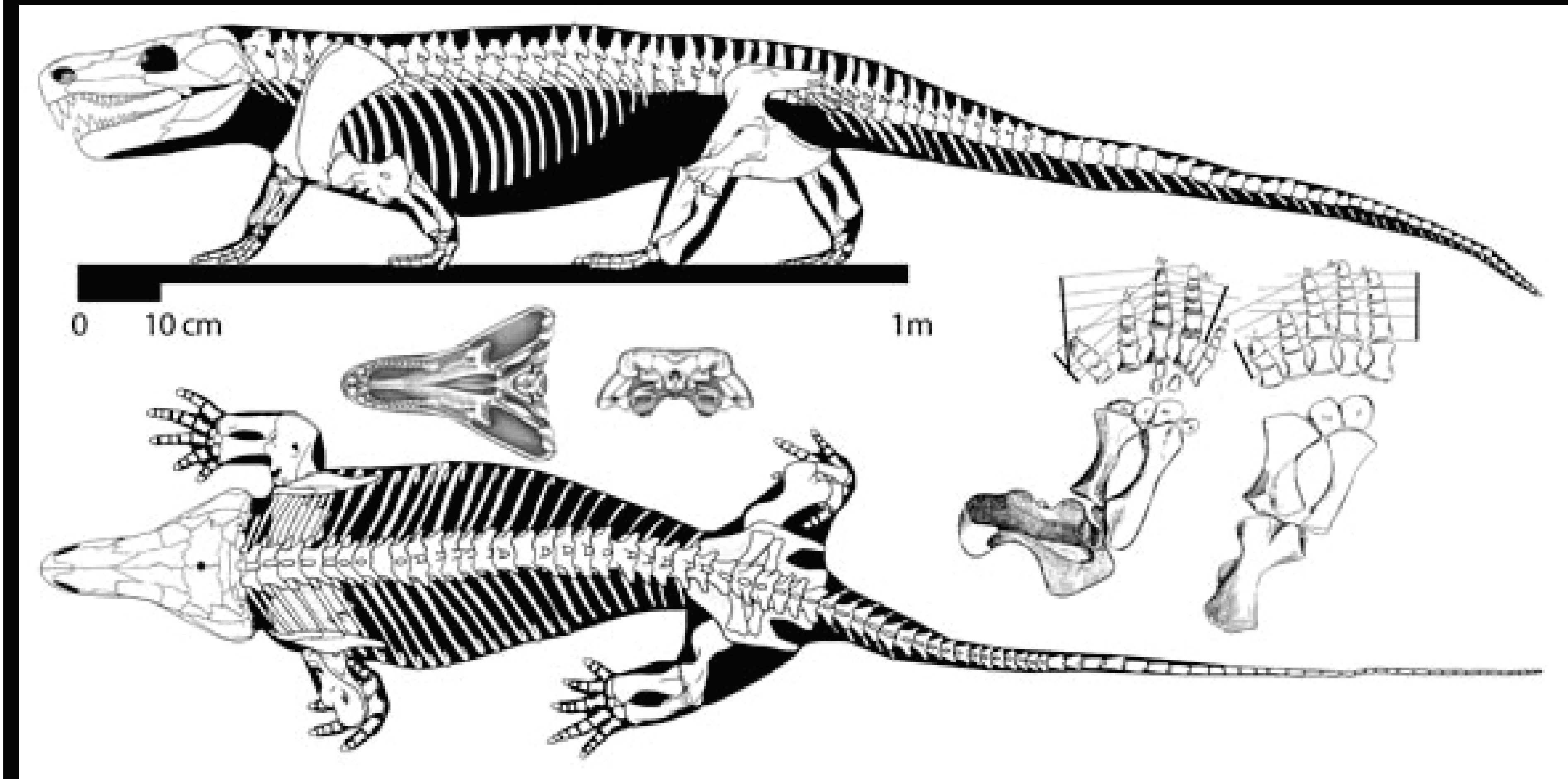
Comparative Anatomy & Evolution of Vertebrates



