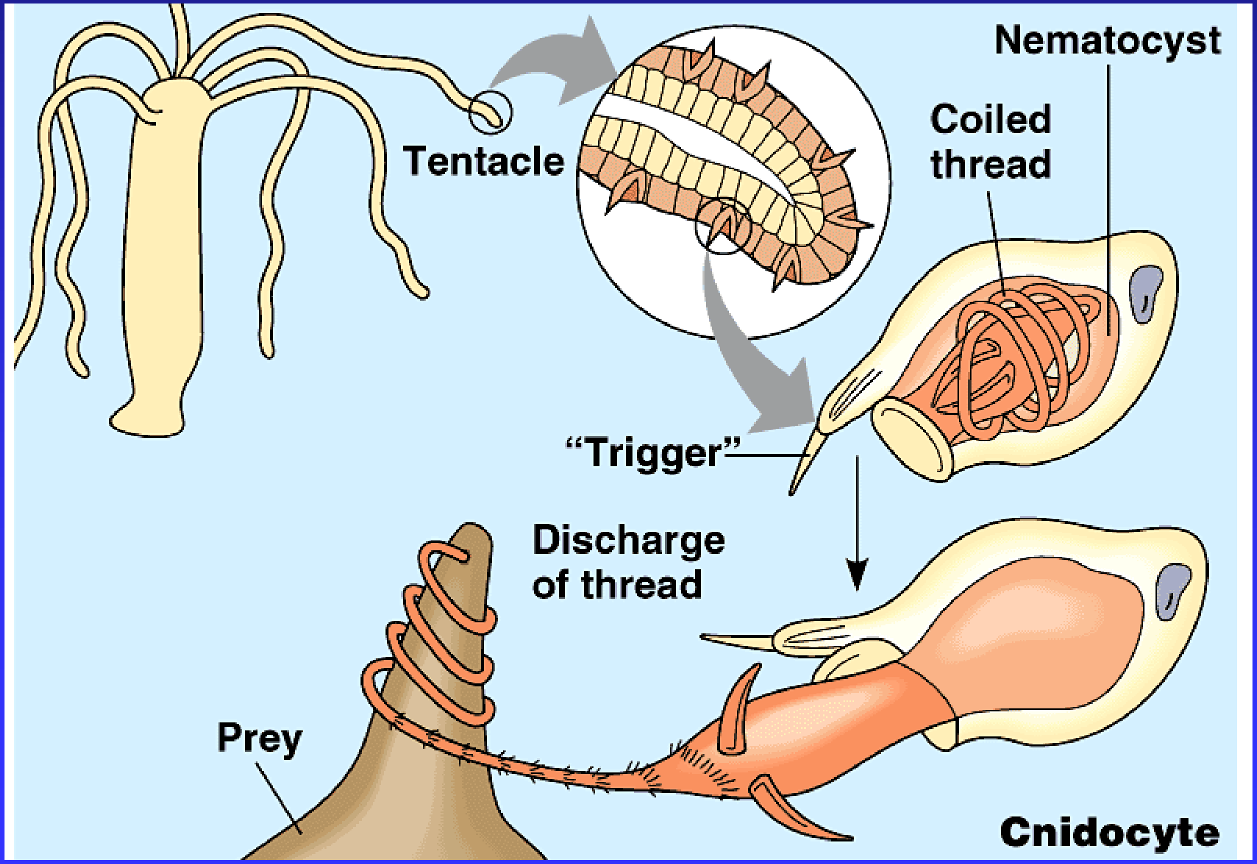
- Polyp: sessile form
- Medusa: planktonic form
- General features:
  - Tentacles w/ cnidoblasts
  - Gastrodermis lined w/ flagellated cells
  - mesoglea




(a) Sea anemone: a polyp
(b) Jelly: a medusa

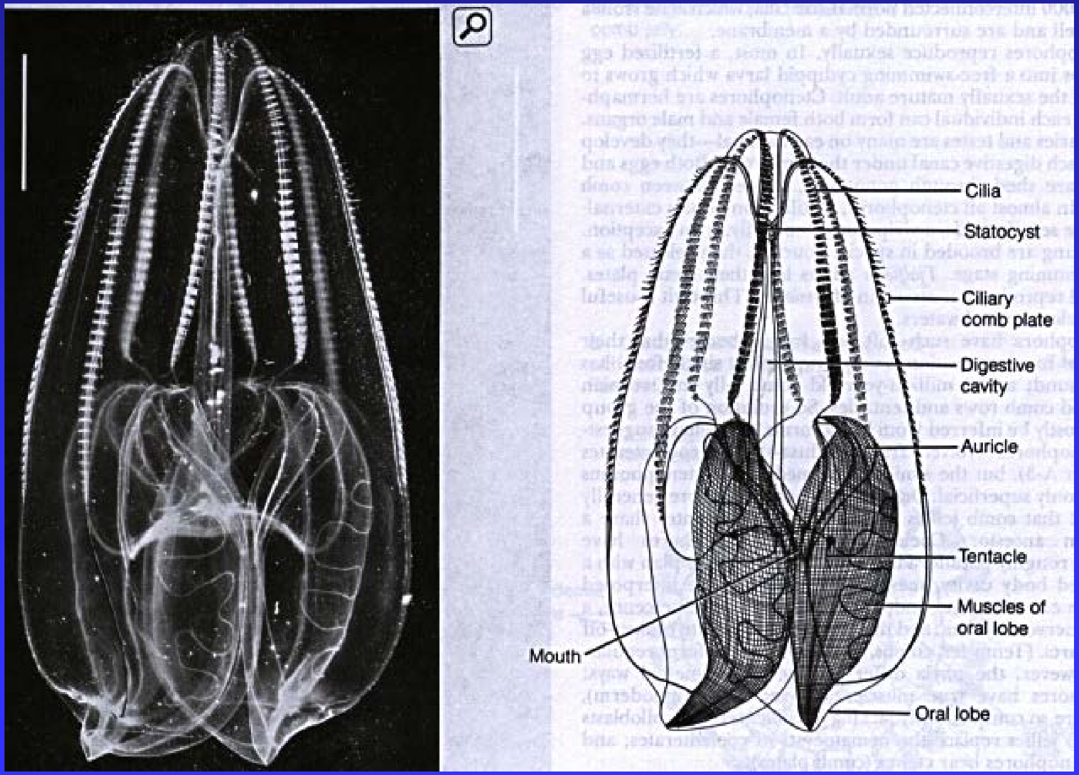
# Cnidarians are Carnivores

- Tentacles capture and deliver prey to GV cavity
- Cnidoblasts: cnidocil (trigger), nematocyst (barbed fiber w/ poison)
- Simple neuromuscular system and hydrostatic skeleton

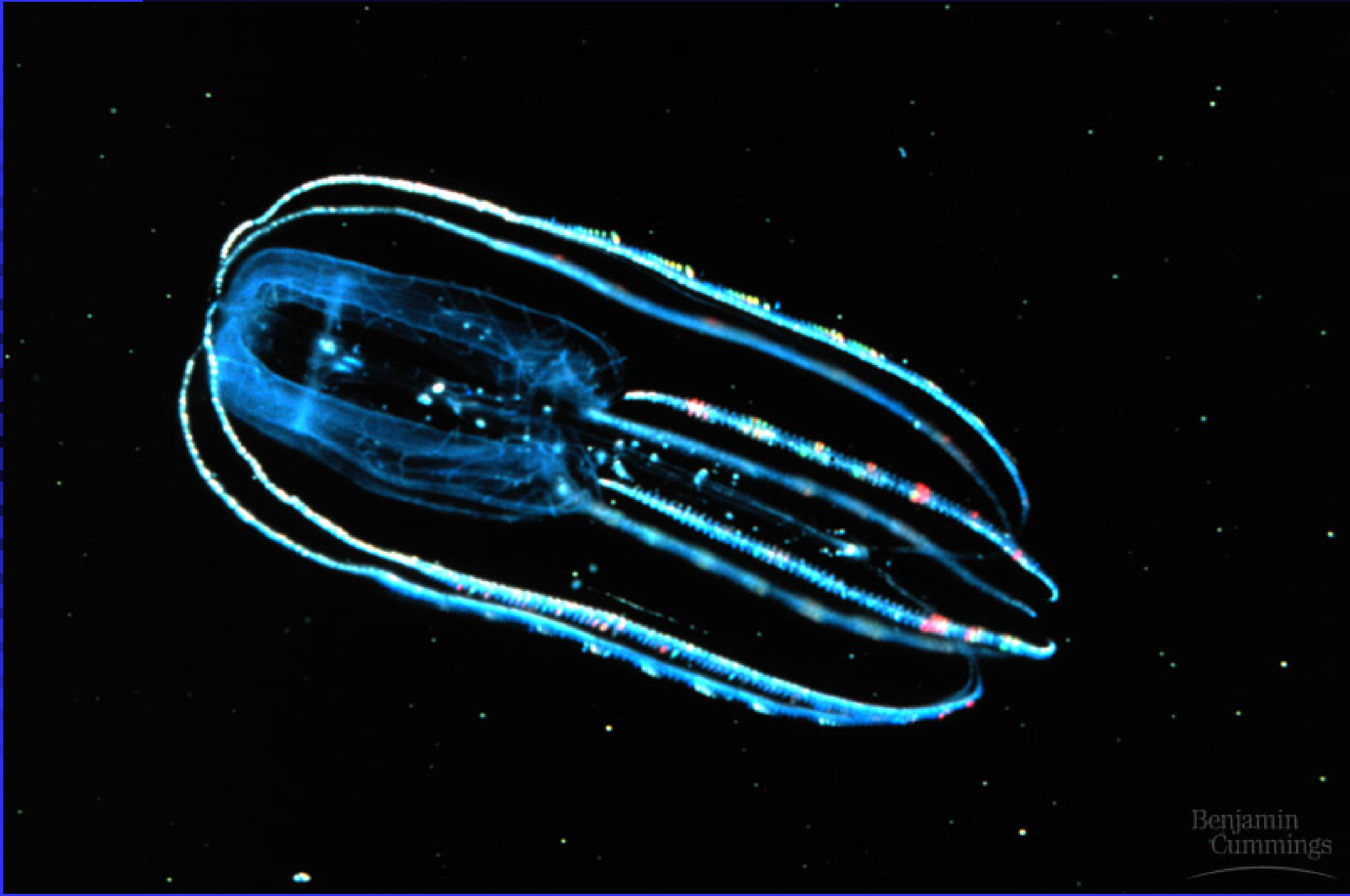


# Phylum Ctenophora: comb jellies

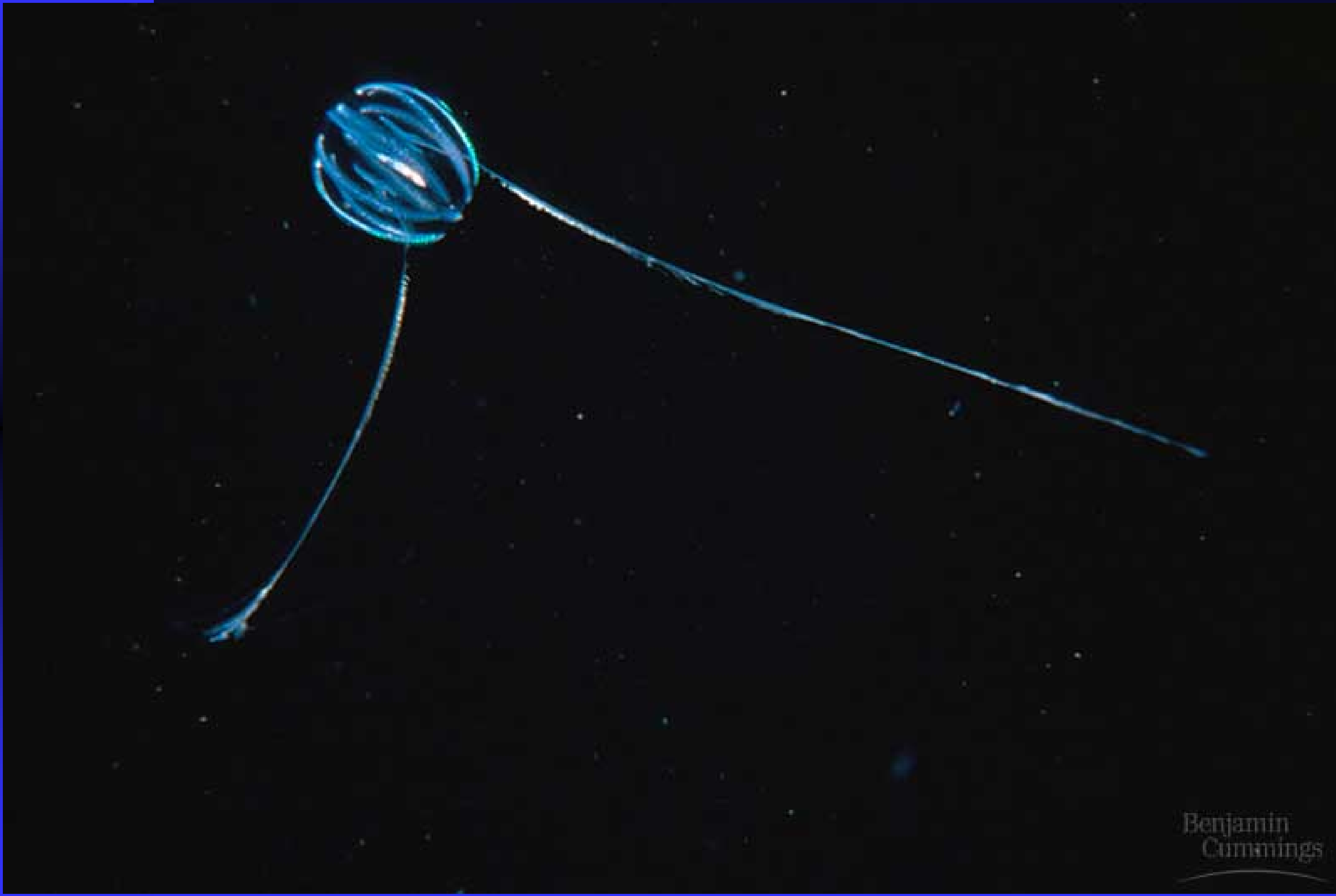
- Homology to Cnidarians
- Unique ctenophoran features



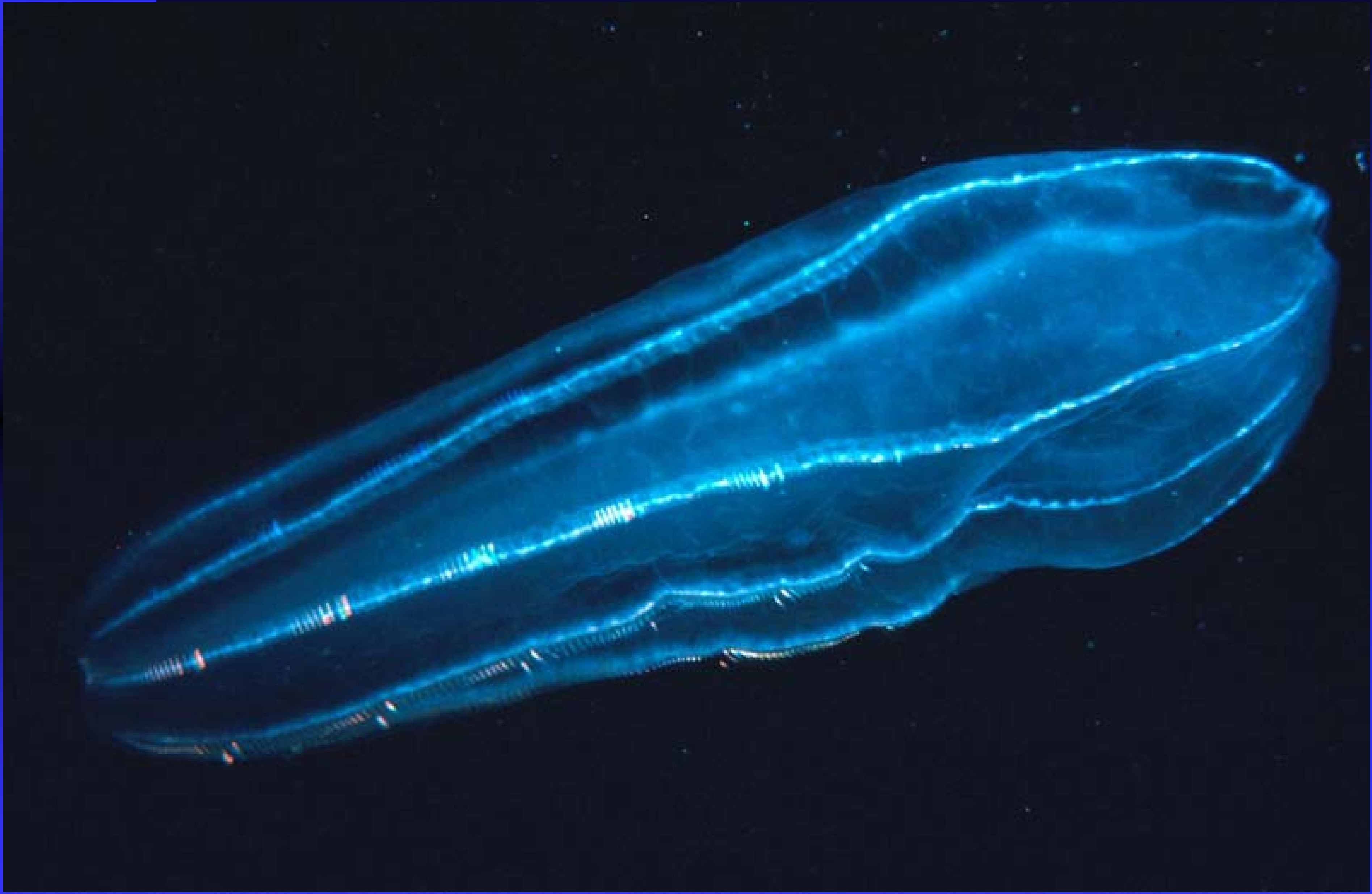
# A ctenophore, or comb jelly



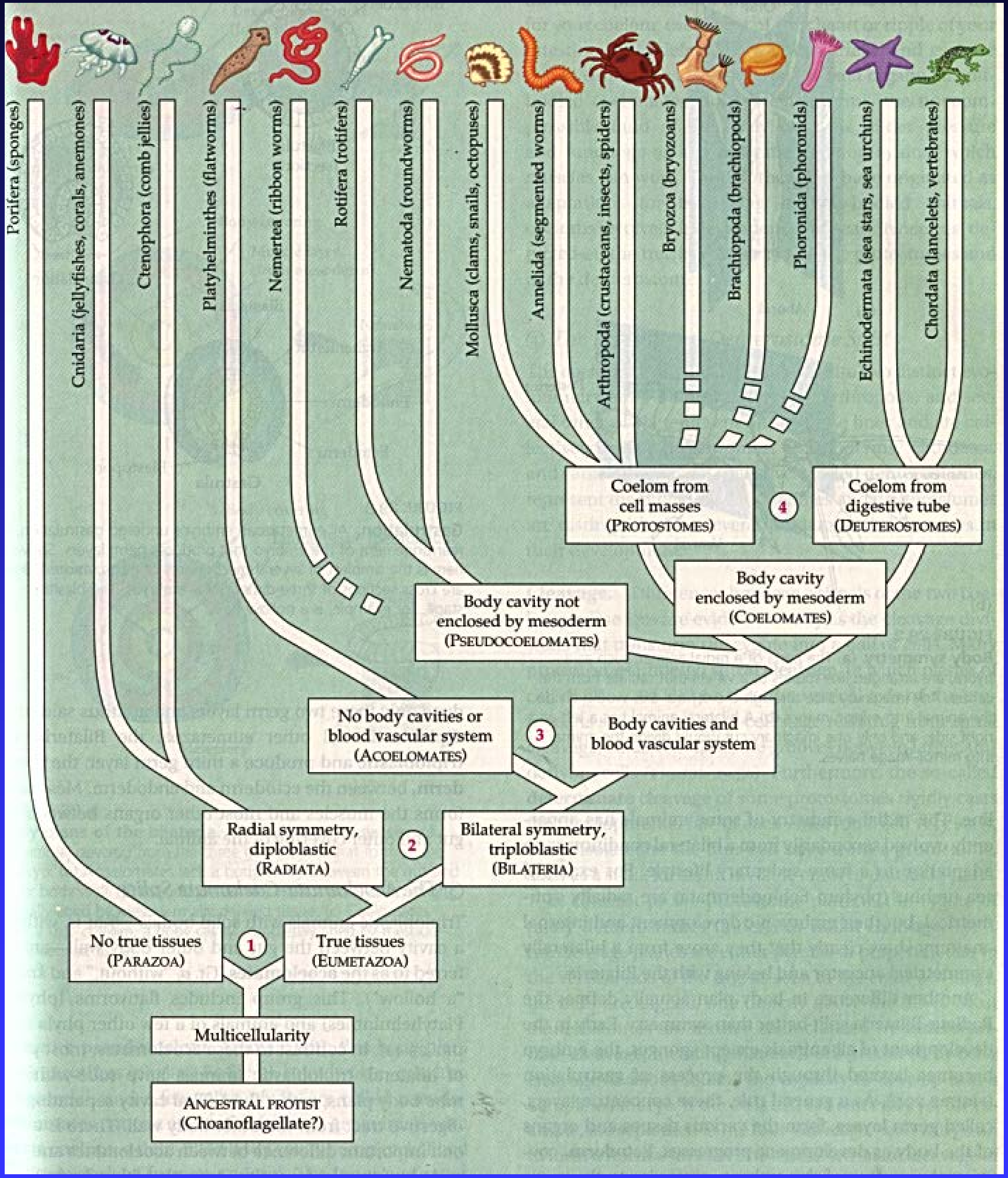
# Sea gooseberry, *Pleurobrachia pileus*