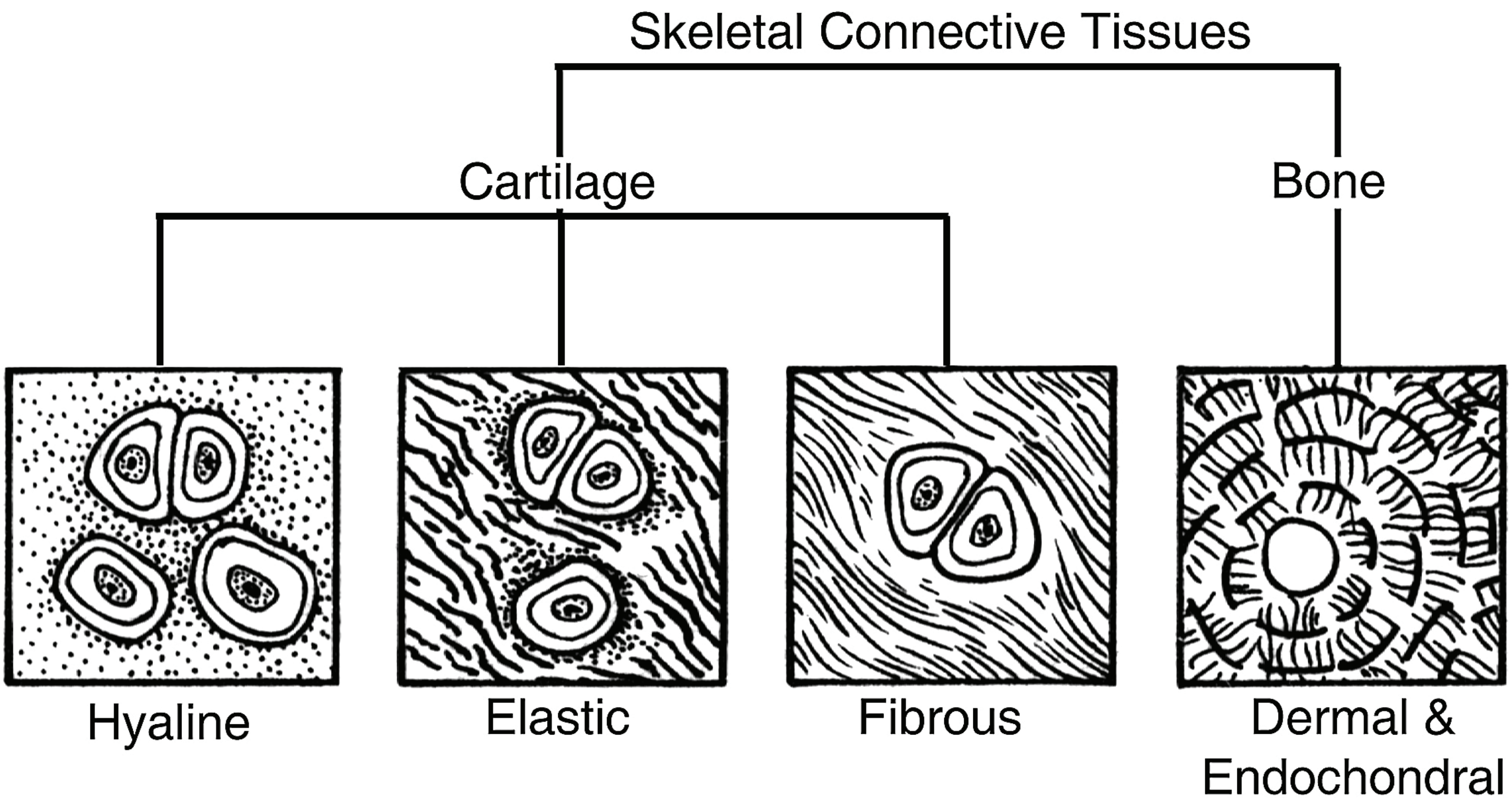
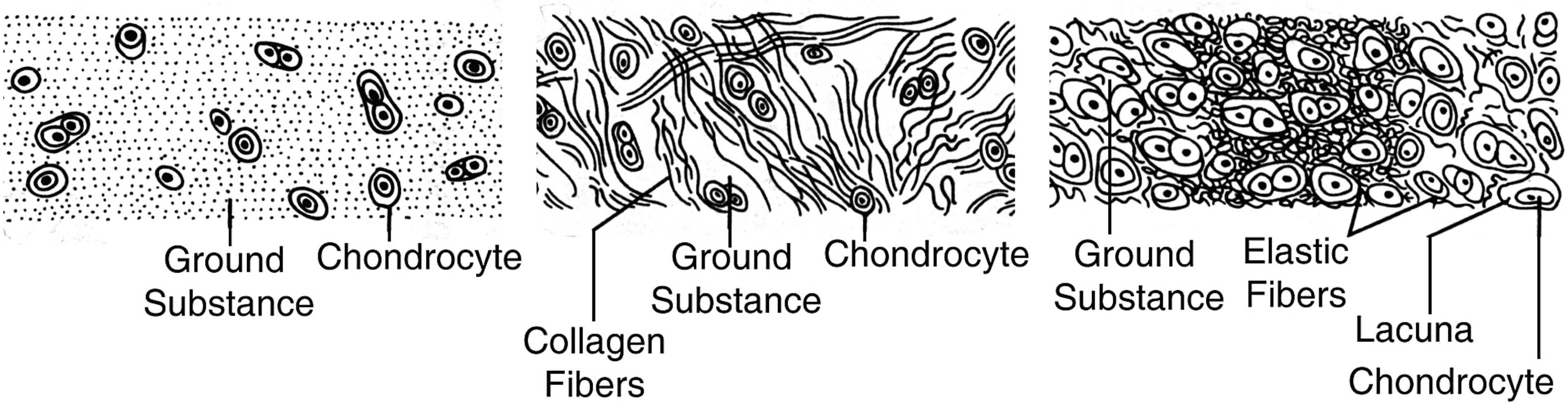