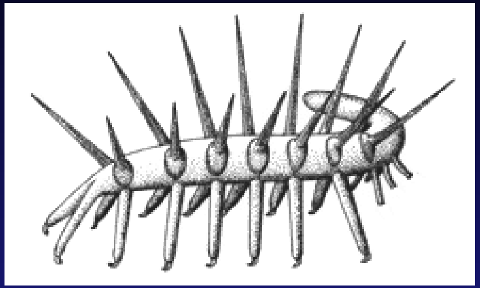
# Ctenophore



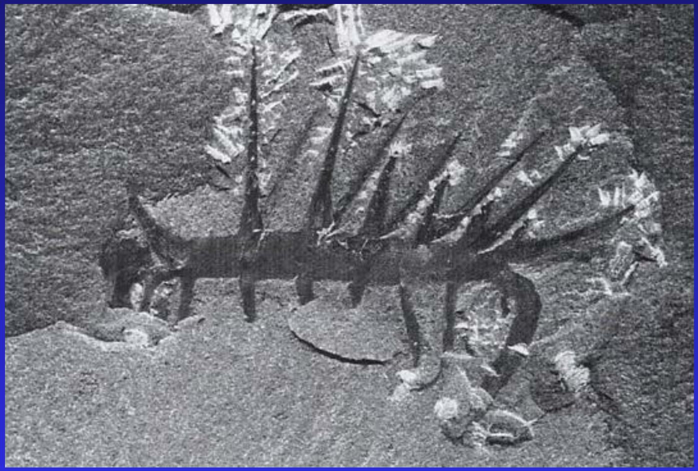
# A Hypothetical Phylogeny of Animals

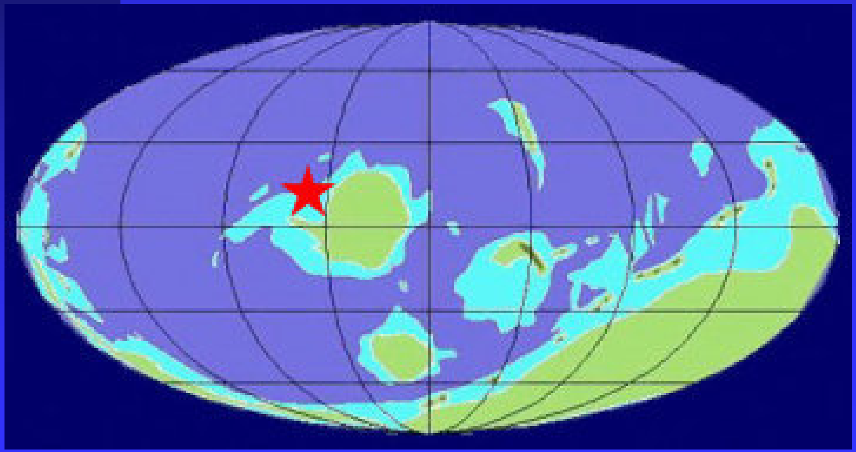


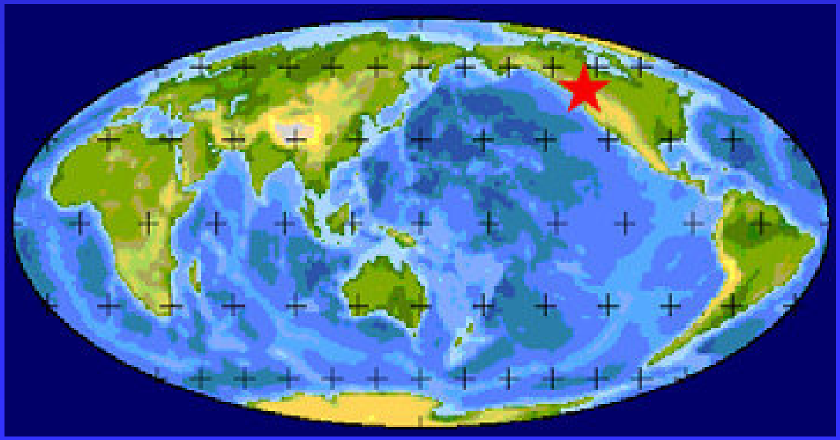
# The Serendipity of Fossils



- Preservation
- Non-compression
- Mineralization
- Elevation, Erosion and Exposition







# The Burgess Shale: Yoho National Park, British Columbia, Canada

# Field, British Columbia, Canada
Aug 21, 2004

# On the trail and in search of Trilobites

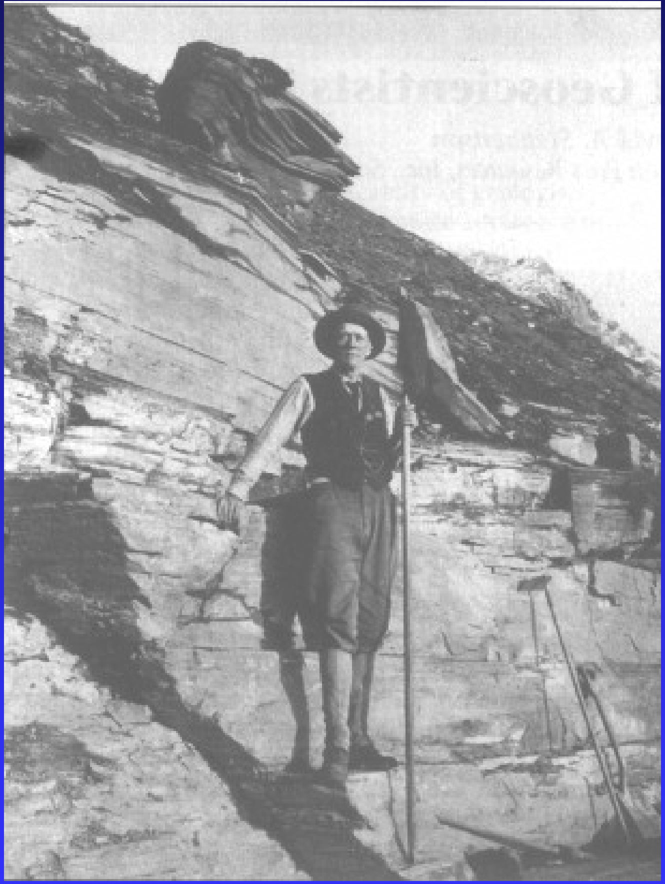
# On route to the Walcott Quarry


WAPTA HIGHLINE TRAIL
NOTICE OF CLOSED AREA / ZONE INTERDITE
This trail passes adjacent to Burgess Shale Fossil Beds. These fossil beds have been designated as a UNESCO World Heritage Site, and are located in a Closed Area. Access and entry to the Burgess Shale Fossil Beds is Prohibited. For more information contact the Field Visitor Information Center.
Ce sentier passe près des lits fossilifères des schistes argileux de Burgess. L'Unesco les a designés site du patrimoine mondial; ils sont situés dans un secteur fermé. L'accès aux lits fossilifères des schistes argileux de Burgess est interdit. Communiquer avec le centre d'accueil de Field pour obteni de plus amples renseignements
IT IS UNLAWFUL TO REMOVE FOSSILS / IL EST ILLÉGAL DE RECUEILLIR DES FOSSI

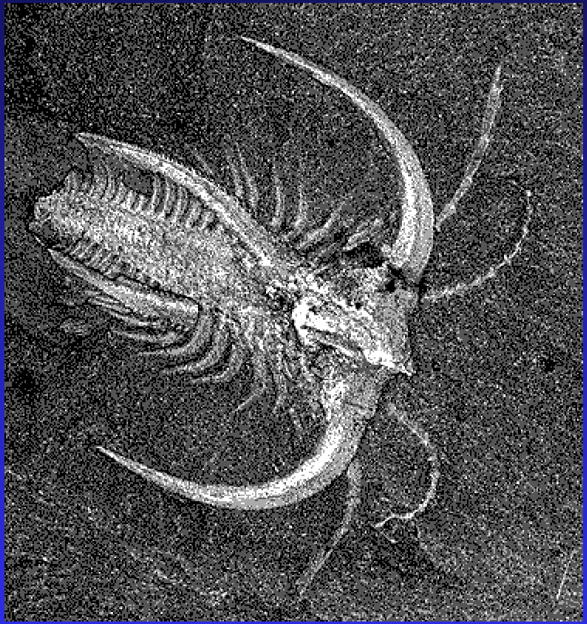
# The Burgess Shale, then and now…

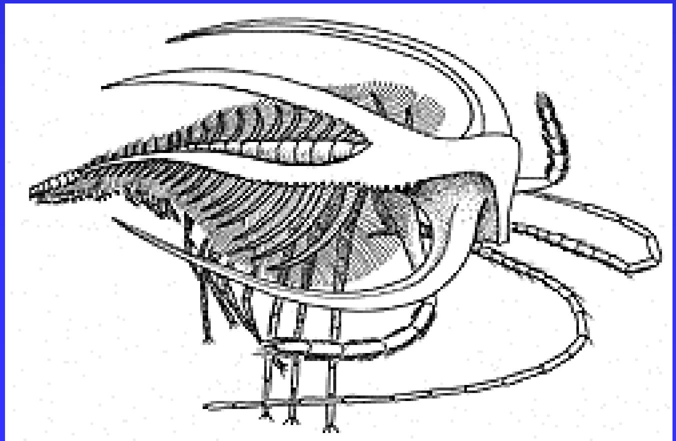
- The Burgess Shale Aug 27, 2004

*Marrella splendens:* A primitive arthropod, <1 in., first collected by Walcott ("lace crab"), the most abundant specimen in the quarry (15,000 specimens)

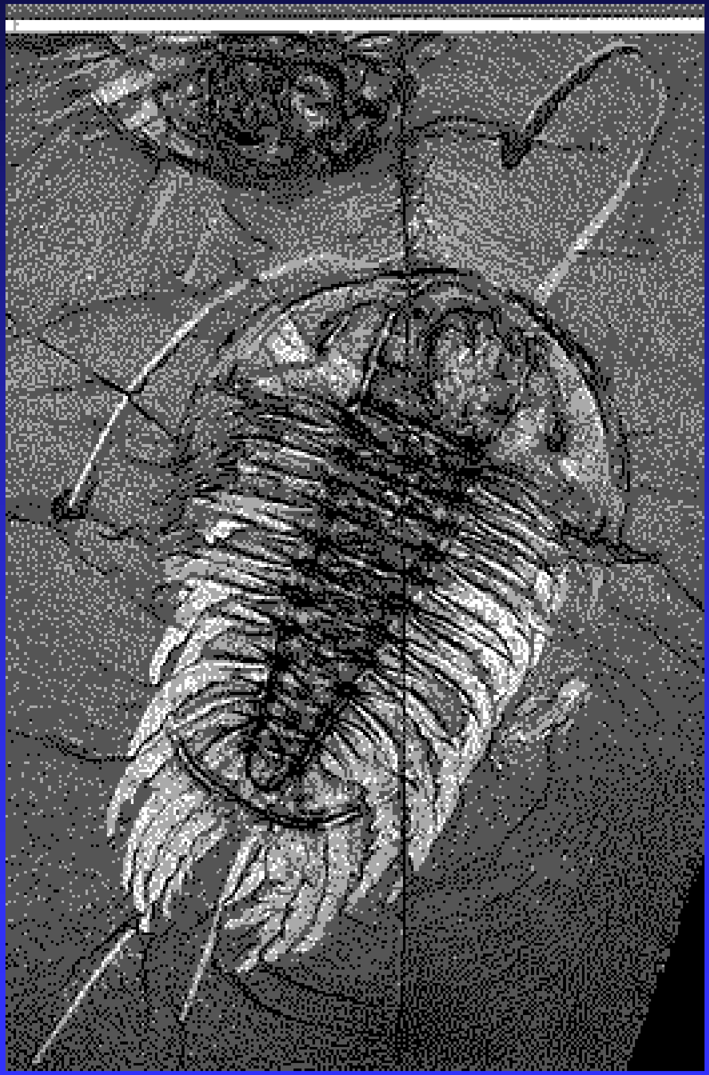


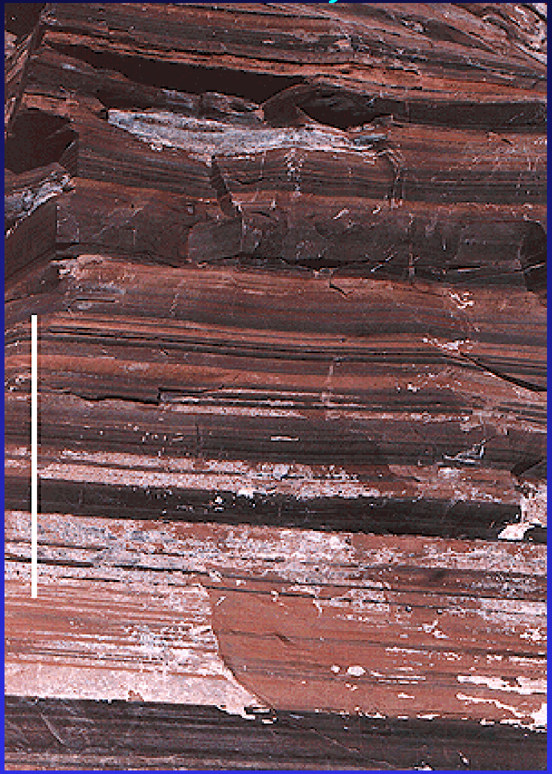
Charles Doolittle Walcott
Director of Smithsonian Inst.

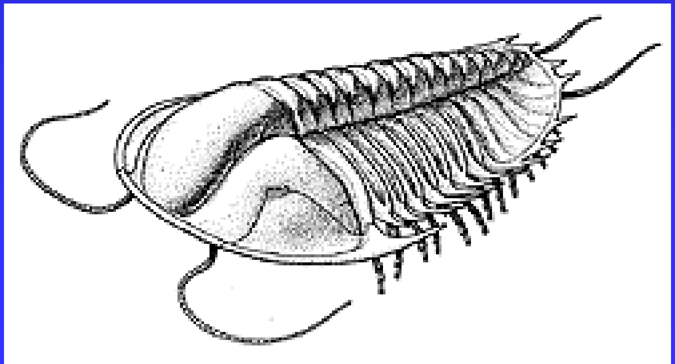




# *Olenoides serratus:* Trilobite, 4 in.

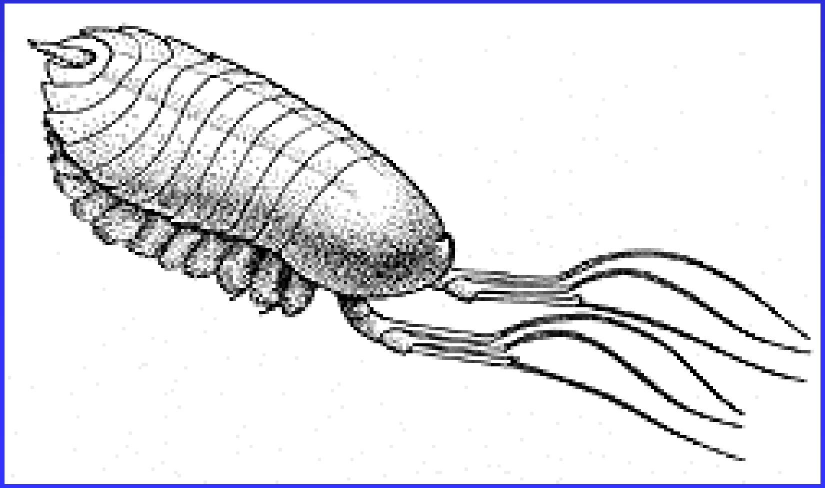




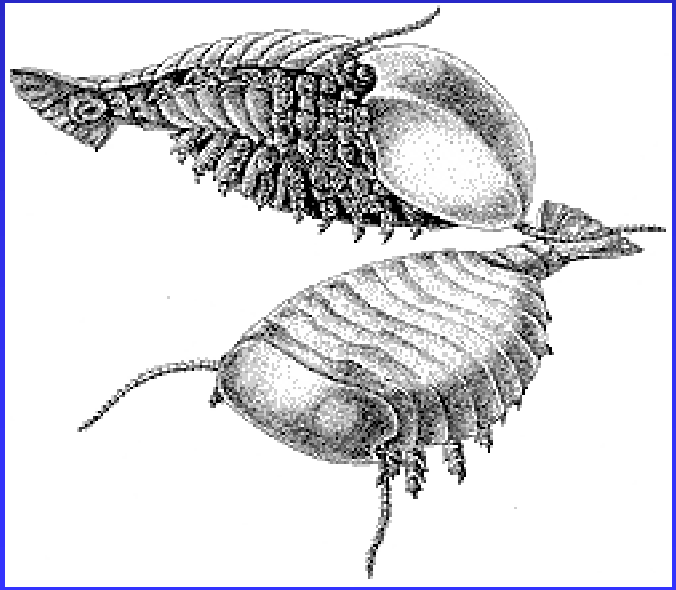


*Leanchoilia superlata:* Arthropod, no eyes, but long feelers, 2 in., related to spiders and scorpions

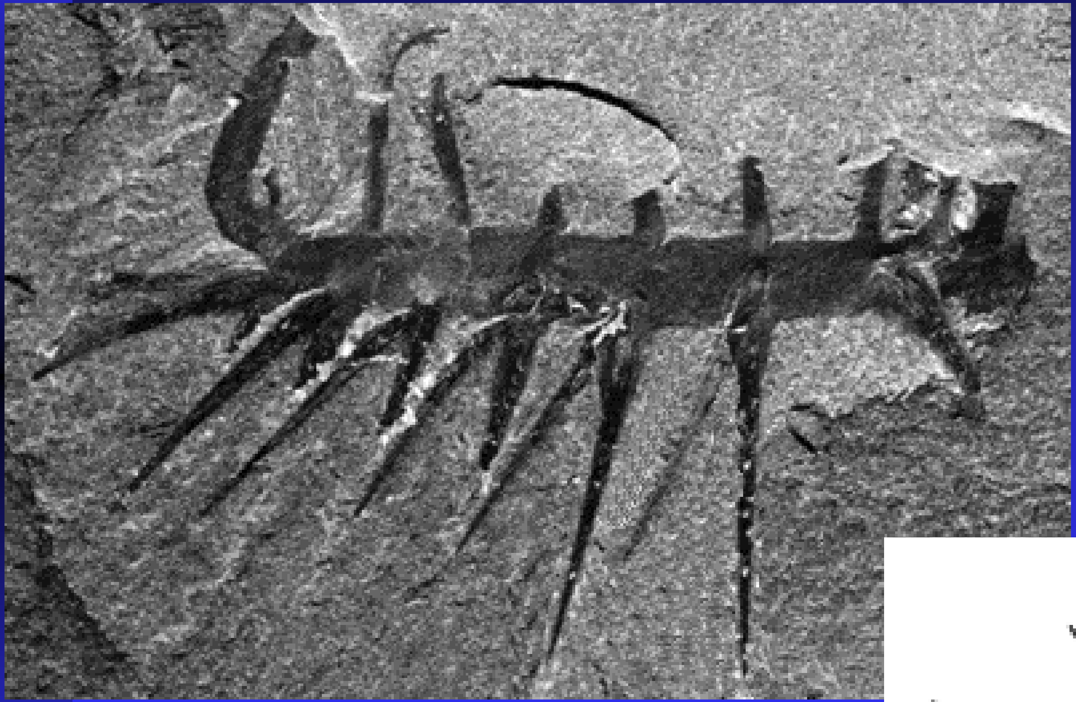
Dr. Desmond Collins, Curator
Royal Ontario Museum

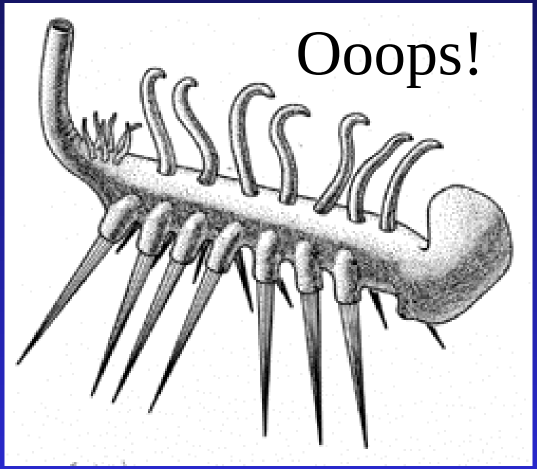


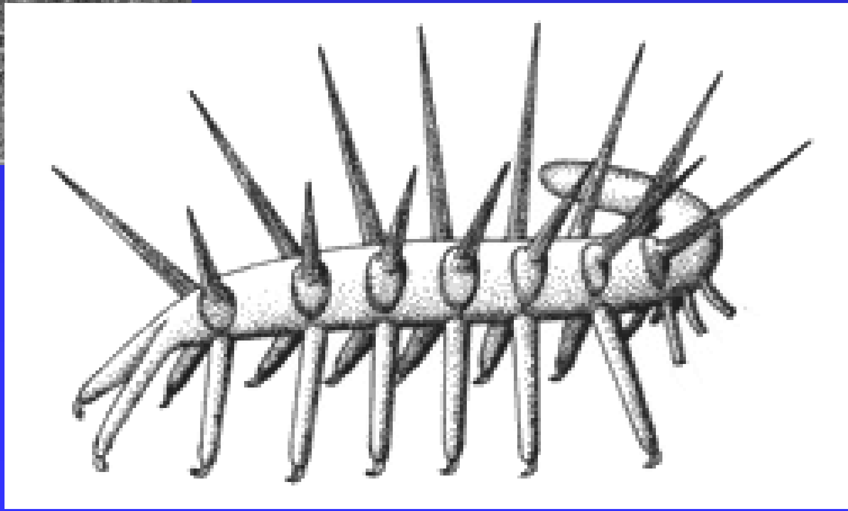
*Sidneyia inexpectans:* arthropod, very numerous in Burgess shale, 5 in.



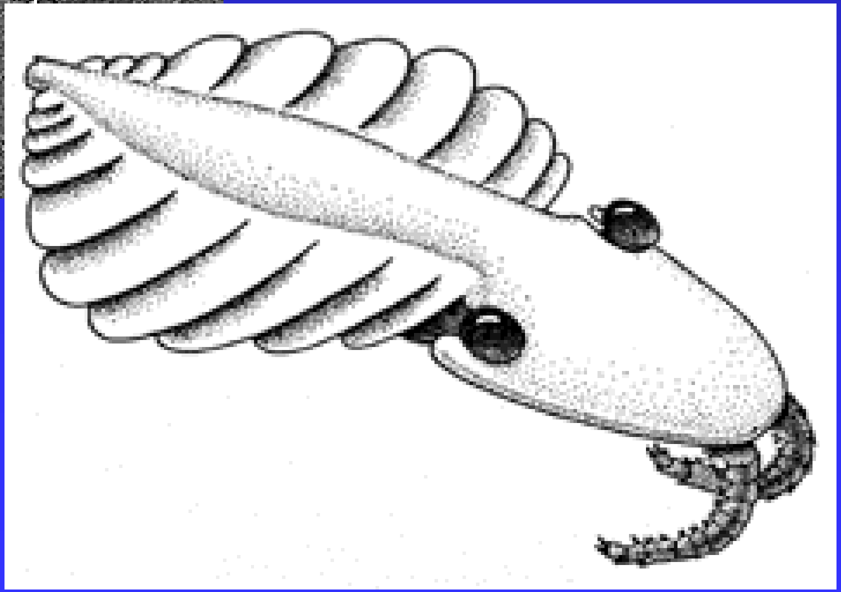
# *Hallucigenia sparsa:* An onychophoran ("velvet worm")



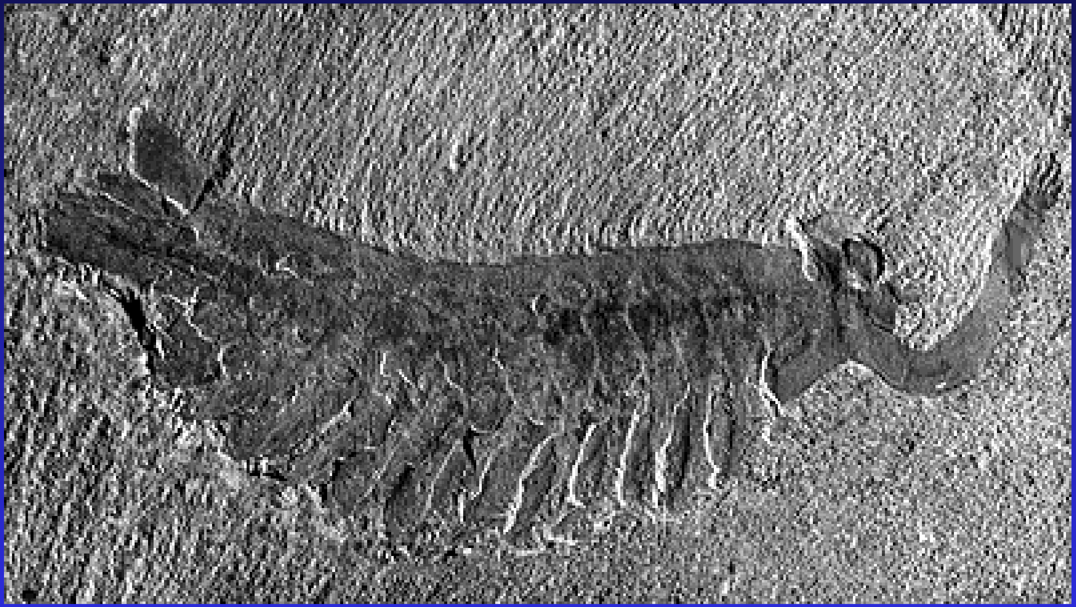


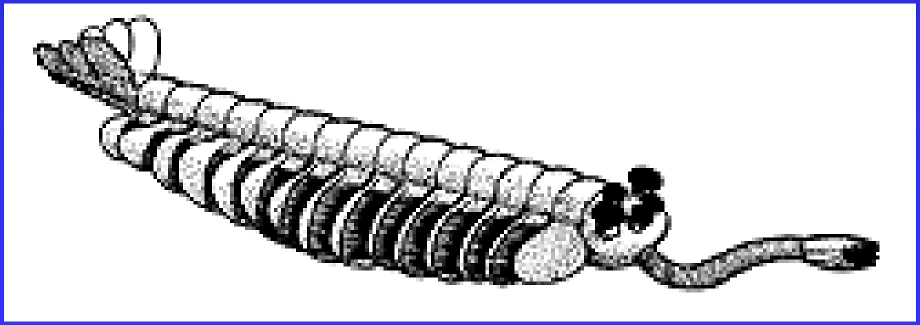



# *Anomalocaris canadensis: a* proto-arthropod, widely distributed and up to 6 ft. long



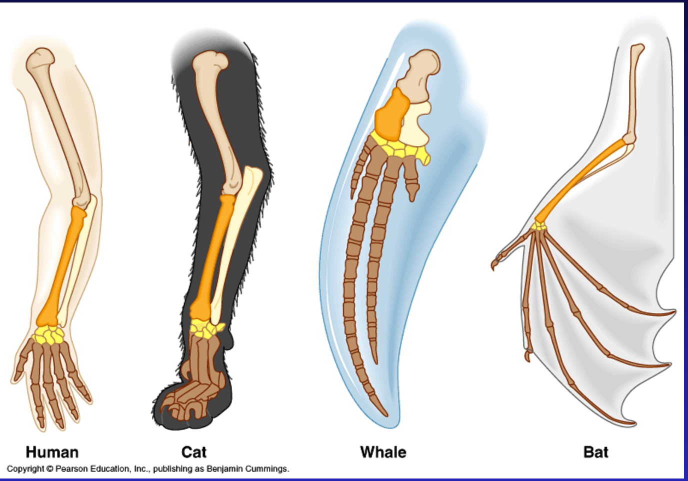
# *Opabinia regalis:* Unassigned to any major group, 5 eyes, a long flexible clawed-proboscis, 4 in.

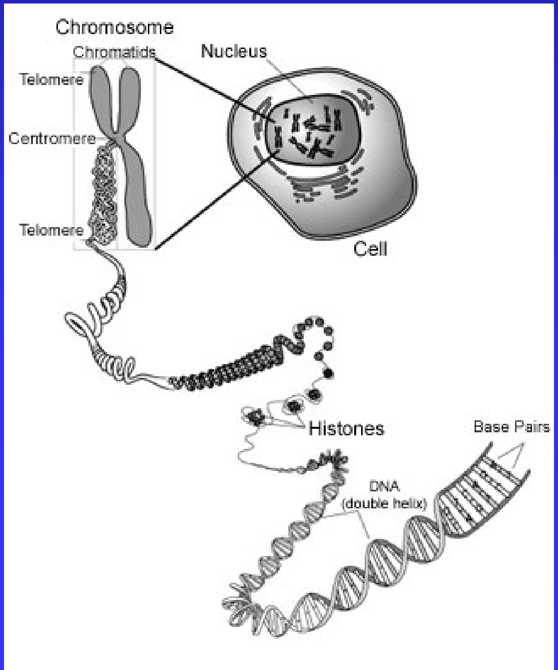




# A paradoxical view of biodiversity based on homology and shared genes

- Biodiversity as viewed by Darwin
- A modern view of Biodiversity:
  - Anatomical, cellular, biochemical and genetic homology
  - Paradoxical revelations from our genome
    - 22,500 human genes=6 X *E. coli* or 1.5 X fruit fly
    - Homologies: bacteria 15%, yeast 25%, fruit fly 50%, frog 70%, mouse 93%, chimpanzee >98%
- Building bodies Lego style:
  - Modular construction, repetition, serial homology
- With so much homology, novelty and complexity can only emerge as products of *conservation and renovation*, not *innovation*!

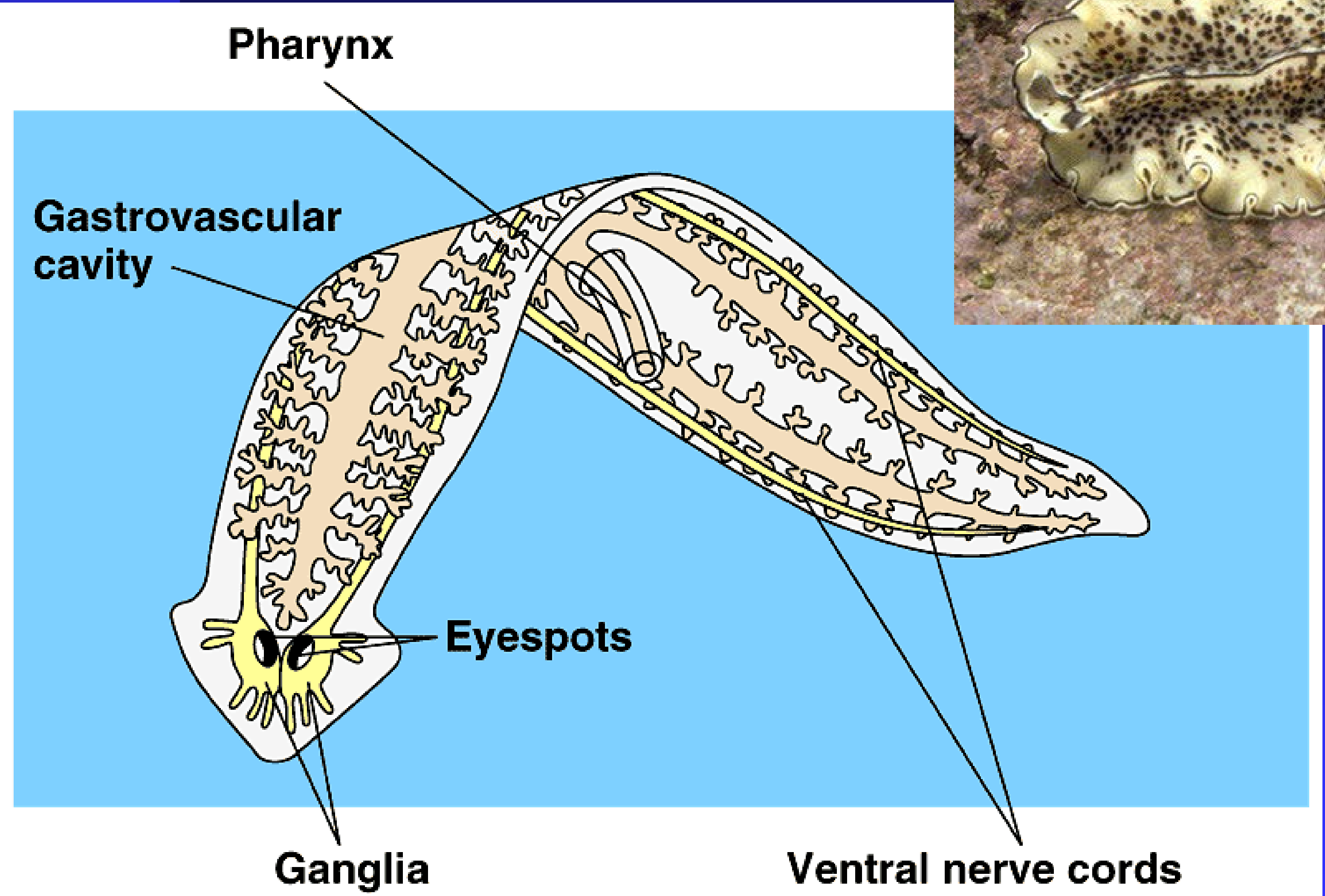


# Phylum Platyhelminthes

- Dorso-ventrally flattened: high SA:vol
- Parasitic and free-living
- 3 Primary tissues:Organ level organization
    - Digestive system
    - Nervous system
    - Reproductive system
    - Excretory system

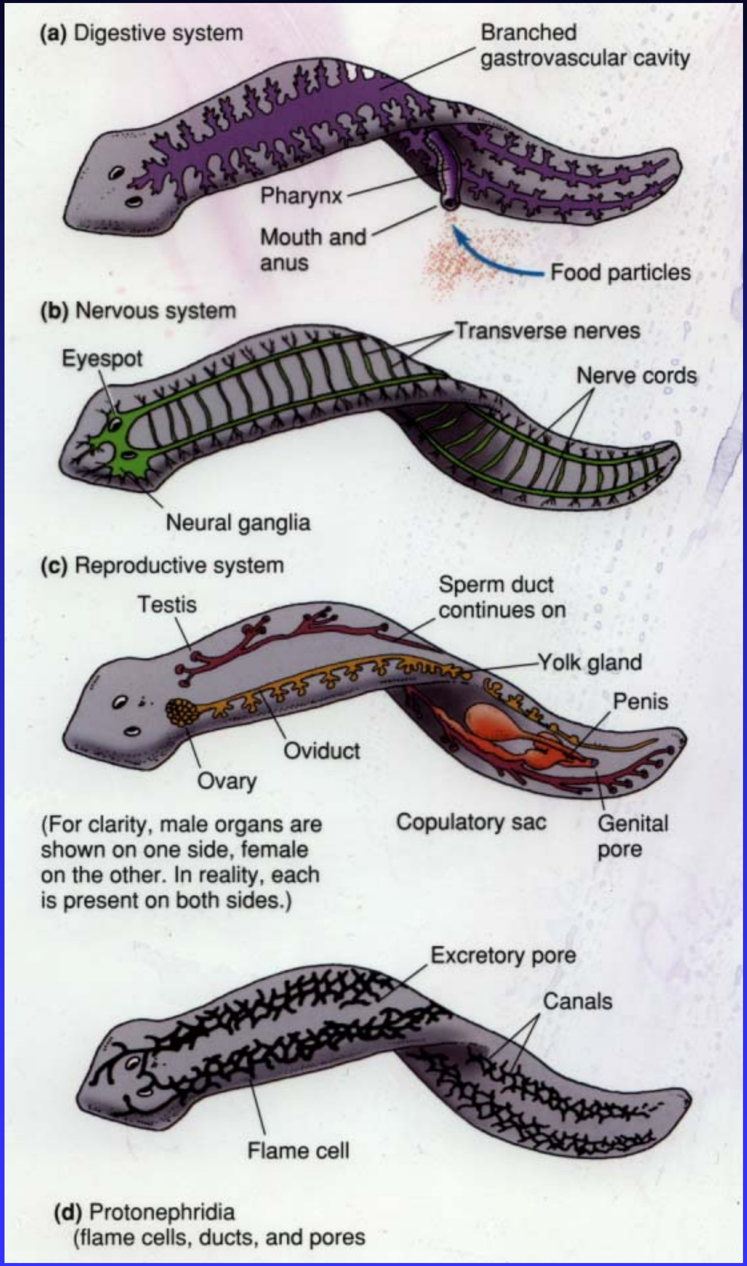
# Anatomy of a planarian



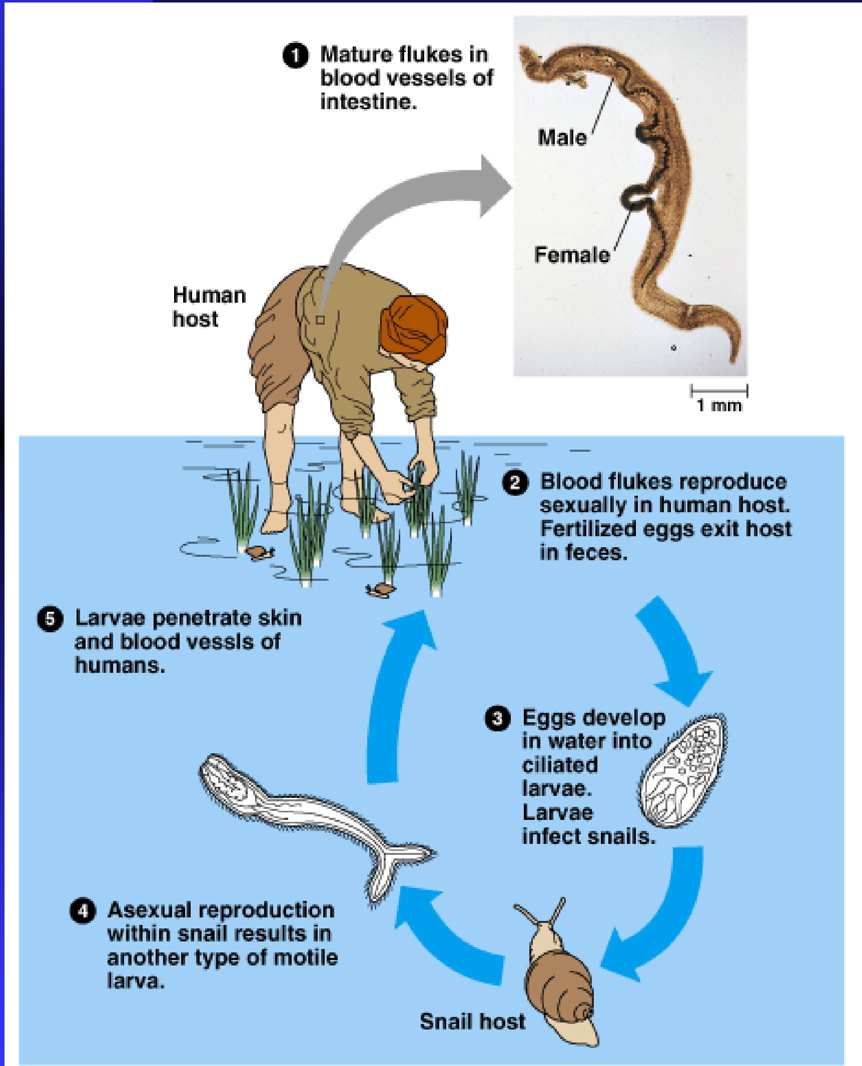


# The template for all animal life to come…

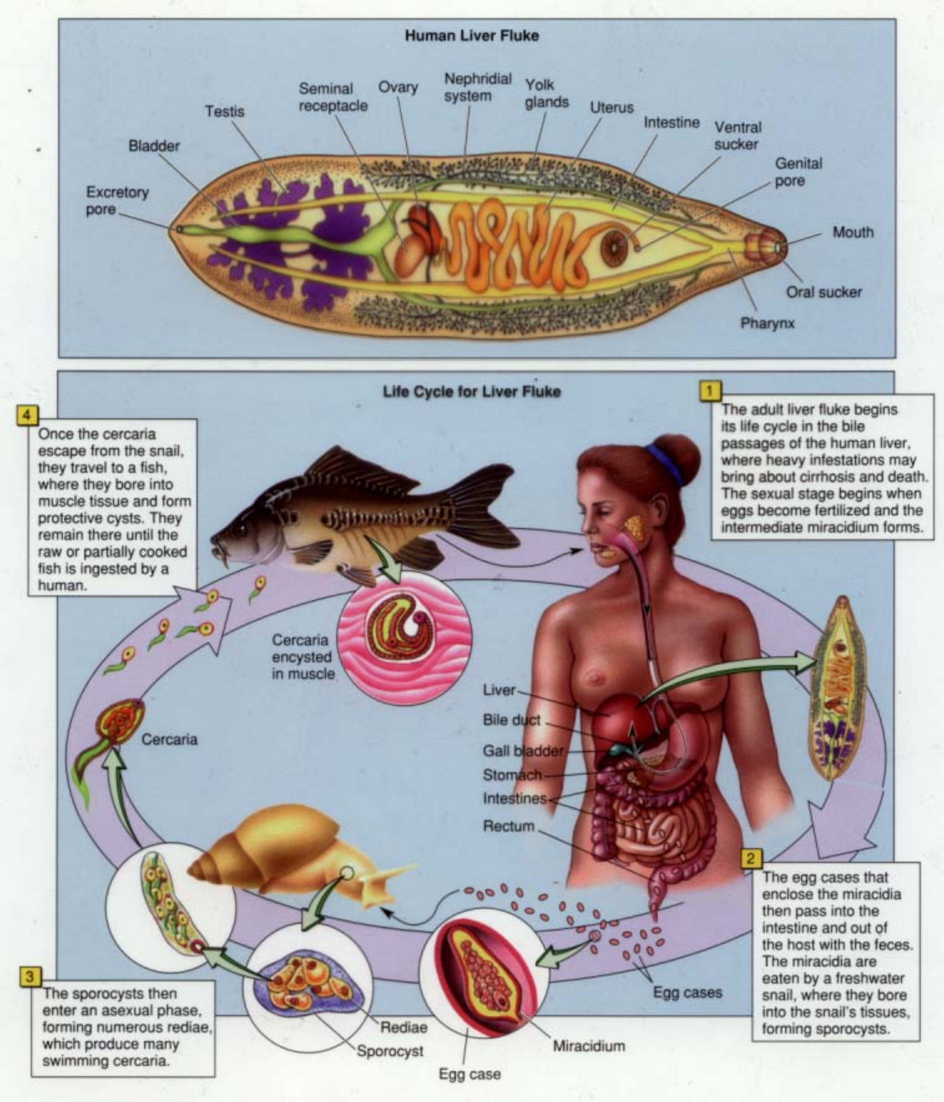
- Digestive system
- Epidermis
- Body muculature
- Nervous system
- Excretion
- Osmoregulation
- Reproduction



# Class Trematoda: The life history of a blood fluke and a liver fluke





# Class Cestoda

- Scolex instead of a head
- No digestive system
- Proglottids as reproductive packets

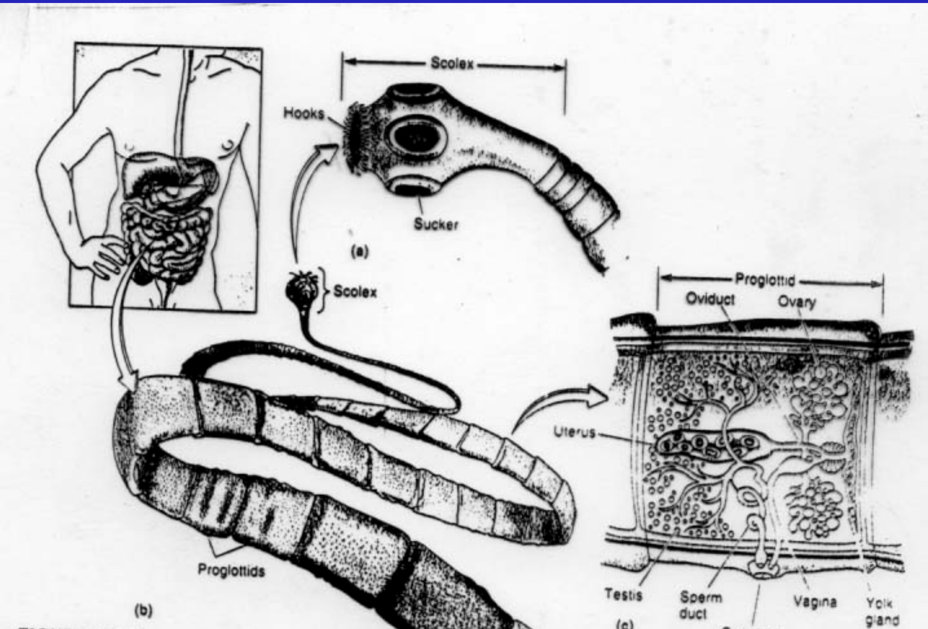
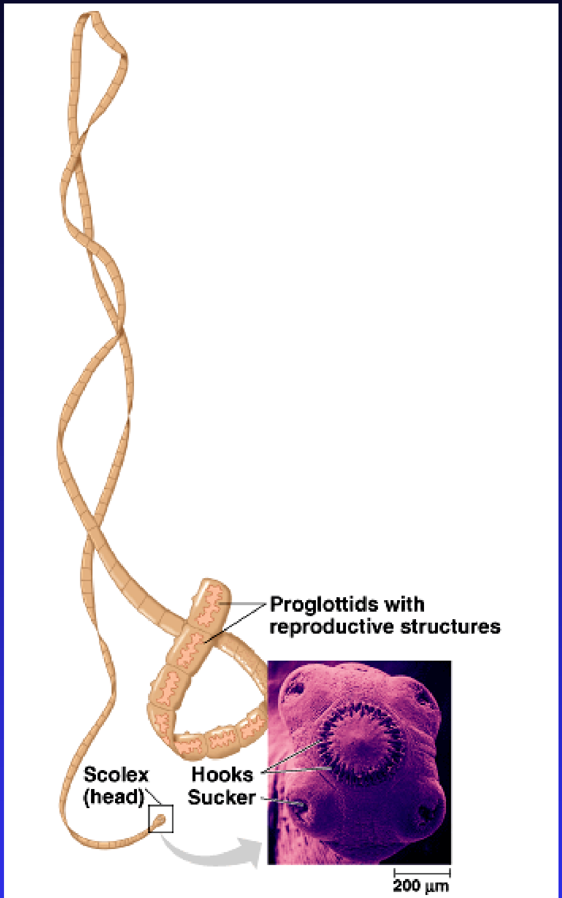
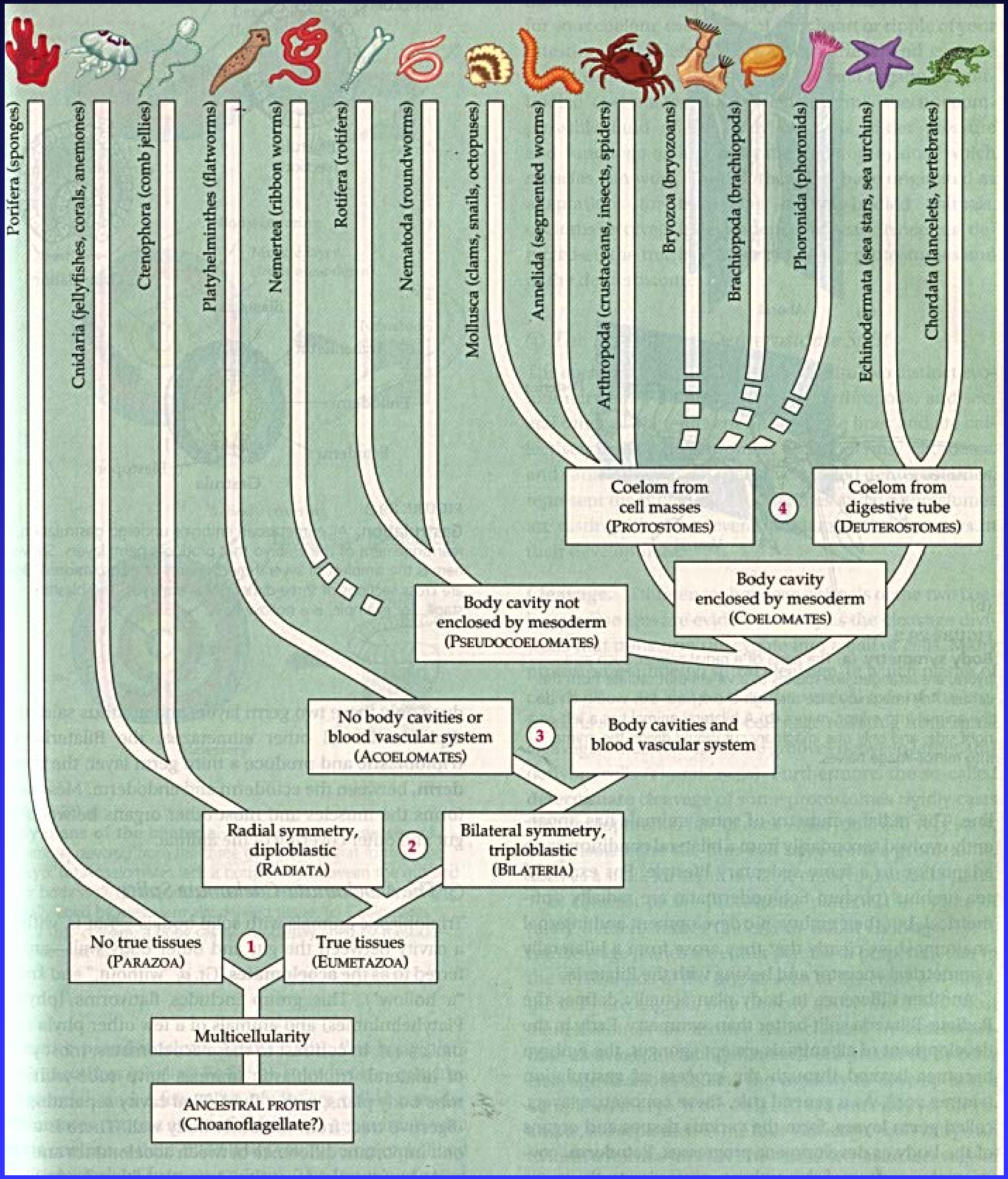