FIGURE 122. Primary skeletal connective tissue types. (*after Kardong*)



A. Hyaline Cartilage **B. Fibrocartilage** **C. Elastic Cartilage**

FIGURE 123. Types of cartilage. The cartilage cell or chondrocyte is surrounded by a matrix composed of chondroitin ground substance and protein fibers. **A.** Although hyaline cartilage contains a small amount of collagen fiber these fibers are not apparent when the matrix ix viewed with a light microscope. In contrast, **B.** fibrous cartilage or fibrocartilage contains abundant amounts of collagen fiber, imparting mechanical resistance to tensile forces. **C.** Elastic cartilage contains abundant amounts of elastin fiber which makes the cartilage springy and flexible. (*after Kardong; Romer & Parsons*)

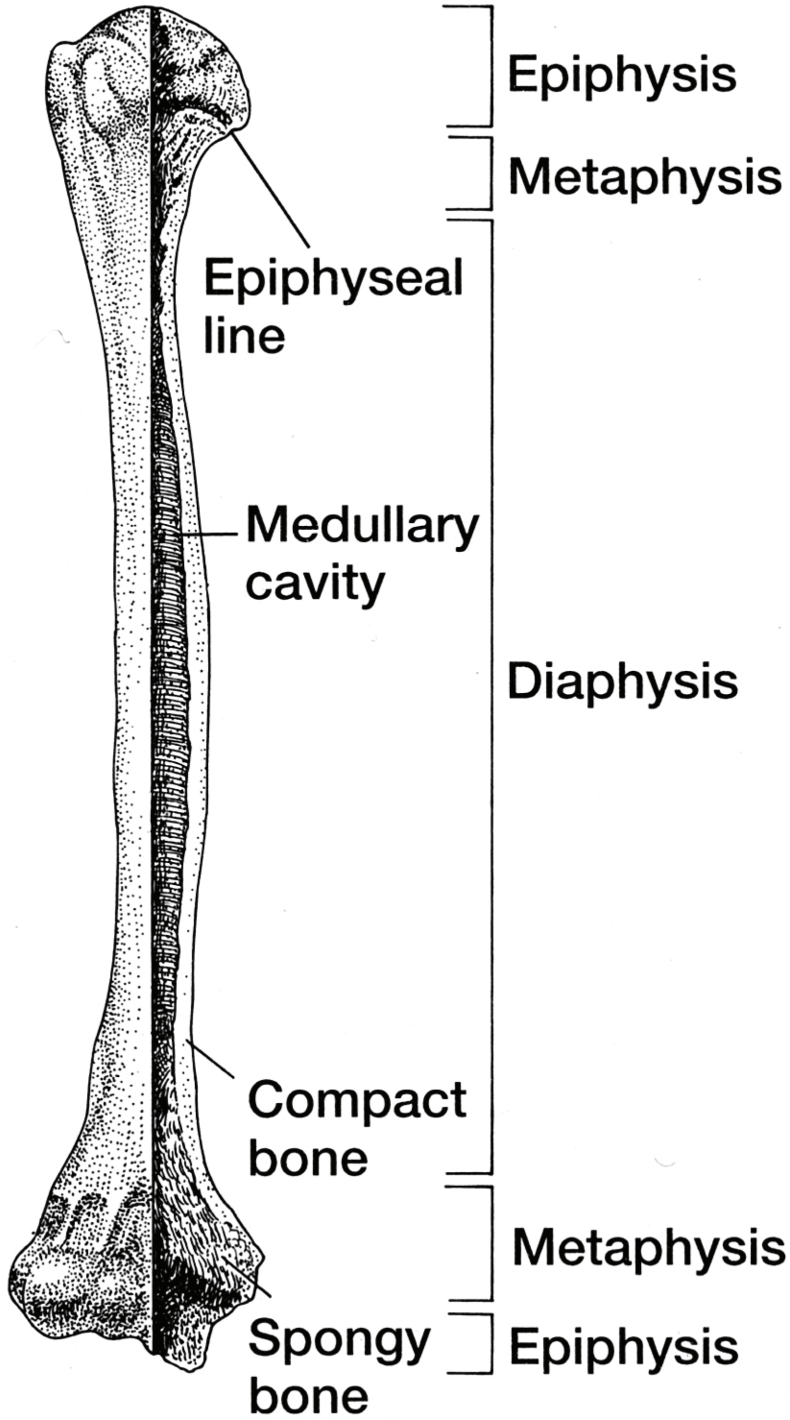


FIGURE 124. Regions of a long bone. The middle section of bone is the *diaphysis* or shaft and contains the medullary cavity. In mammals, the ends of the bones are secondary centers of ossification, or *epiphyses*, although this term is sometimes used to mean simply the end of a bone. Between the diaphysis and the epiphysis is the metaphysis, the actively growing region of the bone. Compact bone is dense. Spongy or cancellous bone is porous. The medullary cavity and all spaces in spongy bone are filled with blood-forming or *hemopoietic* tissues. (*after Kardong*)

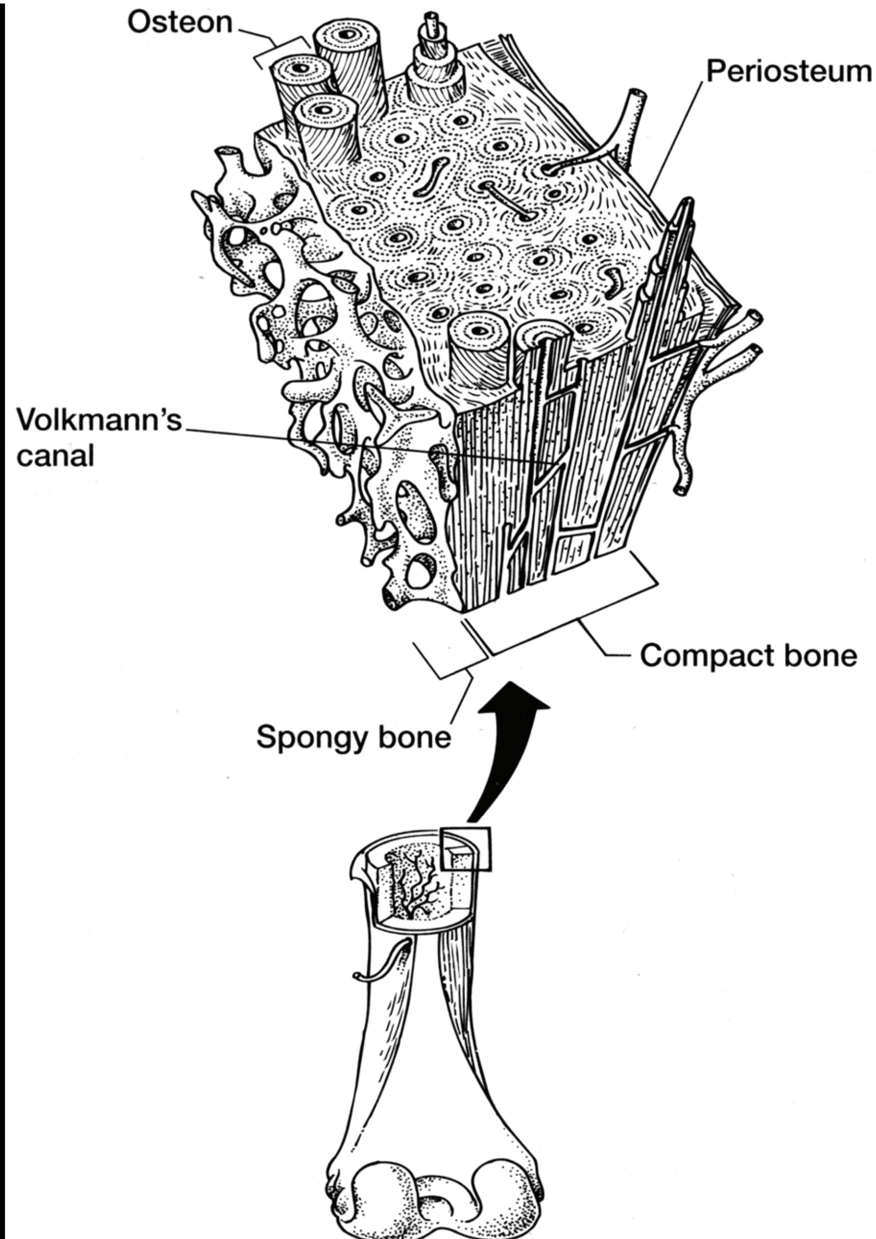


FIGURE 125. Bone architecture. Compact bone is comprised of a series of organizational units called *osteons.* Each osteon is a series of concentric rings of osteocytes and their matrix. Nerves and blood vessels pass through a central canal within each osteon. Volkmann's canals are diagonal connections that allow blood vessels to interconnect between osteons. As new osteons form they usually overrun existing, older osteons as part of the ongoing dynamic process of bone remodelling. The complex organization produced by osteons is called the Haversian system. (*after Kardong*)