FIGURE 26.15
Tapeworm Anatomy

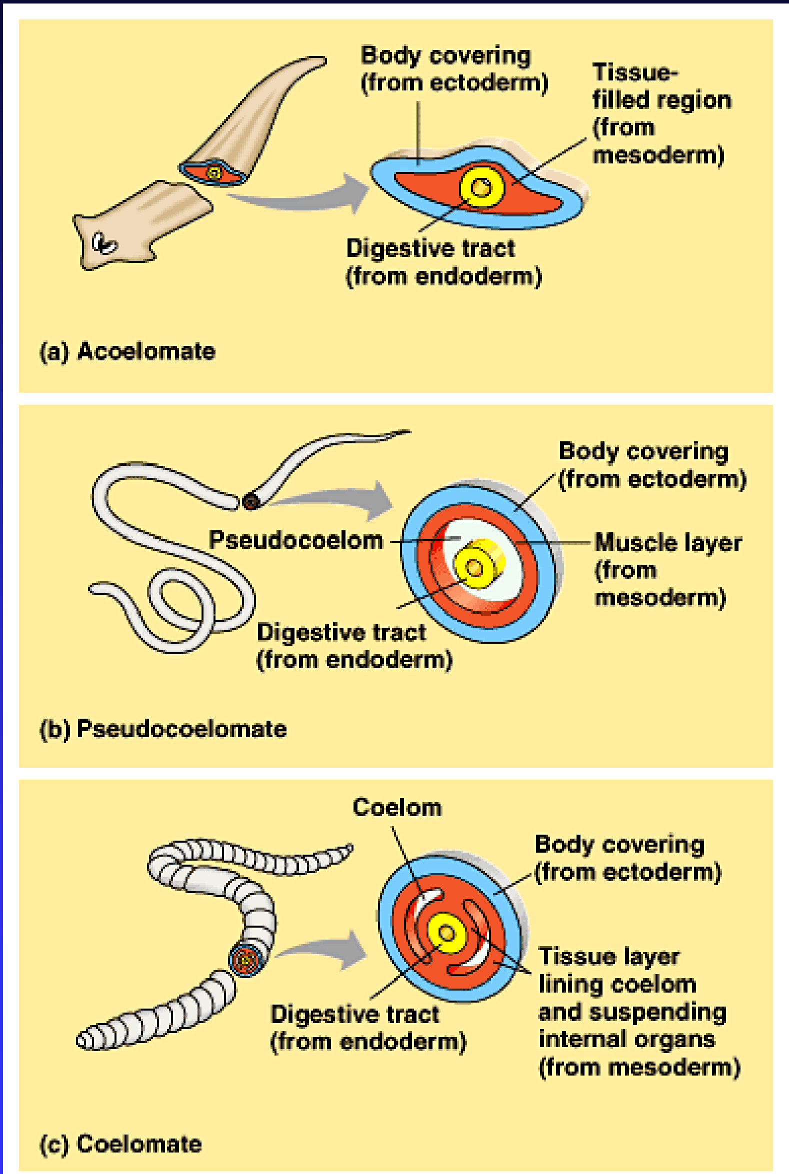


# A Hypothetical Phylogeny of Animals



# Evolution of a Coelom

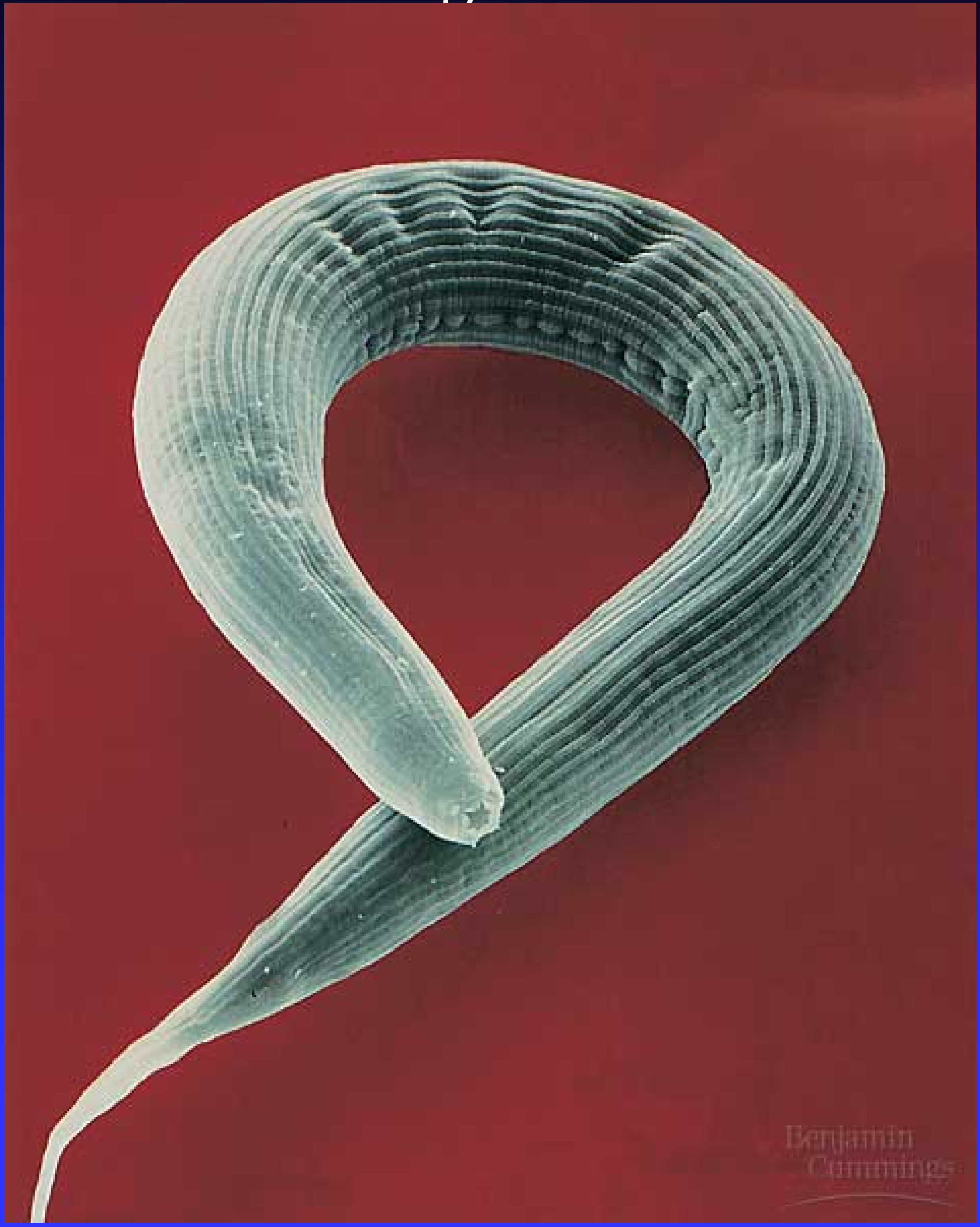
- Lower invertebrates
  - Acoelomates: flatworms
  - Pseudocoelomates: Nematodes
  - Higher Invertebrates and Vertebrates are True Coelomates
  - Independent digestive system
  - Hydrostatic skeleton
  - Enhanced reproductive capacity
  - Vertebrate peritoneum



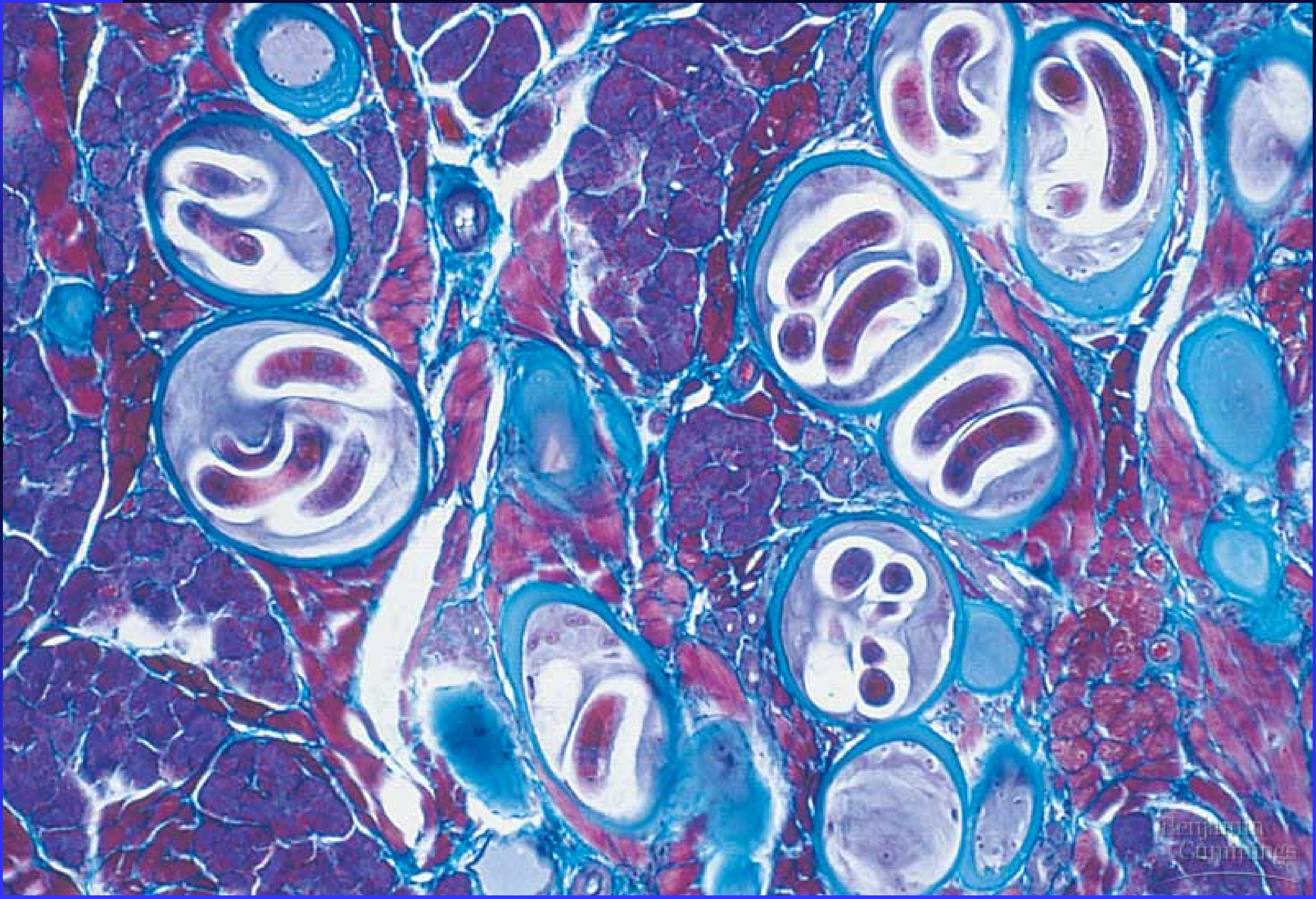
# Phylum Nematoda: Roundworms

- Freeliving and parasitic pseudocoelmates
- Body structure:
  - high SA:vol
  - Complete digestive tract
  - Separate sexes
- *C. elegans:* an experimental model
- Parasites:*Trichinella spiralis*, *Ascaris lumbricoides*, Elephantiasis

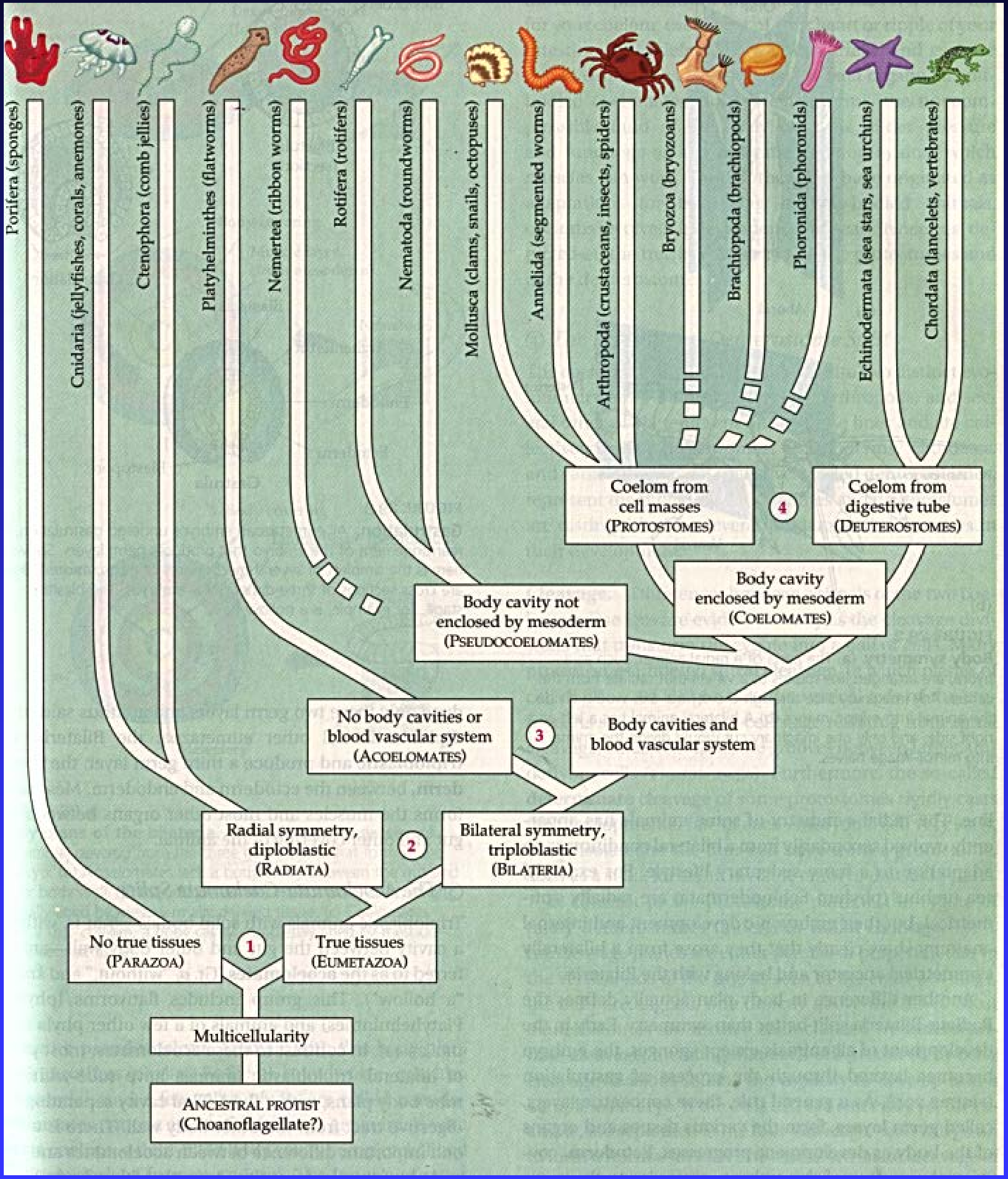
# Free-living nematode



# Parasite nematode, *Trichinella spiralis*

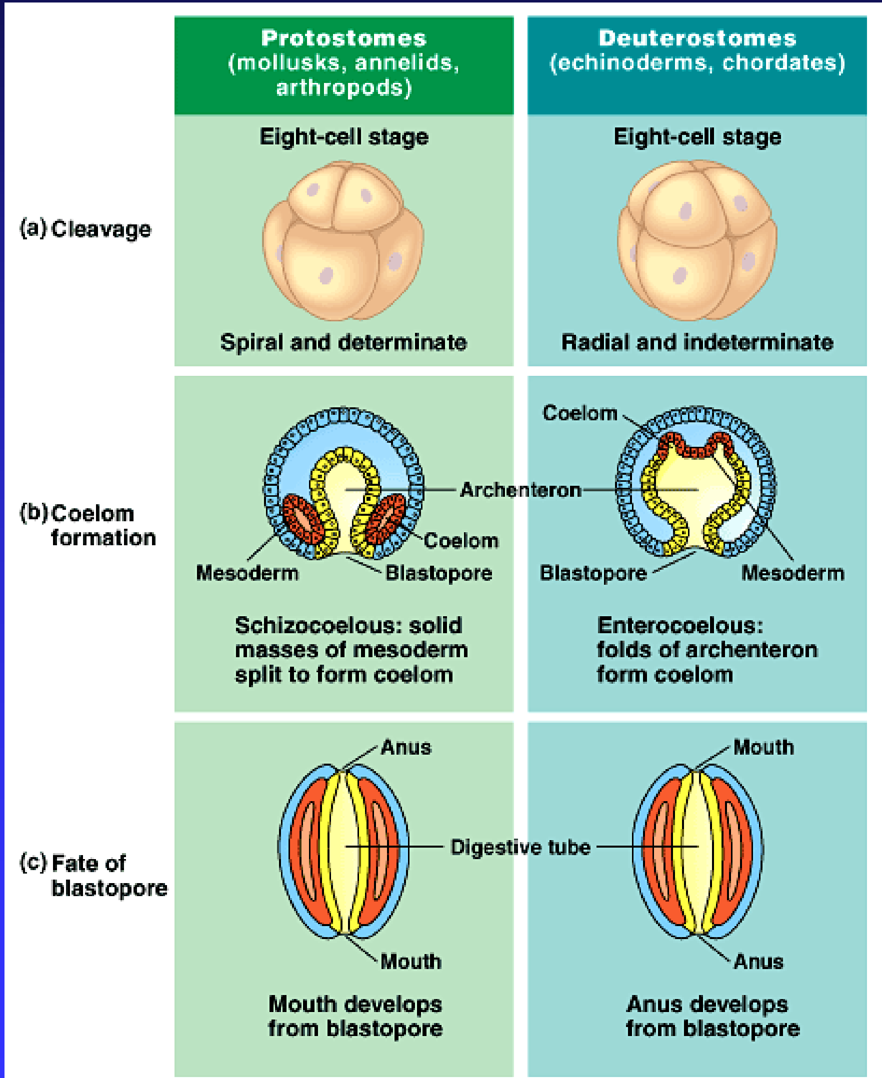


# A Hypothetical Phylogeny of Animals



# Evidence of a major divergence among higher invertebrates and vertebrates:

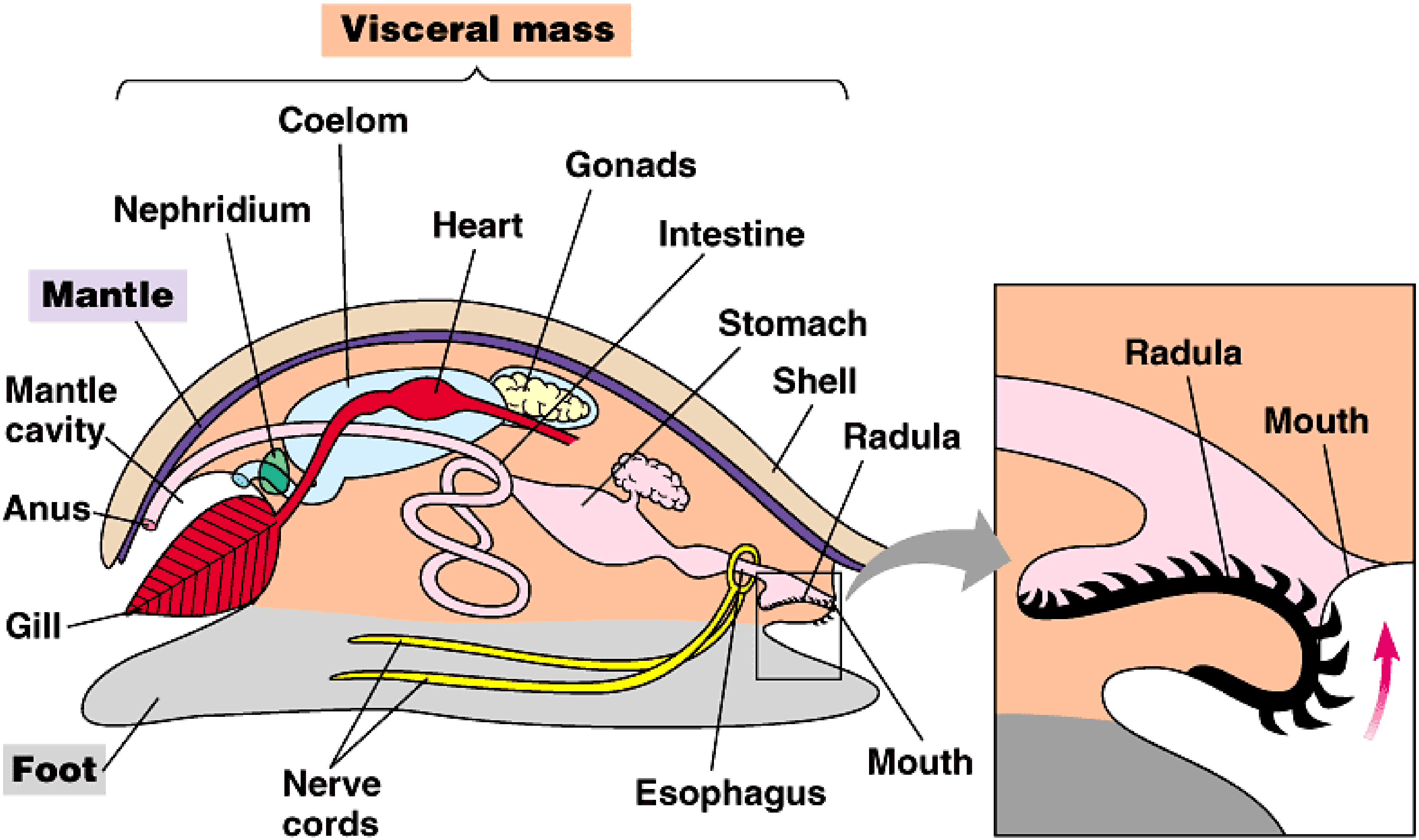
A comparison of early development in protostomes and deuterostomes



# Phylum Mollusca: snails, slugs, chitons, clams, octopus and squid

- Trend toward rounder body: low SA/vol ratio
- Lack of segmentation
- Hypothetical Molluscan ancestor
  - Mantle and mantle cavity, shell
  - Muscular foot: sensory and locomotory
  - Visceral Mass
    - Cephalization: sensory and feeding
    - Gills(except in pulmonates)
    - Complete GI w/ glands, radula
    - Open circ. system: heart and haemocoel
    - Metanephridium
    - Separate sexes

# Basic body plan of mollusks



# Class Polyplacophora: chitons

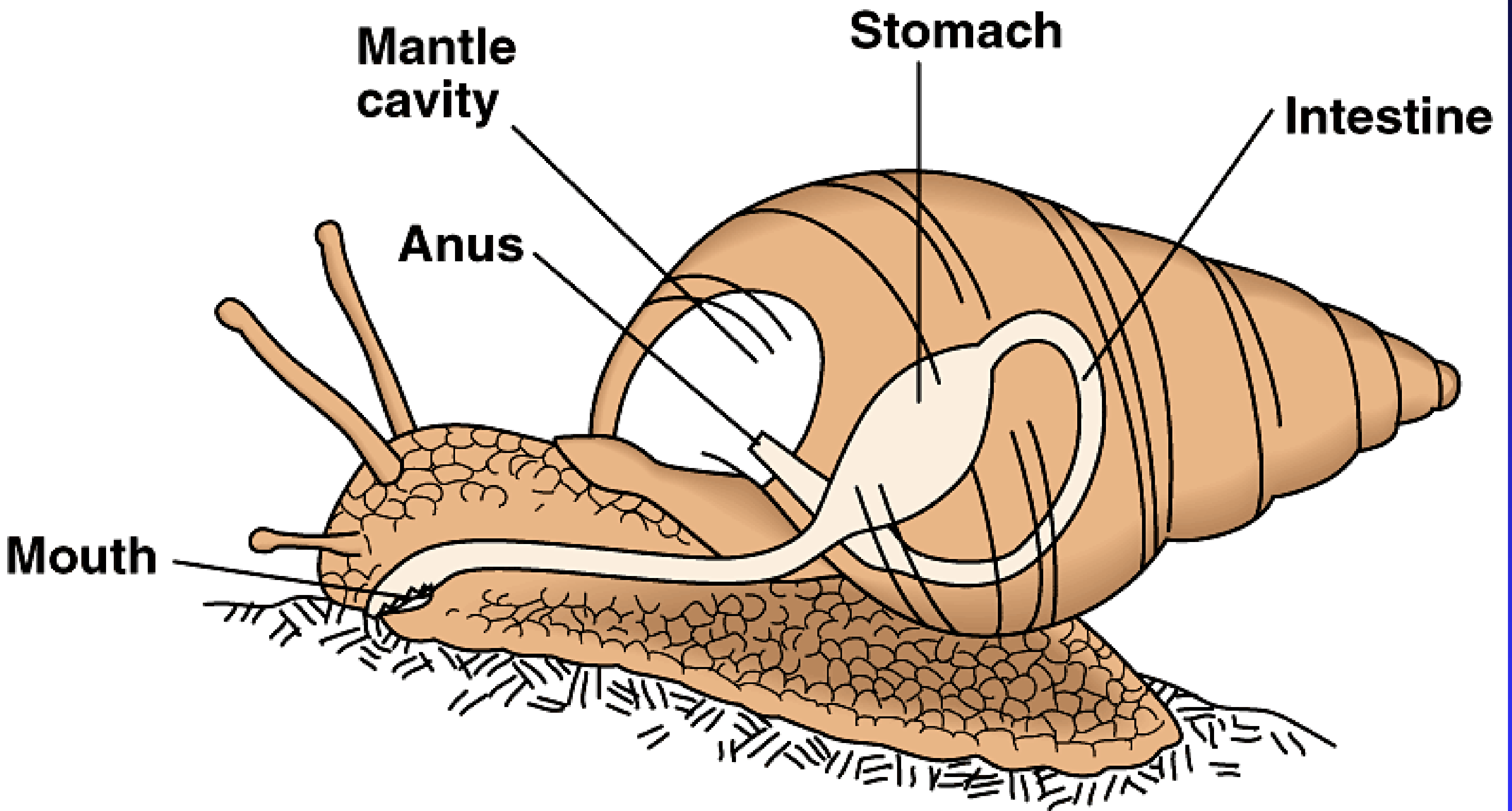
- 600 living species, mostly intertidal
- Most similar to ancestral mollusc
- Broadfooted herbivores
- 8 overlapping plates
- Very little cephalization: no eyes or tentacles, small head w/ radula

# Class Gastropoda: snails, slugs, limpets

- Largest molluscan class, 40,000 species
- Mobile: Herbivores and carnivores
- 3 important changes from ancestral mollusc
  - Greater cephalization: affects sensory and locomotion
  - Asymmetrical spiral shell: portable protection
  - Torsion: realignment of body with shell
- Feeding strategies and specializations
- Gills or “lungs”

Gastropods: Nudibranchs (top left and bottom left), terrestrial snail (bottom left), deer cowrie (bottom right)

# The results of torsion in a gastropod

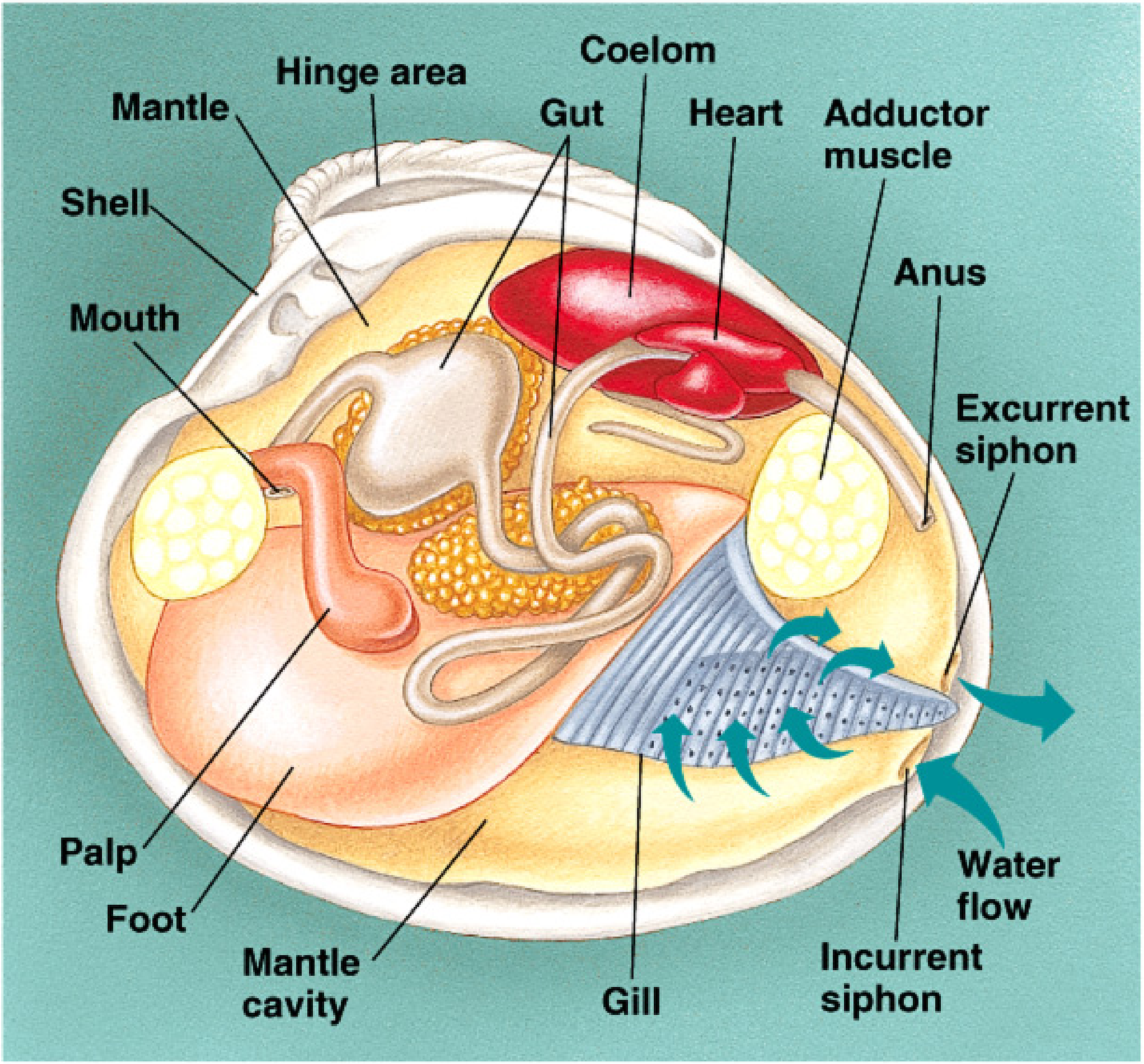


# Garden snail

# Class Bivalvia: clams

- Laterally compressed w/dorsal hinge
- Very large mantle cavity: use of gills for respiration and suspension (filter) feeding
  - Incurrent and excurrent siphons
- No radula or distinct head present
- Pearls: require inner nacreous layer

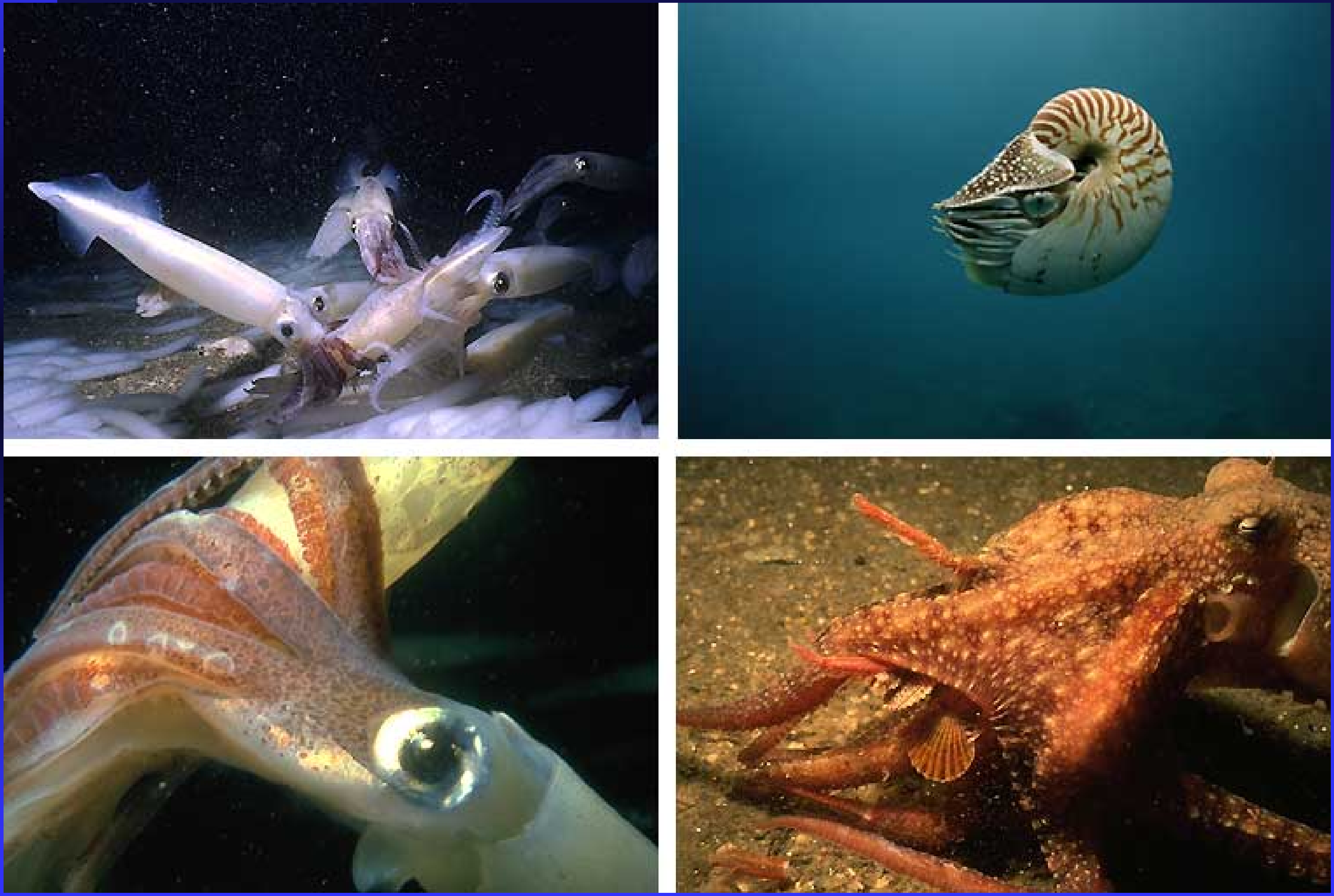
# Anatomy of a clam



# Cl. Cephalopoda: nautilus, squid, octopus

- 650 species, extinct members include Ammonites (65 mya)
- Predators
- Swimming lifestyle: jet propulsion
- Reduced or absent shell
- Closed circulatory system
- Cephalization: sensory, movement, learning
- Foot gives rise to tentacles (arms)
- Direct development (larvae?)
- Cephalopod eye: convergence

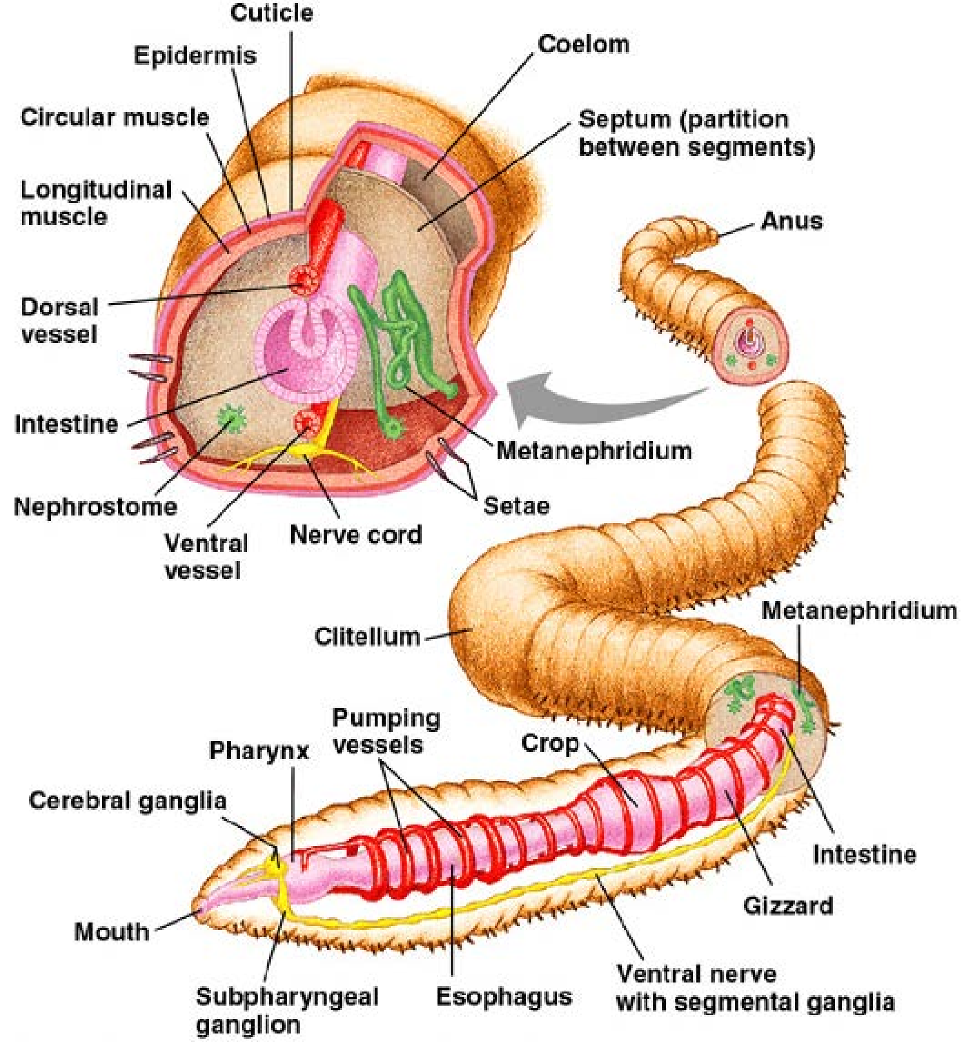
# Cephalopods: Squid (top left and bottom left), nautilus (top right), octopus (bottom right)



# Phylum Annelida: “ringed worms”

- Metamerism: separate evolutions
- Subdivided coelom w/ hydrostatic skeleton
- Segmental specialization and independence
  - locomotion
  - digestion
- Setae made of chitin
- Closed circ system
- Cephalization
- Hermaphrodites

# Class Oligochaeta: earthworms





# Classes of Phylum Annelida

| Class and Examples | Main Characteristics |
|---|---|
| Oligochaeta (terrestrial and freshwater segmented worms; e.g., earthworms) (see FIGURES 33.23 and 33.24a) | Reduced head; no parapodia, but setae present |
| Polychaeta (mostly marine segmented worms) (see FIGURE 33.24b and c) | Well-developed head; each segment usually has parapodia with setae; tube-dwelling and free-living |
| Hirudinea (leeches) (see FIGURE 33.24d) | Body usually flattened, with reduced coelom and segmentation; setae absent; suckers at anterior and posterior ends; parasites, predators, and scavengers |

# Class Polychaeta: segmented marine worms

- About 5000 species
- Most live in burrows or tubes
- Increased cephalization
- Parapodia: locomotion, respiration, feeding
- Trochophore larvae
- Possible ancestors of Arthropods

# Class Hirudinea: leeches

- Mainly freshwater, flattened segmented worms
- Parasitic, scavengers, predatory
- Reproduction is similar to earthworms
- Secrete anesthetic and anticoagulant
- Medically significant

# Phylum Arthropoda: "jointed foot"

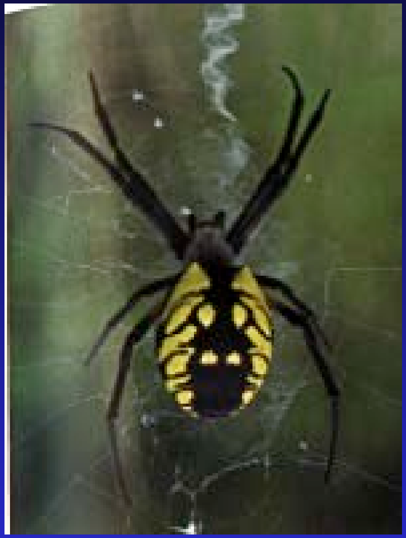
- Evolutionary Origin: Annelid ancestors?
- Evolutionary Trends
  - 1. Loss or fusion of body segments
  - 2. Specialization of segments
  - 3. Increased cephalization
- Unique Arthropod Features
  - 1. Jointed appendages
  - 2. Exoskeleton
  - 3. Reduced coelom
  - 4. Molting and hormonal control
  - 5. Open circulatory system
  - 6. Gills or tracheal tubes
  - 7. Adaptive radiation and reproductive potential

# Subphylum Trilobita: extinct

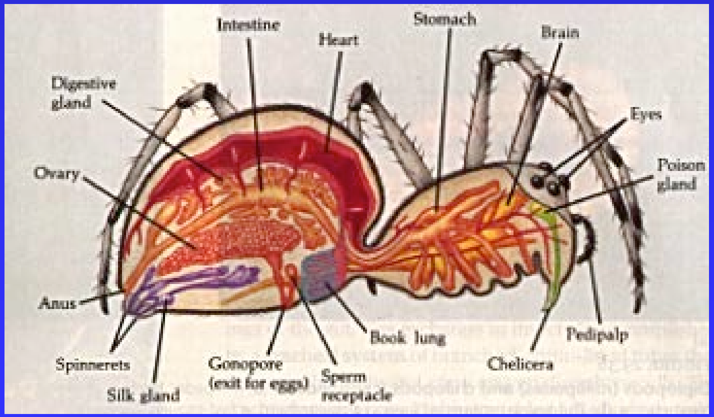
- Segmentation with some fusion
- Basic body plan: cephalon, thorax (3 lobes), pygidium
- Segmental specialization, but little spec. in appendages

# Class Arachnida: spiders

- General Features:
  - 2 major body segments
  - 6 pairs of appendages w/ specializations
    - 1 pair chelicerae
    - 1 pair sensory palps
    - 4 pair walking legs

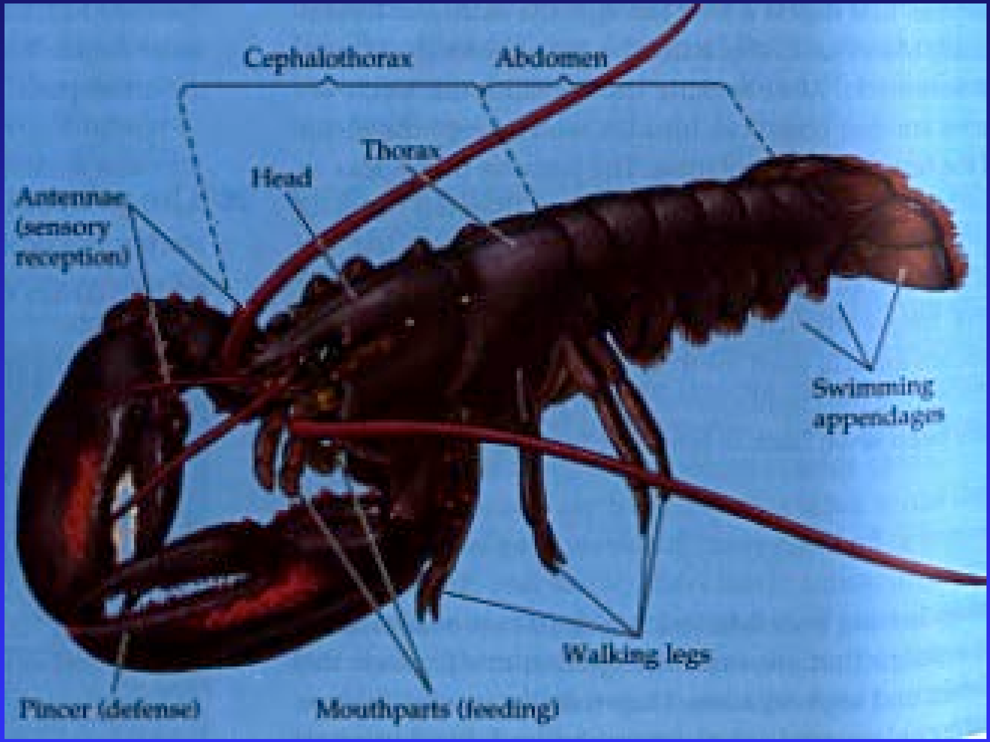


  - Adaptations to land:
    - Waxy cuticle
    - Gill replaced by book lungs
    - Appendage spec.
    - Malpighian tubules
    - Abdominal silk glands



# Subp. Crustacea: Marine Arthropods

- Decapods, isopods, copepods, barnacles
- 3 body parts: fusion and segmentation
- Head: 5 pairs of appendages
- Thorax: 3+ pairs of walking legs
- Abdomen: special appendages for locomot. and reprod.