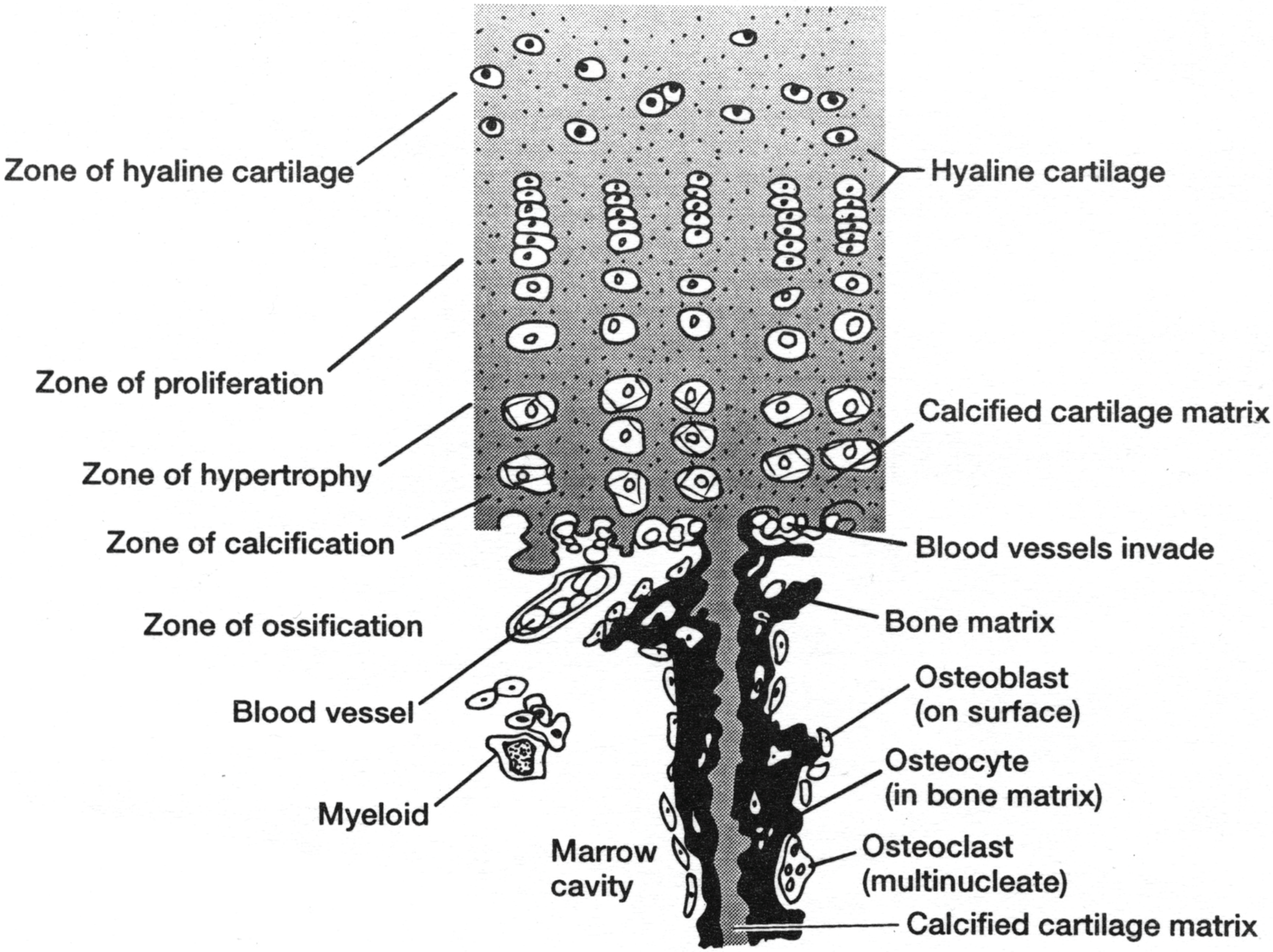


FIGURE 126. **Formation of endochondral bone.** Endochondral bone is formed by the mineralization and ossification of a cartilage template. Osteocytes in the immature bone proliferate and hypertrophy as they deposit the crystaline matrix of mature bone. As bone develops, blodd and nervous elements are sheathed to form haversian canals. (*after Kardong*)

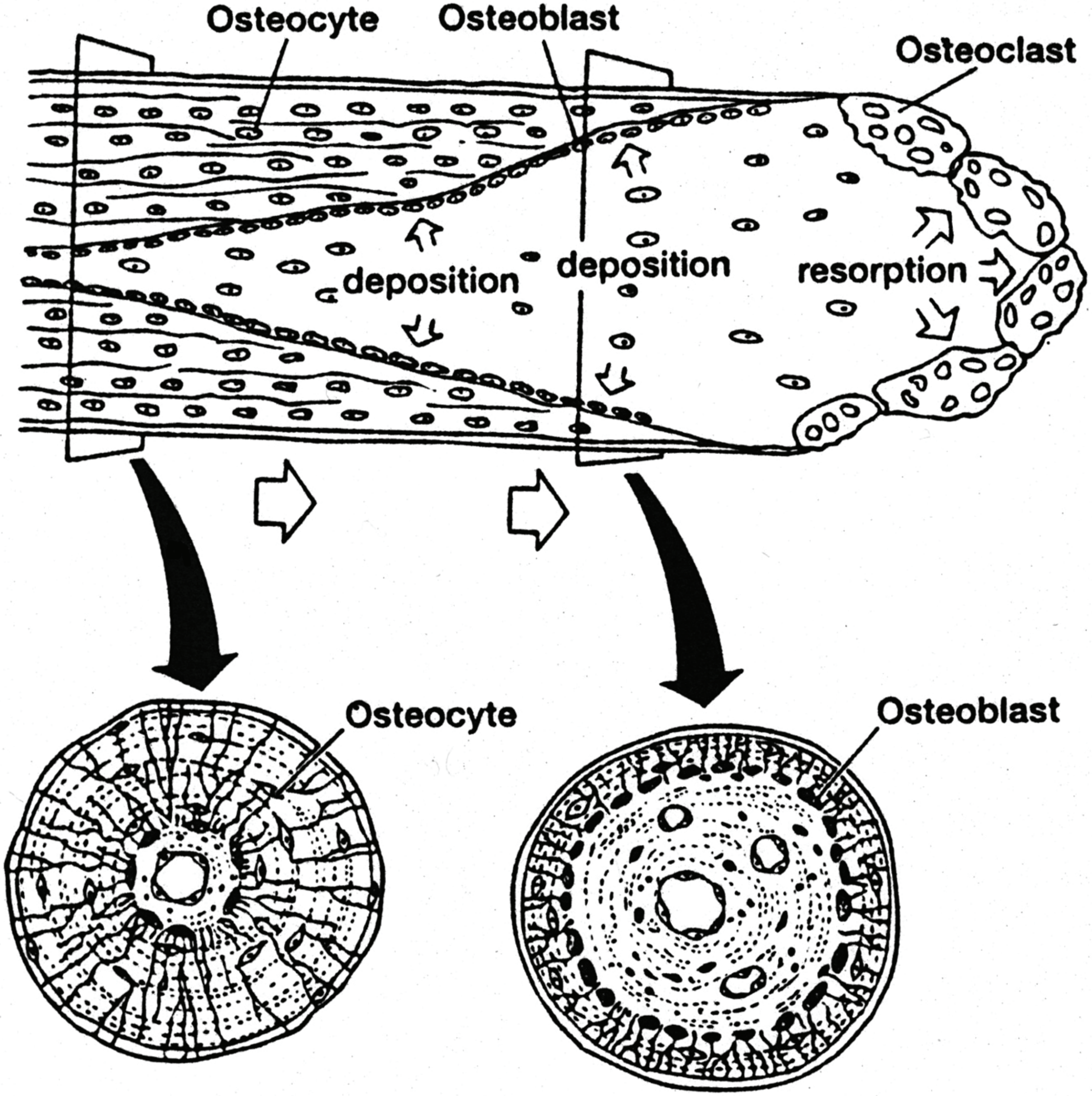
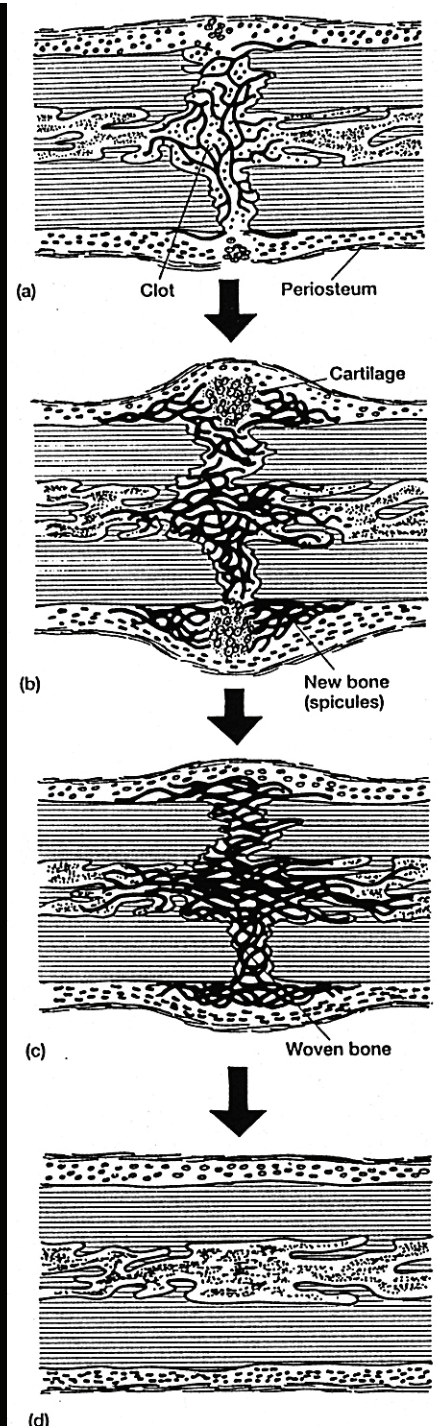


FIGURE 127. Formation of a new osteon or Haversian canal. An advancing line of osteoclasts removes bone cells by eroding through existing bone matrix to open a channel. Osteoblasts appear along the perimeter of the channel and immediately begin to form concentric rings of new matrix. As they become surrounded by the matrix they become osteocytes and simply maintain their surrounding bone matrix. (*after Kardong*)