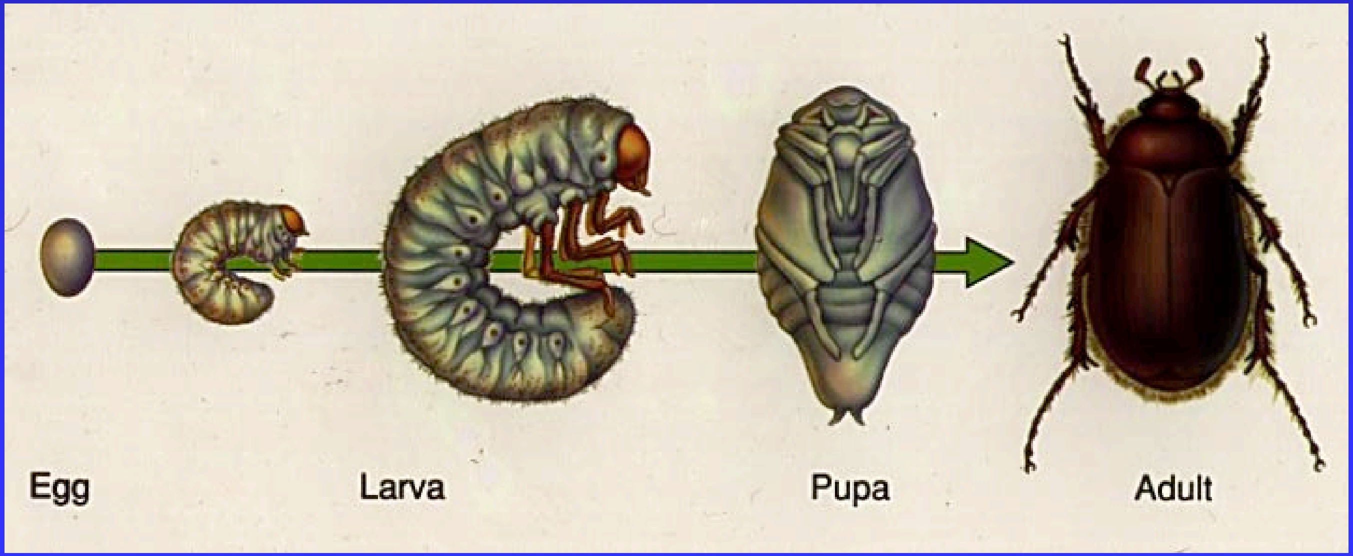
# Crustaceans: Lobster (top left), banded coral shrimp (bottom left), barnacles (right)

# Class Insecta: Incised body plan

- Invertebrate bragging rights
- Reasons for success:
  - 1.Small size
  - 2.Specialization reduces competition
  - 3.Metaporphosis: intraspecific specialization
  - 4.Flight
  - Body plan adapted for terrestrial existence
    - Head: sensory and feeding
    - Thorax: locomotion
    - Abdomen: organ systems

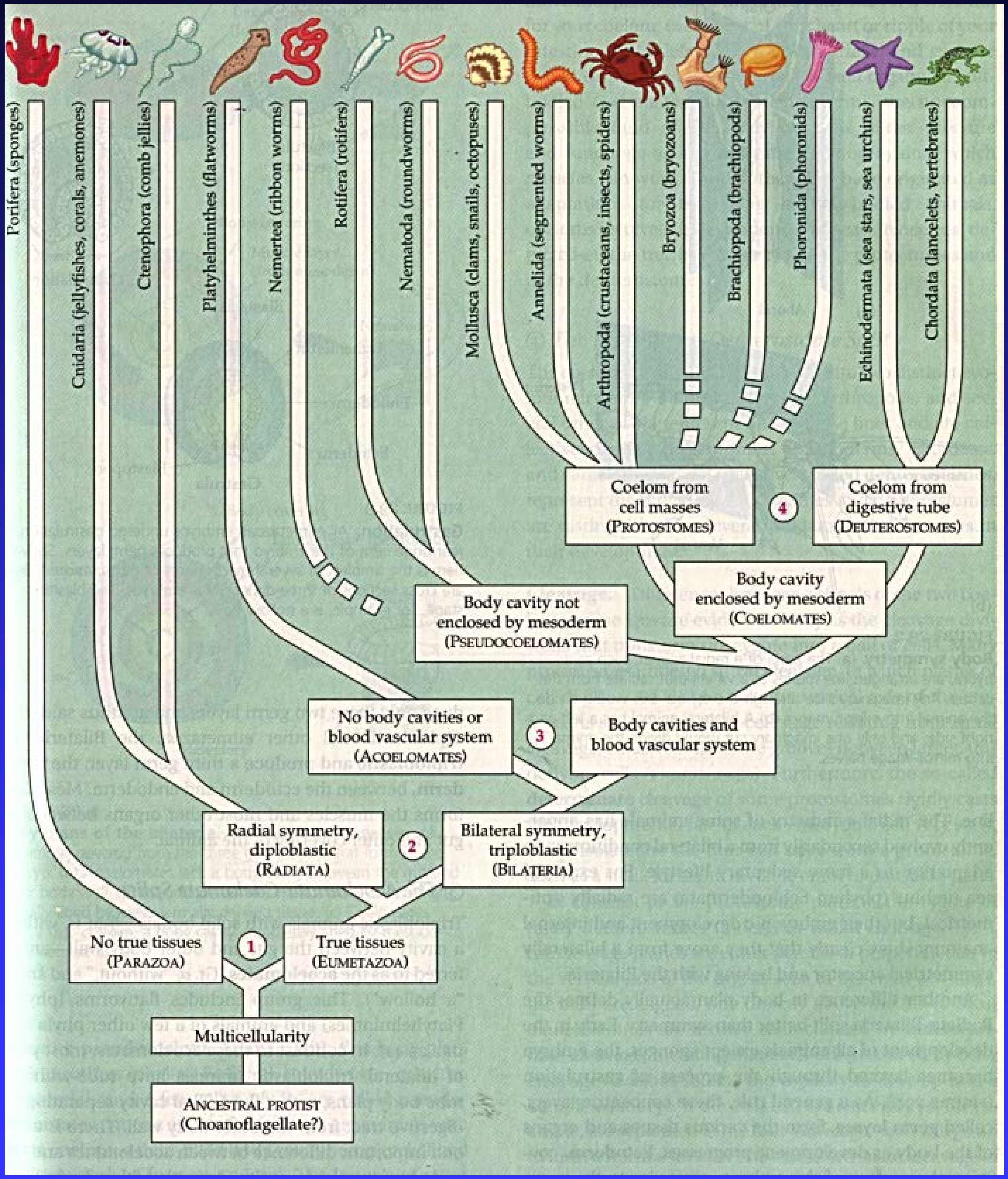

# Metapmorphosis: Primitive and Advances Insects

- Gradual (Incomplete) Metamorphosis: cockroaches, grasshoppers.
- Complete Metamorphosis:
  - egg, larva, pupa (dormant form), adult

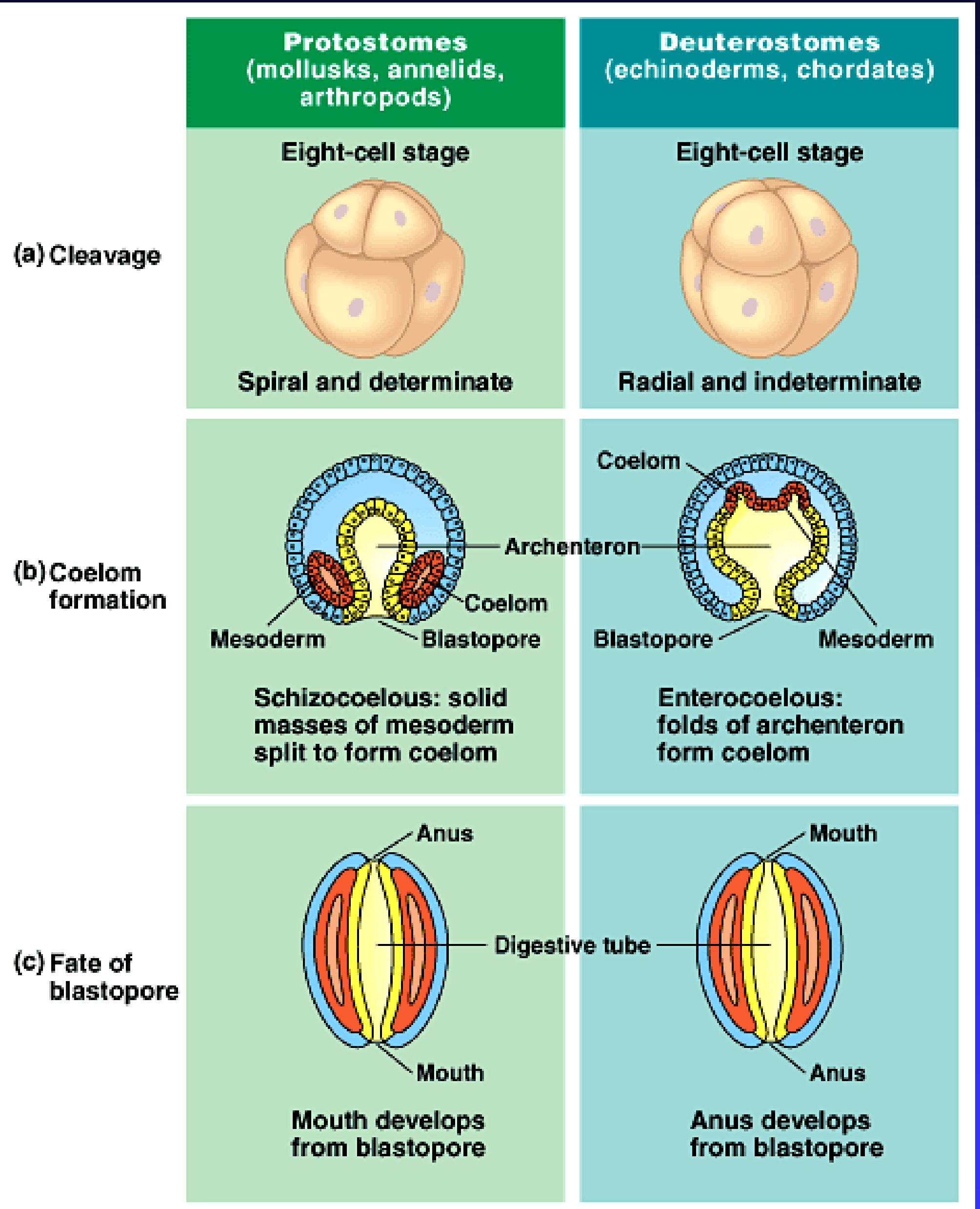


# Complete Metamorphosis of a butterfly

# A Hypothetical Phylogeny of Animals



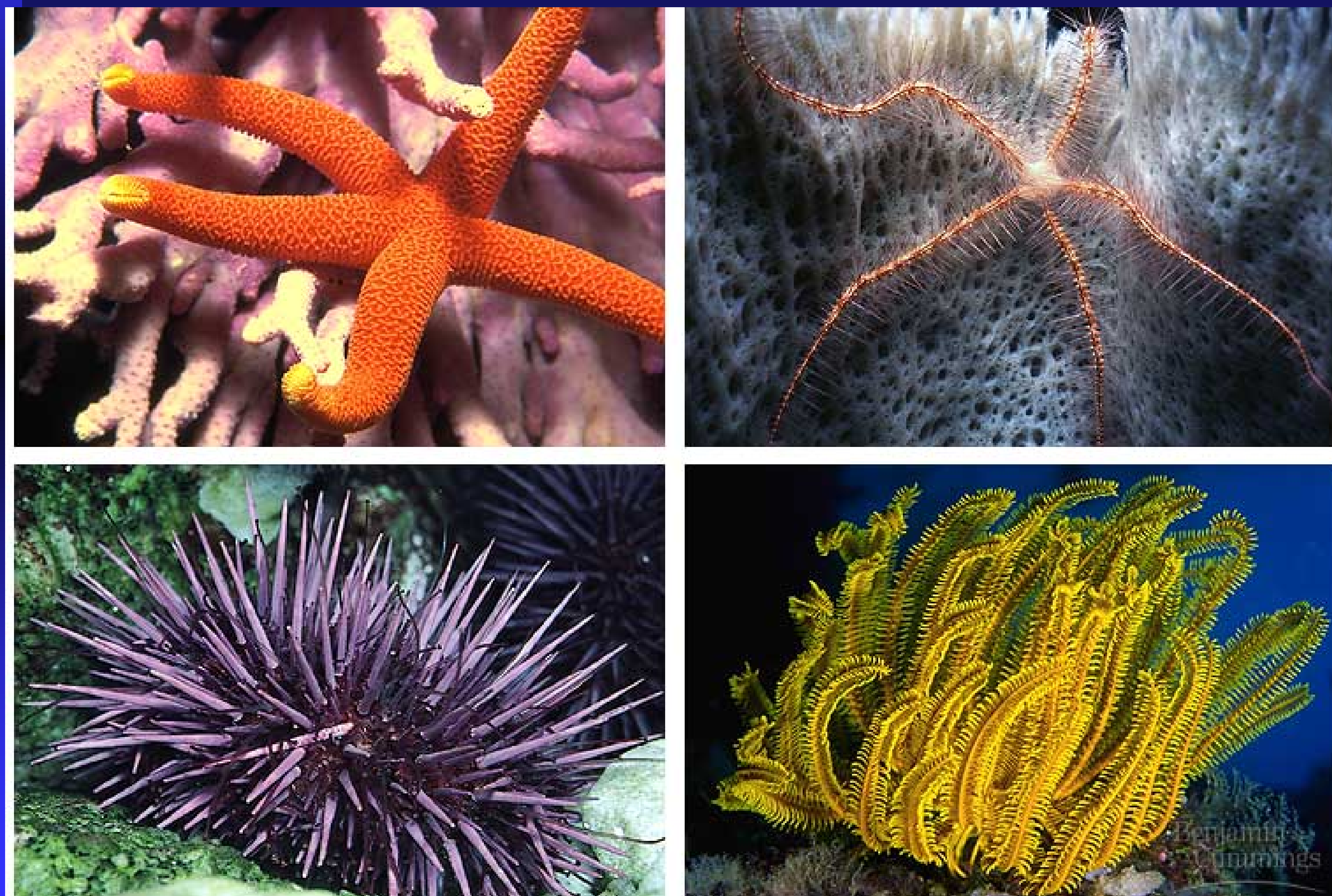
# A comparison of early development in protostomes and deuterostomes



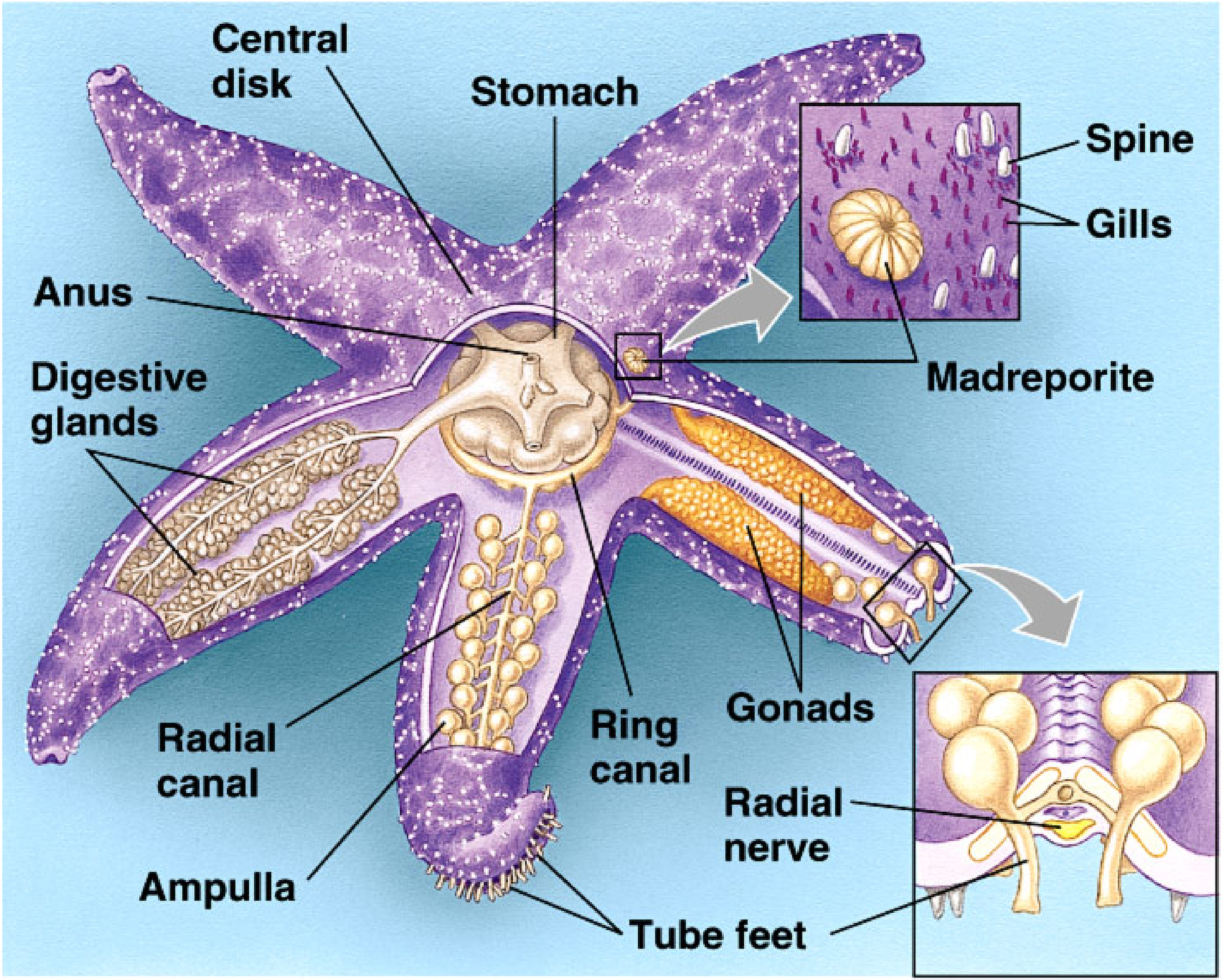
# Phylum Echinodermata: "spiny skin" - sea stars, brittle stars, sea cucumbers, sea lilies, urchins-

- General Features
  - Exclusively marine
  - Benthic herbivores or detritovores
  - Bilateral larvae, radial adult
  - Endoskeleton
  - Non-centralized nervous system
  - Water-vascular system
  - Non-segmented
  - Cutaneous respiration
  - Regenerative Capacity

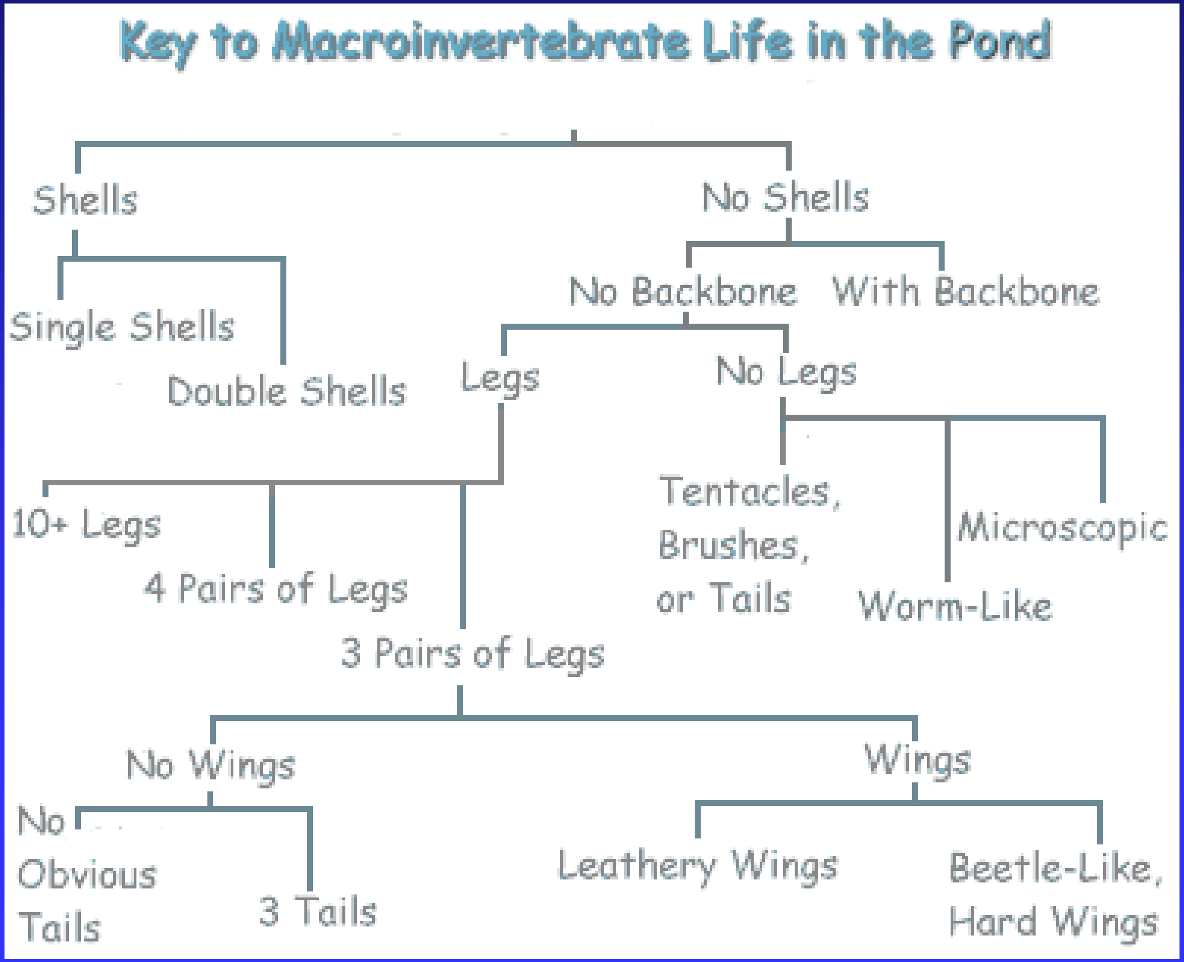
# Echinoderms: Sea star (top left), brittle star (top right), sea urchin (bottom left), sea lily (bottom right),



# Anatomy of a sea star

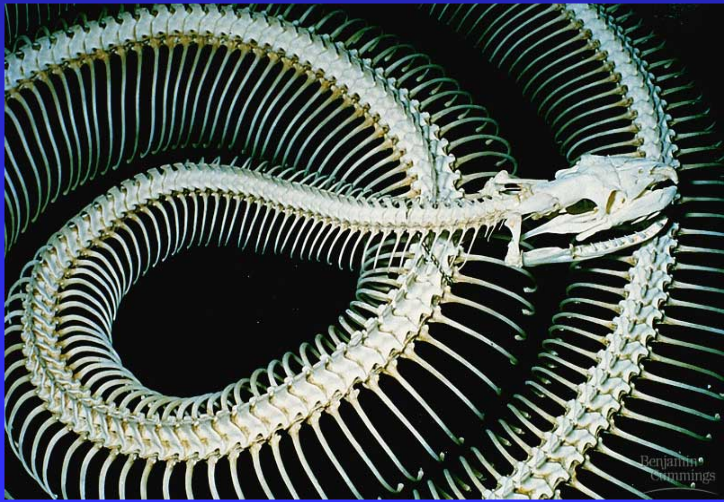


# Using a dichotomous key to identify species

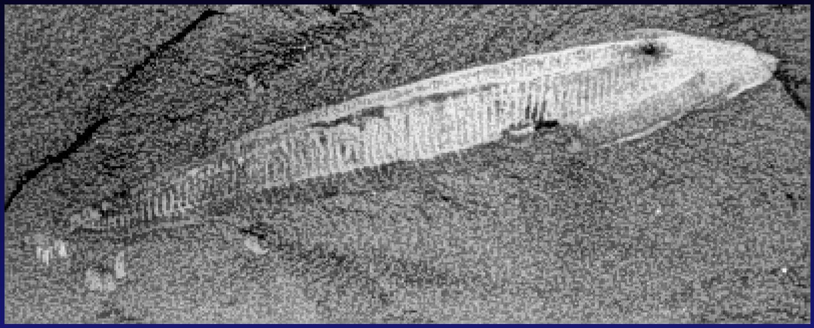


# Phylum Chordata

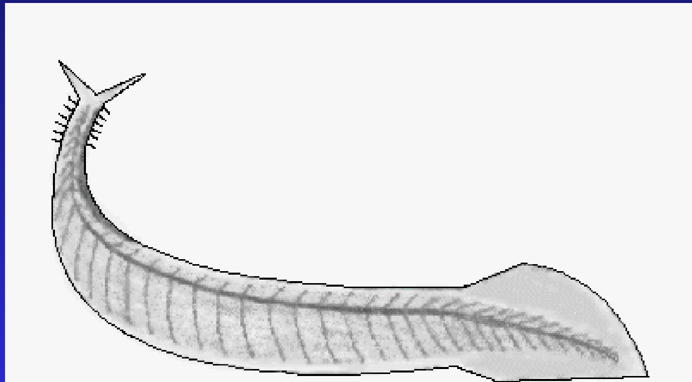
- Distinguishing Features
  - 1. Pharyngeal gill slits
  - 2. Dorsal hollow nerve cord
  - 3. Notochord
  - 4. Muscular postanal tail
- Subphylum Vertebrata:
  - Segmentation
  - Cephalization
  - Vertebrae
  - Cranium
  - Endoskeleton
  - *NEURAL CREST MATERIAL*