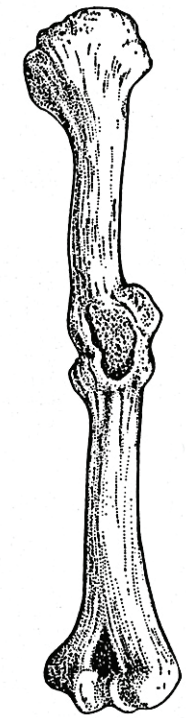
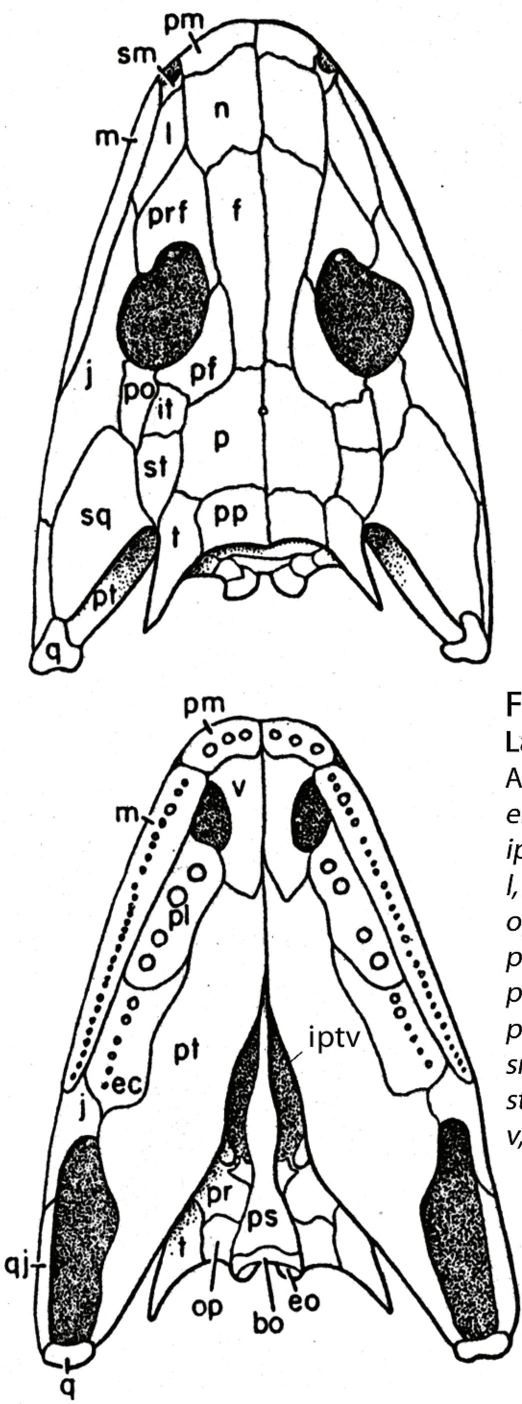
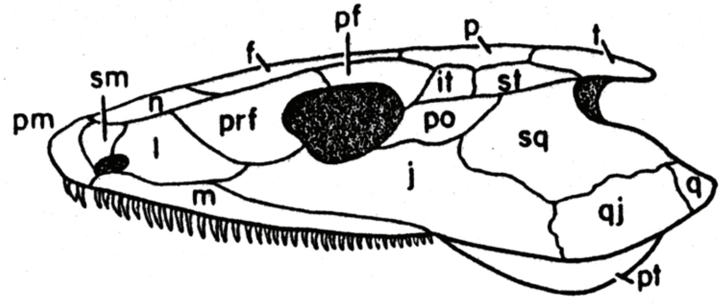


FIGURE 128. Repair of breaks in bone. **(a)** When a fracture occurs, a callus of clotted blood and debris forms between the ends of the broken bone **(b)**, but it is soon replaced by cartilage. The cartilage becomes calcified, blood vessels invade, osteoblasts and osteoclasts appear, and new bone matrix is laid down. **(c)** The spicules of woven bone hold the broken ends of the fracture together and through remodeling **(d)** come to fully replace the broken section of bone. **(e)** A healed fracture. Most breaks in bone heal and a nearly normal shaped is resored after a period of remodeling. But not always. If the break is severe and "setting" the bone in proper alignment is poorly done, then the repair may be imperfect. This humerus belonged to Dr. Davids Livingstone and clearly reveals the imperfect repair of a fracture he sustained during a lion's attack in Africa 30 years before his eventual death in England. (*after Kardong*)