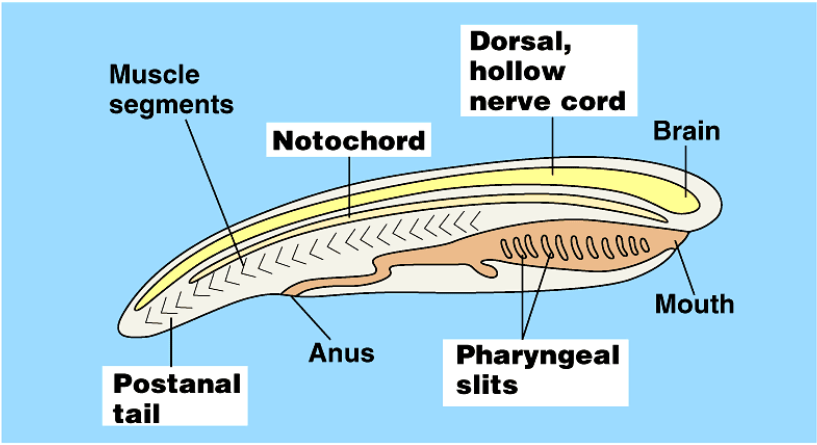
# The Ancestral Chordate: *Pikaia gracilens*, the Cambrian Chordate



- Bilateralia, deuterostomia
- Ch. Derived characteristics
  - 1. Notochord – "chord"-ates; replaced by vertebrae
  - 2. Dorsal hollow nerve cord; ectoderm plate→ sp/brain
  - 3. Pharyngeal groove or gill slits Suspension feeding
    - Gas exchange in fishes
    - Parts of ear, skull, neck in tetrapods
  - 4. Endostyle/Thyroid
  - 5. Muscular postanal tail for propulsion
  - Other derived features:
    - Endoskeleton, ventral heart w/ closed circulatory system
    - No tornaria larvae

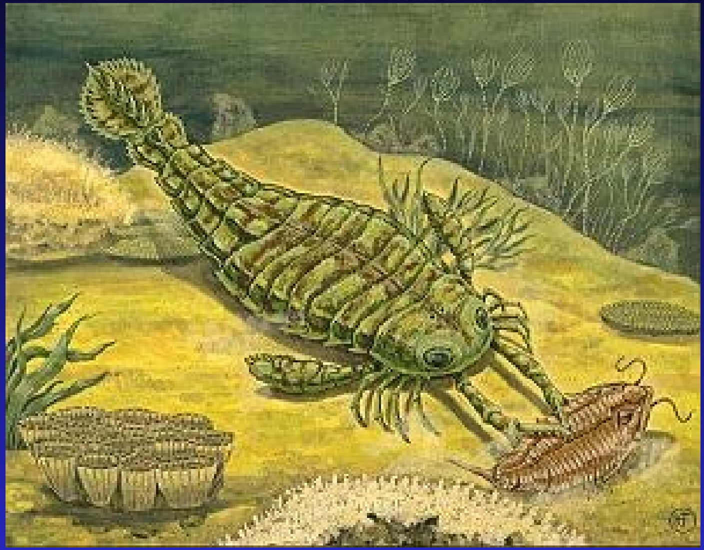


*Pikaia,* the earliest known chordate, from 550 million years ago, possibly an ancestor of humans

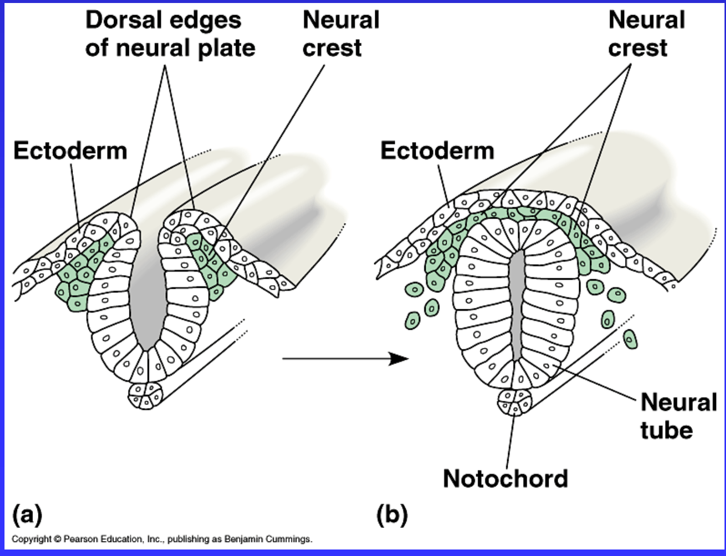


# Subp. Vertebrata: in search of a diagnostic feature

- Deuterostome pattern of devel.
- 5 Chordate characteristics
- Other features: Segmentation, Cephalization, Cranium, Vertebrae
- Mineralized endoskeleton: support/mov't, Eurypterid defense, hydroxyapatite as $Ca^{++}$ and $PO^{-}_{4}$ reservoir resistant to acid bkdn assoc w/ high met.
- *NEURAL CREST MATERIAL: the embryonic source of many unique vertebrate features including gill arches, teeth, skull bones, peripheral sensory and autonomic nerves, melanocytes, middle ear bones



Predatory Eurypterid

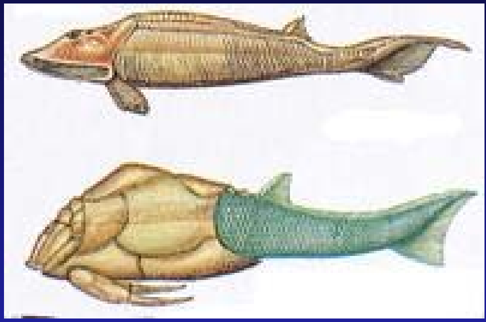


# Seven Extant Classes of Vertebrates

- Agnatha - jawless fishes
- Chondrichthyes - cartilagenous fishes
- Osteichthyes - bony fishes
- Amphibia - amphibians
- Reptilia - reptiles
- Aves - birds
- Mammalia - mammals

# Agnathans: Ancient and modern jawless fishes (polyphyletic)

- Ancestral Agnathans: Cl. Ostracaderma: arose in late Cambrian (470+ mya) extinct 370 mya
  - Jawless, no paired fins, bony armor plates
  - Gills not for feeding, exclusively respiration

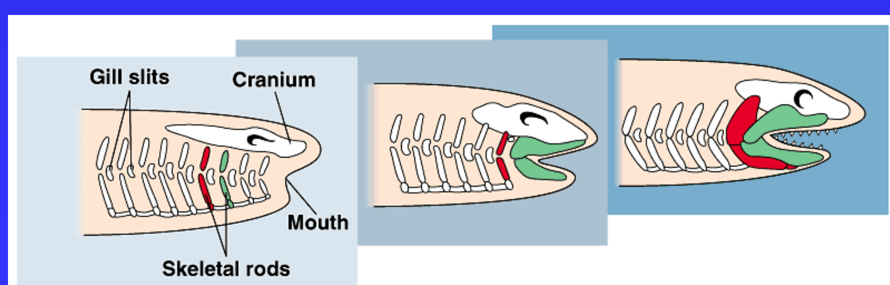


Ostrcoderms:“Shell-skinned”

- Modern representatives: cartilagenous skel, smooth skin, retain notochord
  - Hagfish (Cl.Myxini): craniates
  - Lampreys (Cl.Petromyzontida): these are the oldest vertebrates; “cartilage” vertebrae


# Gnathostomes: Cl. Placoderma: (450-359 mya)

- Placoderms w/ bony exoskel dominated all aquatic habitats FW/SW, included the world's first super predator, show the first example of vivipary, and then die out along with the agnathans
- Several important innovations are <u>coincident</u> with agnathan decline and extinction
  - Hinged jaws and paired fins revolutionize feeding
    - Re-purposing of gill arches for breathing
  - Complete vertebrae replace notochord (rudimentary in modern lampreys)
  - Quadruplicated *Hox* gene complex
- By 420mya diverged into 3 lineages of modern vertebrates: Chondrichthyans, ray-finned fishes, and lobe-fins (Osteichthyans).





*Dunkleosteus*: 10m; 8K#/in$^2$ jaw

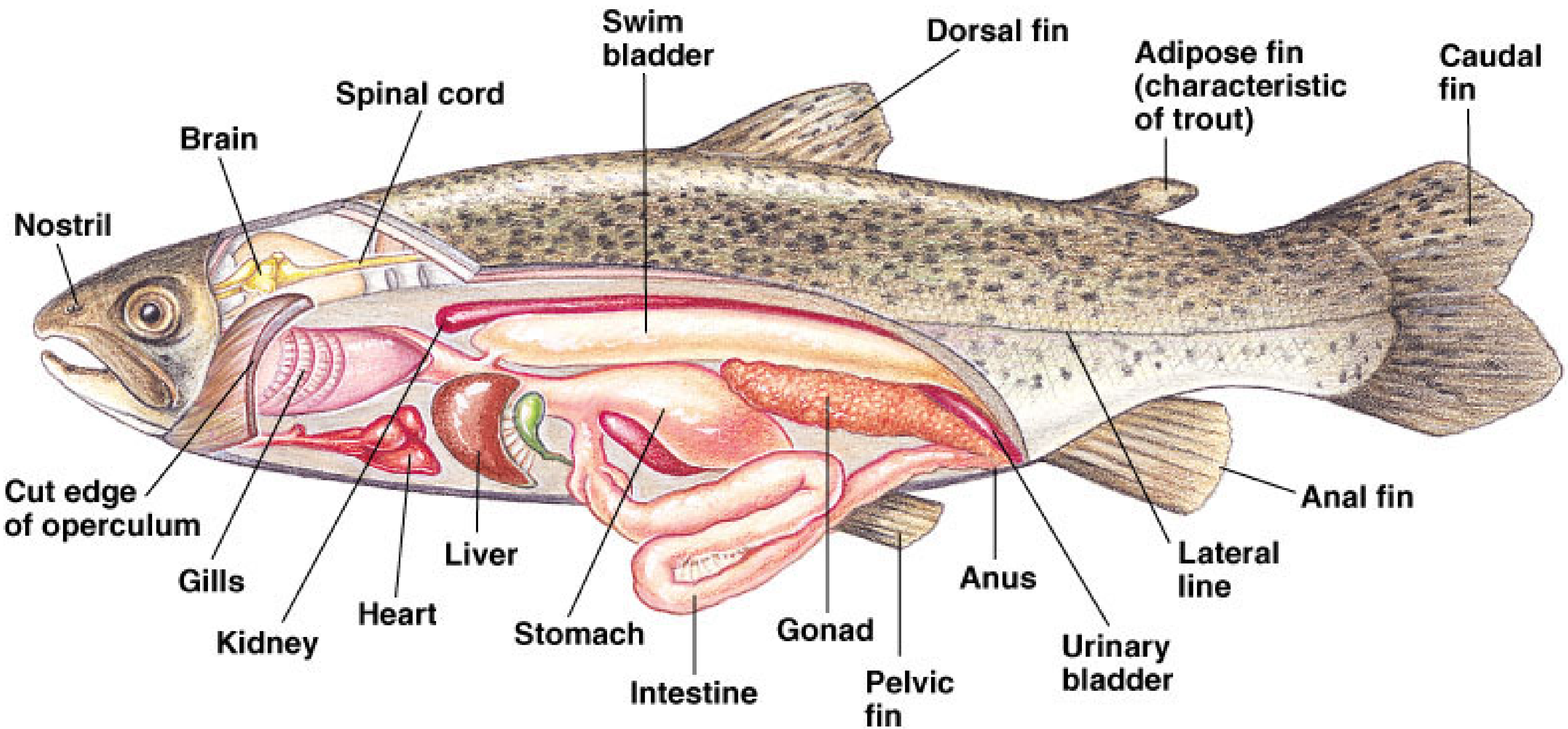
# Class Chondrichthyes: sharks, skates and rays

- Buoyancy control
  - Cartilagenous skeleton
- Adaptations of sharks, skates and rays
  - Ventilation
  - Feeding
  - Sensory
  - Osmoregulation
  - Reproduction

# Class Ostiechthyes: bony fishes

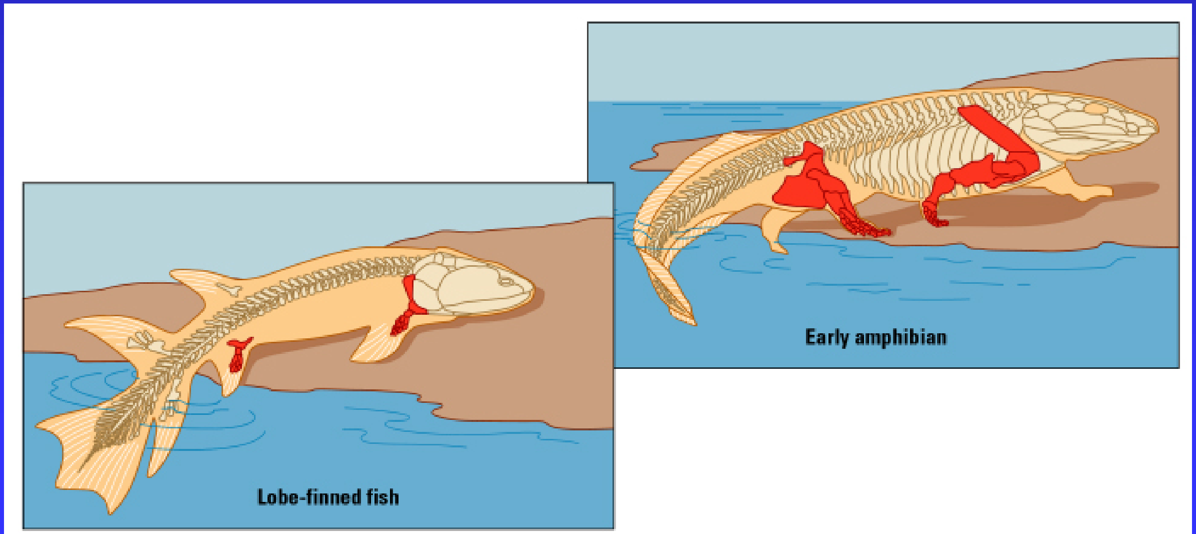
- General features
- Evolution in freshwater: lungs
- Divergence of bony ancestor into 2 groups
  - Ray finned fishes
  - lobe finned fishes and lungfish


# Anatomy of a trout, a representative ray-finned fish



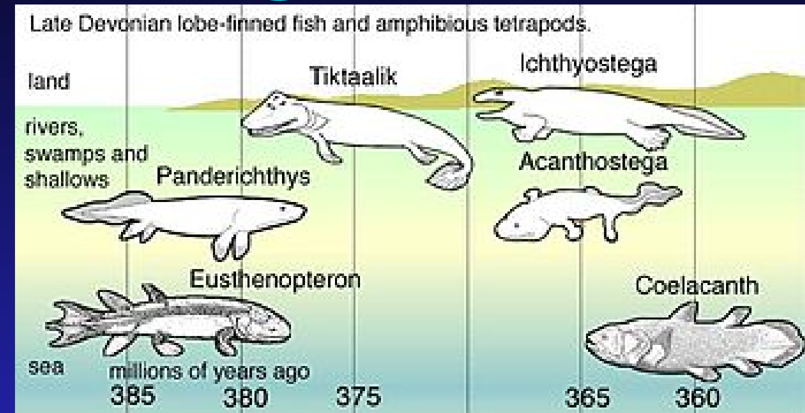
# Vertebrate Invasion Onto Land

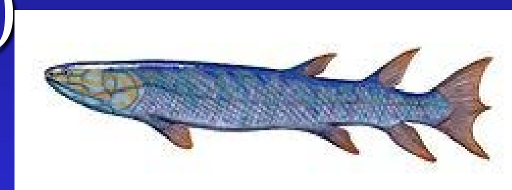
- Demands of terrestrial life:
  - How to move on land?
  - How to exchange gases?
  - How to prevent desiccation?
  - How to reproduce and develop?

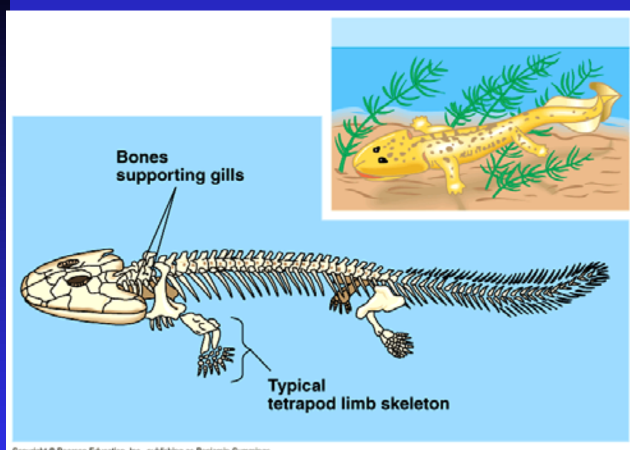


# Walking and breathing on land:

- Sarcopterygian fossils
  - Eusthenopteron (400)
  - Acanthostega (365)

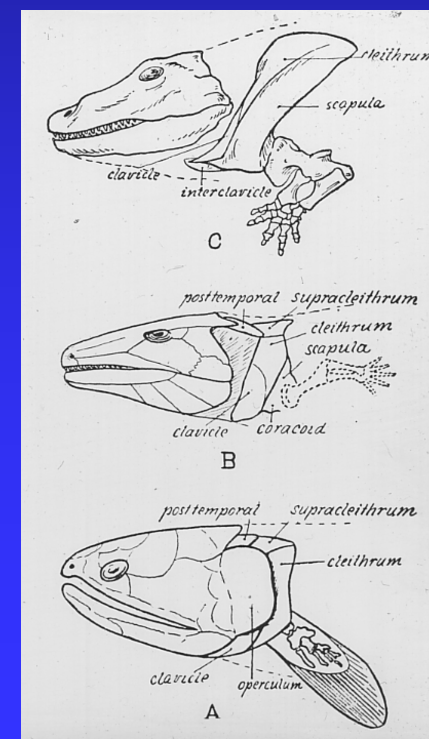




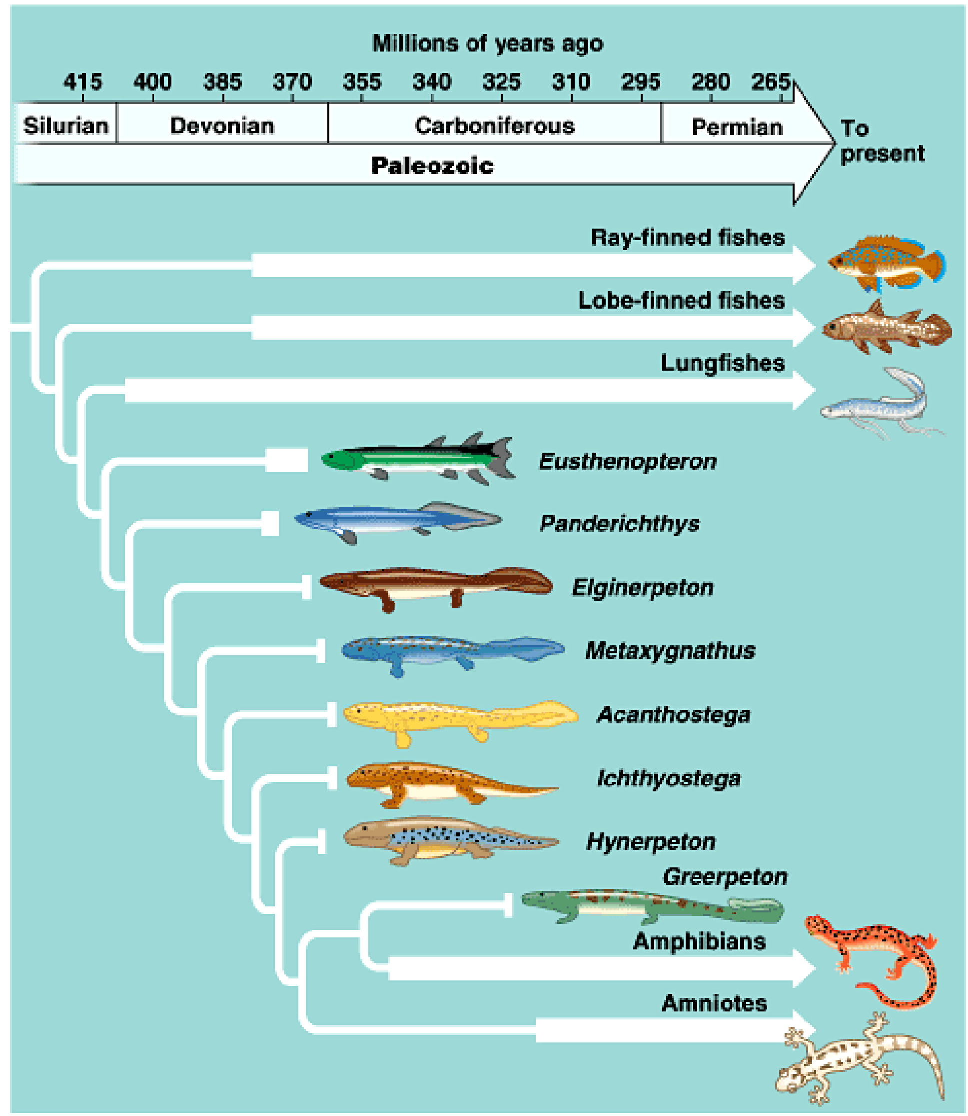

Skeleton of *Acanthostega*, a Devonian (370) tetrapod fish

Relations of the shoulder-girdle to the skull in lobe-finned fishes and early tetrapods. (A) Lobe-finned ganoid (*Eusthenopteron*) from the Devonian period, with the pectoral girdle immediately behind the gill cover (operculum) and fastened to the skull by the post-temporal. (B) Most primitive known amphibian (*Eogyrinus*) from the Lower Carboniferous of England with the pectoral girdle still fastened to the skull by means of the post-temporal. (C) Typical primitive tetrapod (*Eryops*) from the Permian period of Texas, showing shoulder-girdle free from skull, although in life it was tied to it by muscles. Data for A from Bryant 1919; B from Watson 1924; C from Miner 1925



# The origin of tetrapods: From lobe-fins to "limbs with feet" (365 mya) while still in the pond

- Head separated from body by neck
- A second vertebra to turn head
- Pelvic girdle is fused to spine
- Gills repurposed for jaw, ear, etc.
- Ribs for support and breathing
- Limb bone module: long bone, paired bones, small bones and digits



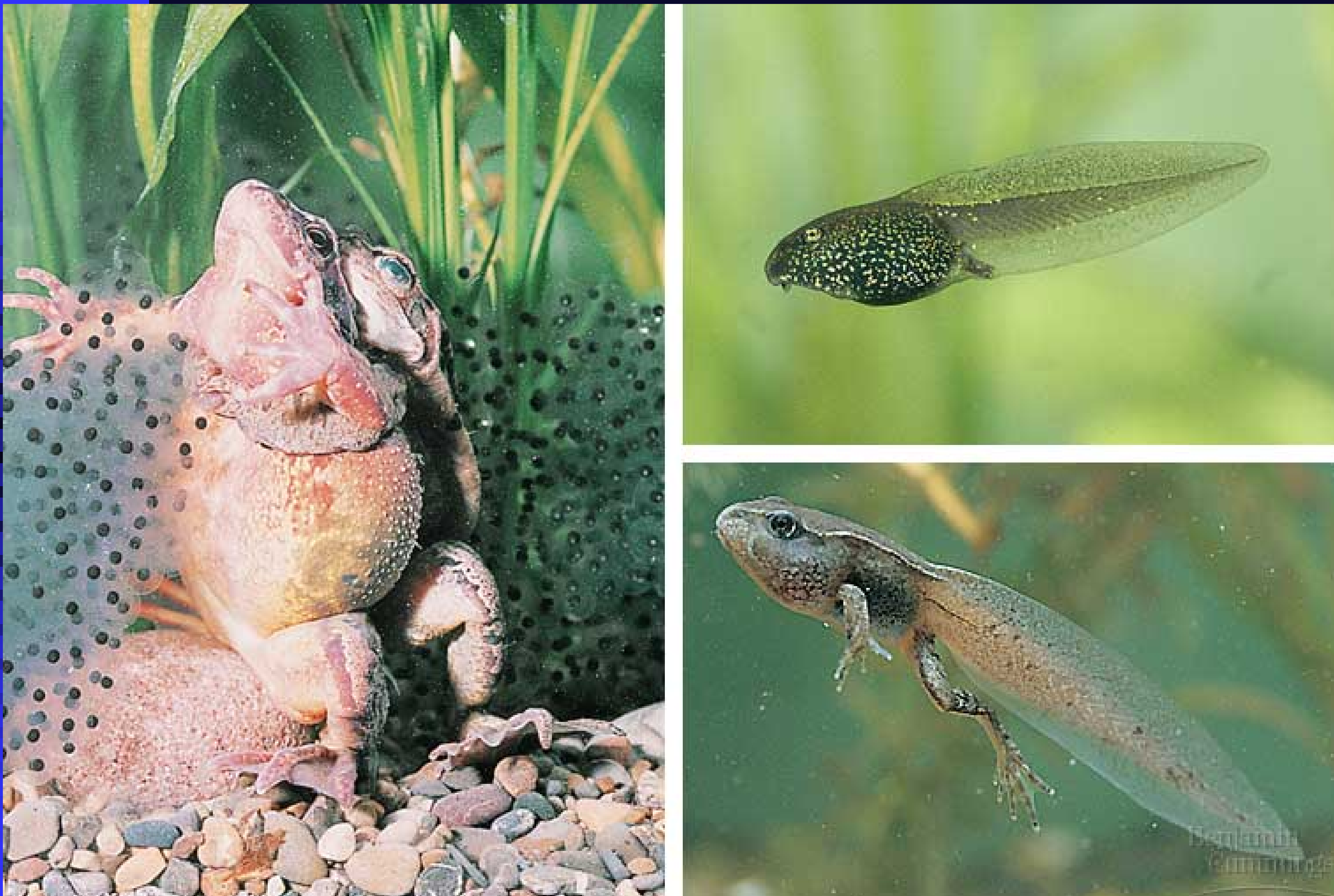
# The Tetrapods: Amphibians, Reptiles, Birds and Mammals

- Amphibians: Early tetrapods
- The Amniotes and the Amniotic Egg
- Dinosaurs: Extinction Theories
- Class Reptilia: Modern Reptiles
- Birds and Mammals:
  - Metabolic Advantages of Endothermy
- Phylogeny of Terrestrial Vertebrates
- Class Aves
  - Archaeopteryx
  - Avian Characteristics
- Class Mammalia
  - Mammalian Characteristics
  - Reproductive Strategies
  - Radiation and convergence

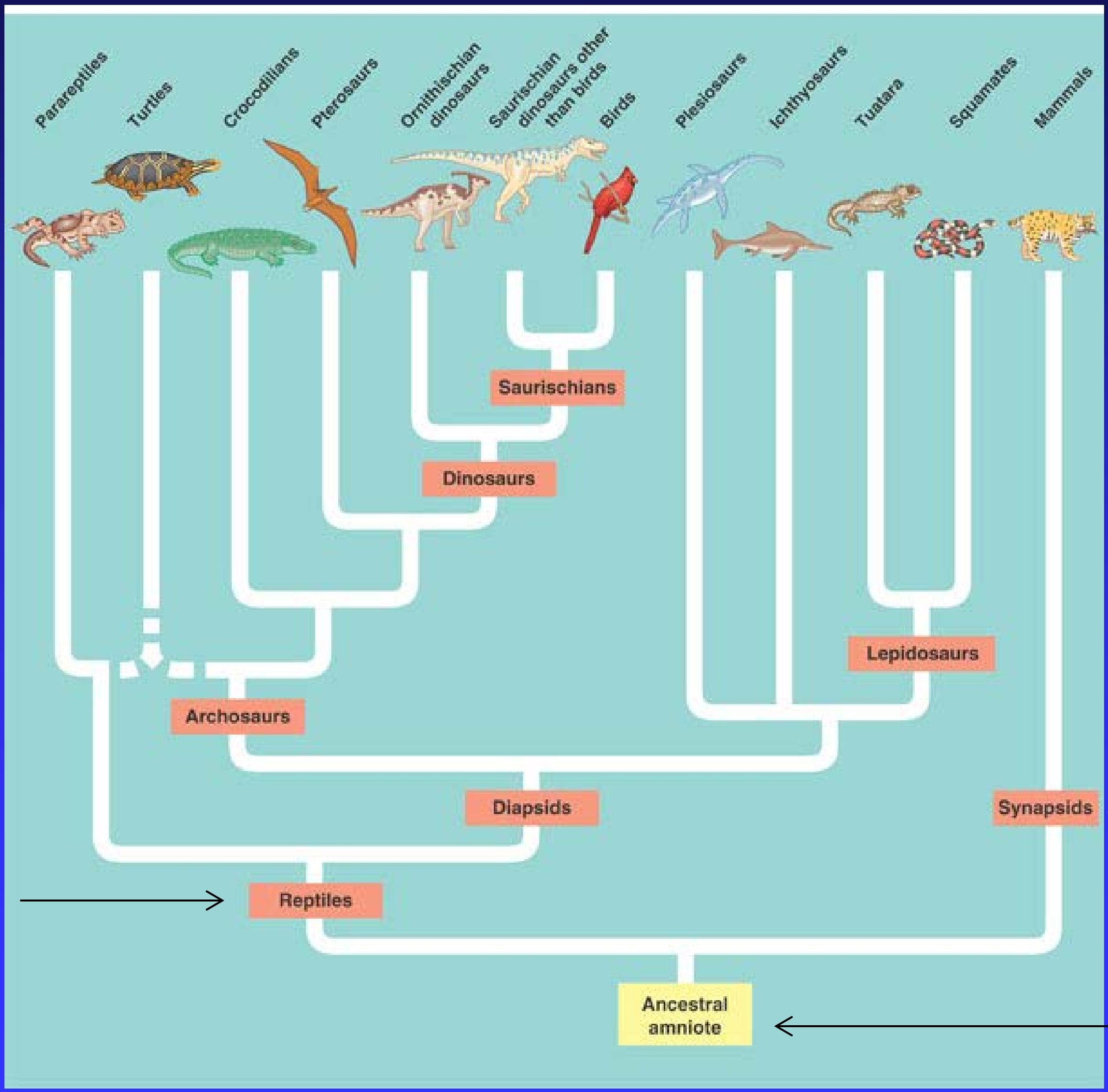
# Amphibians: the first tetrapods

- 3 Orders include: salamanders and newts, frogs and toads, caecilians (legless amphibs)
- General Features
  - Locomotion
  - Feeding
  - Gas exchange
  - Osmoregulation
  - Circulation
  - Reproduction and development
    - Metamorphosis
  - Hearing and voice

# “Dual life” of a frog *(Rana temporaria)*



# A hypothetical phylogeny of terrestrial tetrapods, I.e., the amniotes



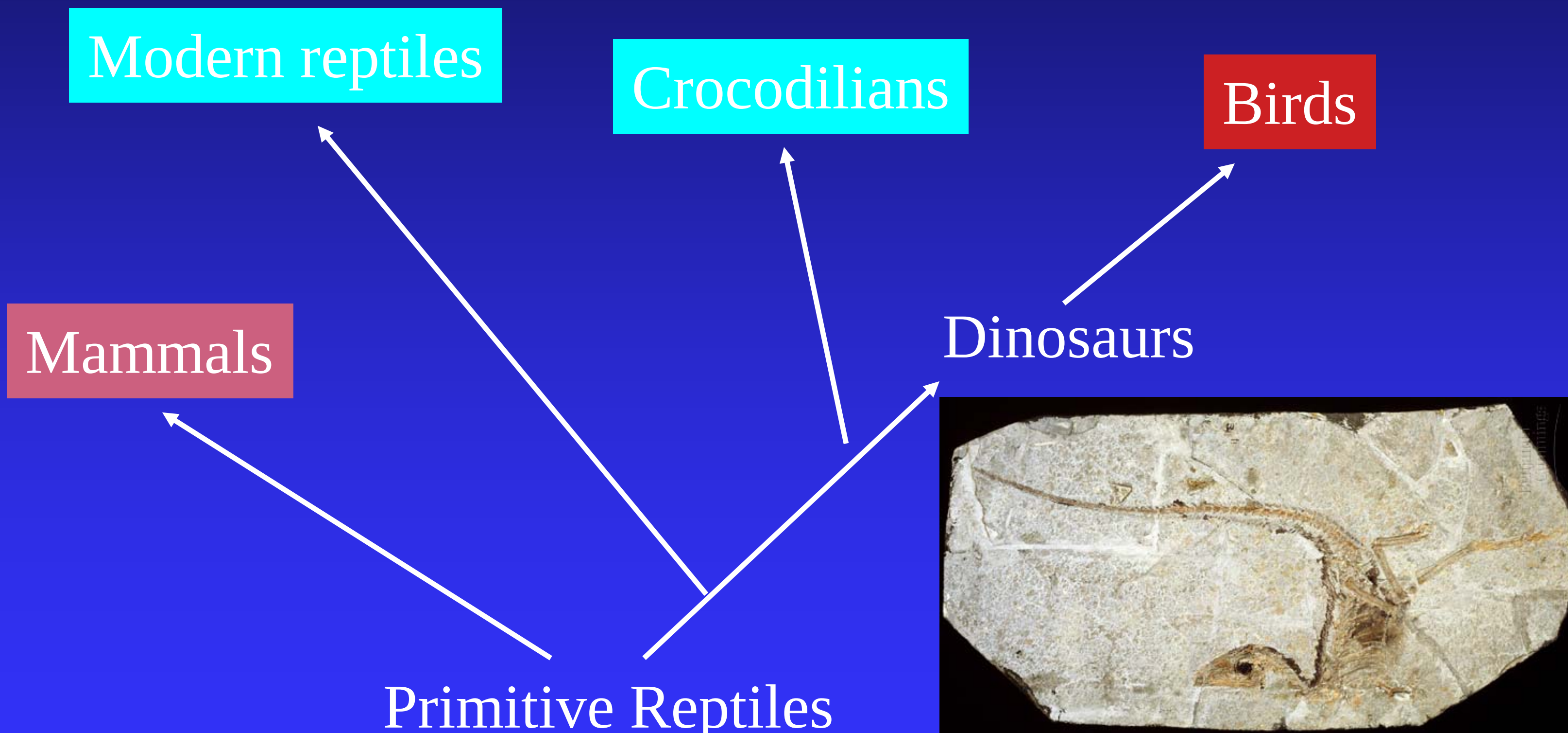

2nd evol radiation: Archosaurs = Dinos (Orniths, "bird" hips and Sauris, "lizard Hips), Pterosaurs, crocs Lepidosaurs = squamata, plesiosaurs and Ichthyosaurs

1st evol radiation into 3 branches (skel anat) Triassic (250 mya)

310 mya

350 mya?

# Phylogenetic relationships between extant poikilotherms and endothermic homeotherms




Cretaceous theropod dinosaurs, e.g., velociraptor, with putative feathers from Chinese sediments: *Sinoauaropteryx*

# Extant Reptiles: Adaptations

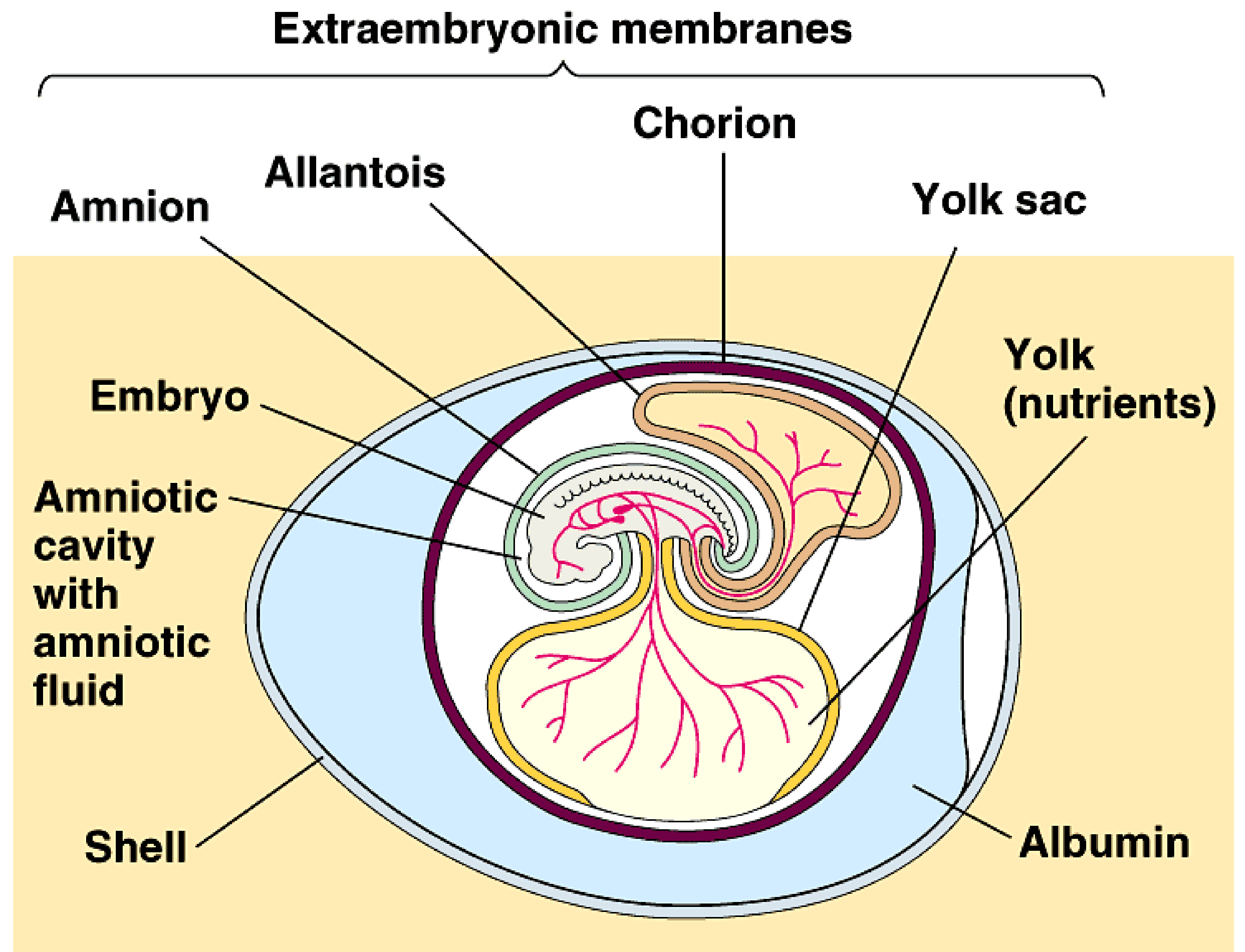
- Desiccation resistant covering
- Respiratory and circulatory changes
- Reproductive advances:
  - amniotic egg
  - extraembryonic membranes
- Metabolism

Testudines

Sphenodontia and Squamata

Crocodilia

# The Amniotic egg

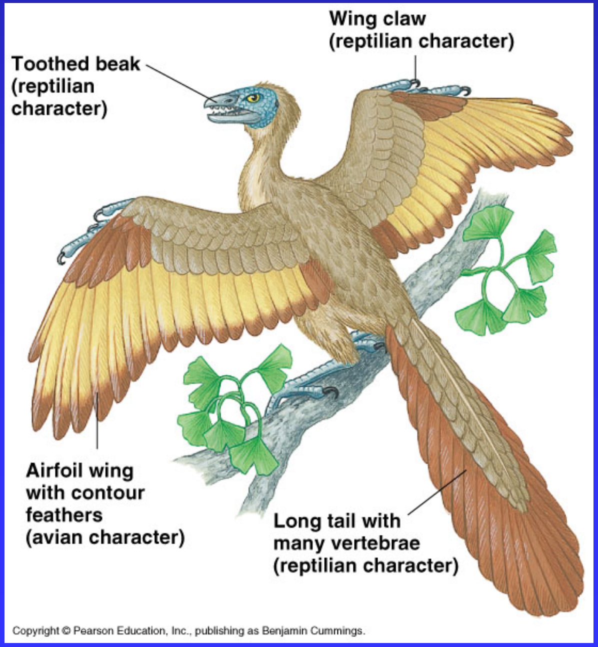


# Birds and Mammals: "Party animals"

- Temperature and metabolic rate
- Poikilotherms: amphibians and reptiles
- Homeotherms: mammals and birds
- Ectothermy
- Endothermy

# Ancient Birds: Archaeopteryx a Jurassic bird-reptile

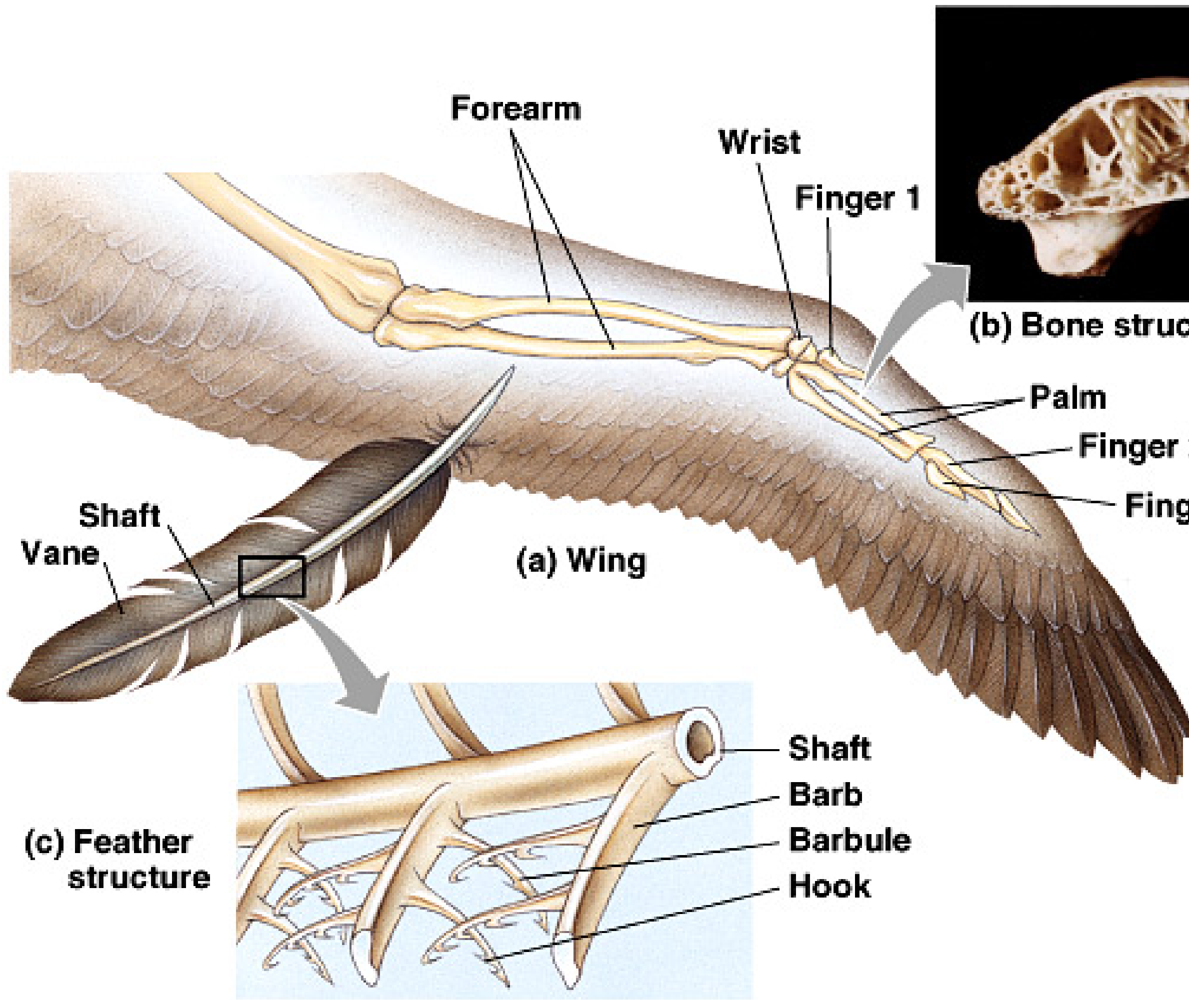

- Reptile-like characteristics
  - Reptilian jaw
  - Claws
  - Tail
  - Solid bones
- Bird-like characteristics
  - Feathers - modified scales
  - Posture
  - Large avian eye
  - Scales on legs



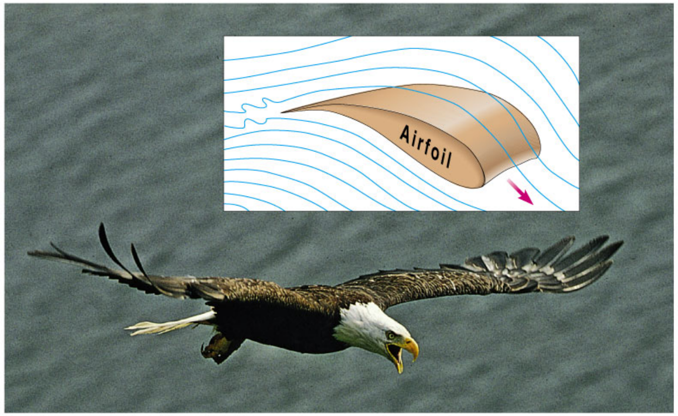
# Avian Characteristics

- 1. Endothermic Homeotherms
- 2. Feathers
- 3. Hollow bones
- 4. Skeletal fusion
- 5. Loss of tail
- 6. Beak
- 7. Gizzard
- 8. Digestive and urinary changes
- 9. Respiratory changes
- 10. Circulatory changes
- 11. Reproductive changes
- 12. Parental care

# Form fits function: the avian wing and feather





# Mammalian Reproductive Strategies:

- Monotremes: Echidna and Duck-billed platypus

- Marsupials: premature delivery
- Placental Mammals:
  - internal development
  - Reuse of extra-embryonic membranes

# Mammalian Characteristics

- 1. Endothermic Homeotherms
- 2. Hair or fur covering
- 3. Mammary glands
- 4. Single boned jaw
- 5. Heterodont dentition
- 6. Rearrangement of pectoral and pelvic girdles
- 7. Circulatory changes
- 8. Respiratory changes
- 9. Reproductive Adaptations