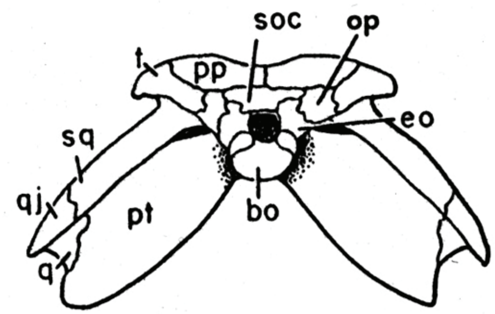
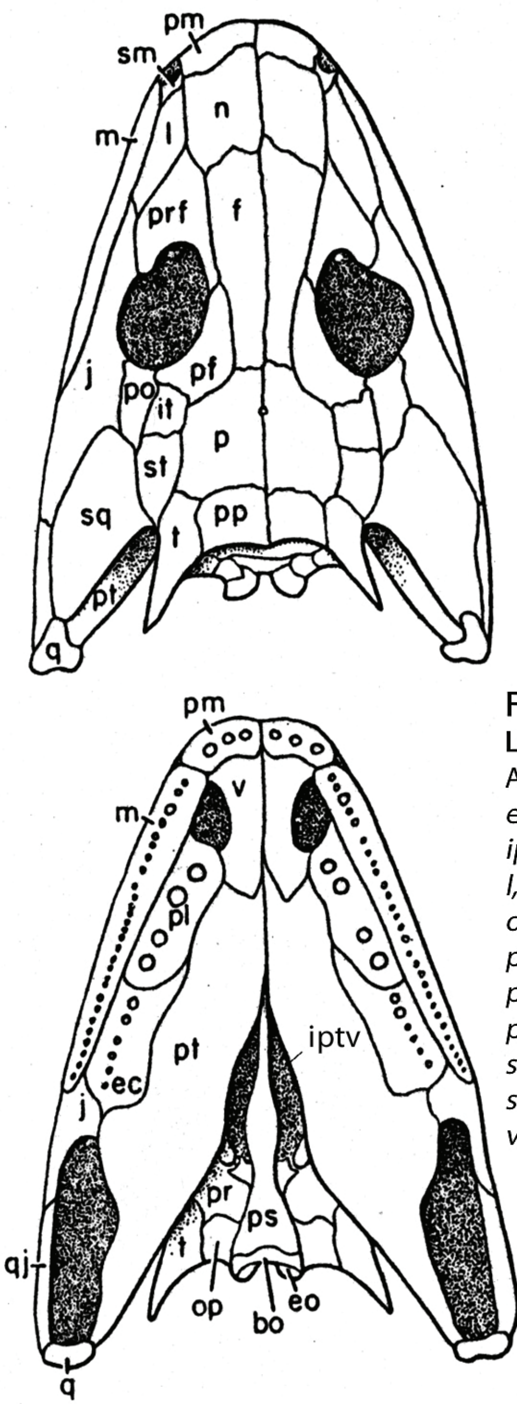
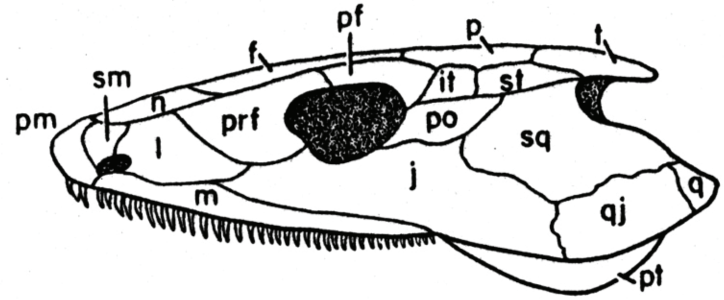


FIGURE 129. Anatomy of the skull: the Carboniferous Labyrinthodont *Palaeoherpeton.* (*after Romer & Parsons*)
Abbreviations: *bo*, basioccipital; *ec*, ectopterygoid; *en*, external nares; *eo*, exoccipital; *f*, frontal; *iptv*, interpterygoid vacuity; *it*, intertemporal; *j*, jugal; *l*, lacrimal; *m*, maxilla; *n*, nasal; *on*, otic notch; *op*, opisthotic; *or*, orbit; *p*, parietal; *pf*, postfrontal; *pl*, palatine; *pm*, premaxilla; *po*, postorbital; *pp*, postparietal; *prf*, prefrontal; *ps*, parasphenoid; *pt*, pterygoid; *q*, quadrate; *qj*, quadratojugal; *sm*, septomaxilla; *soc*, supraoccipital; *sq*, squamosal; *st*, supratemporal; *stf*, supratemporal fossa; *t*, tabular; *v*, vomer.





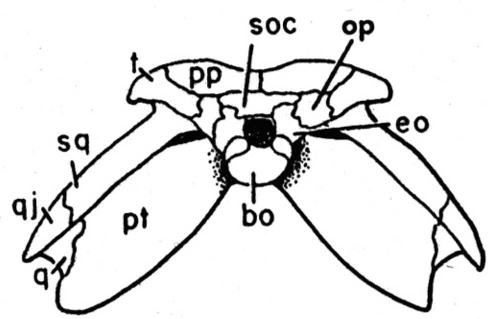


FIGURE 129. Anatomy of the skull: the Carboniferous Labyrinthodont *Palaeoherpeton.* (*after Romer & Parsons*)
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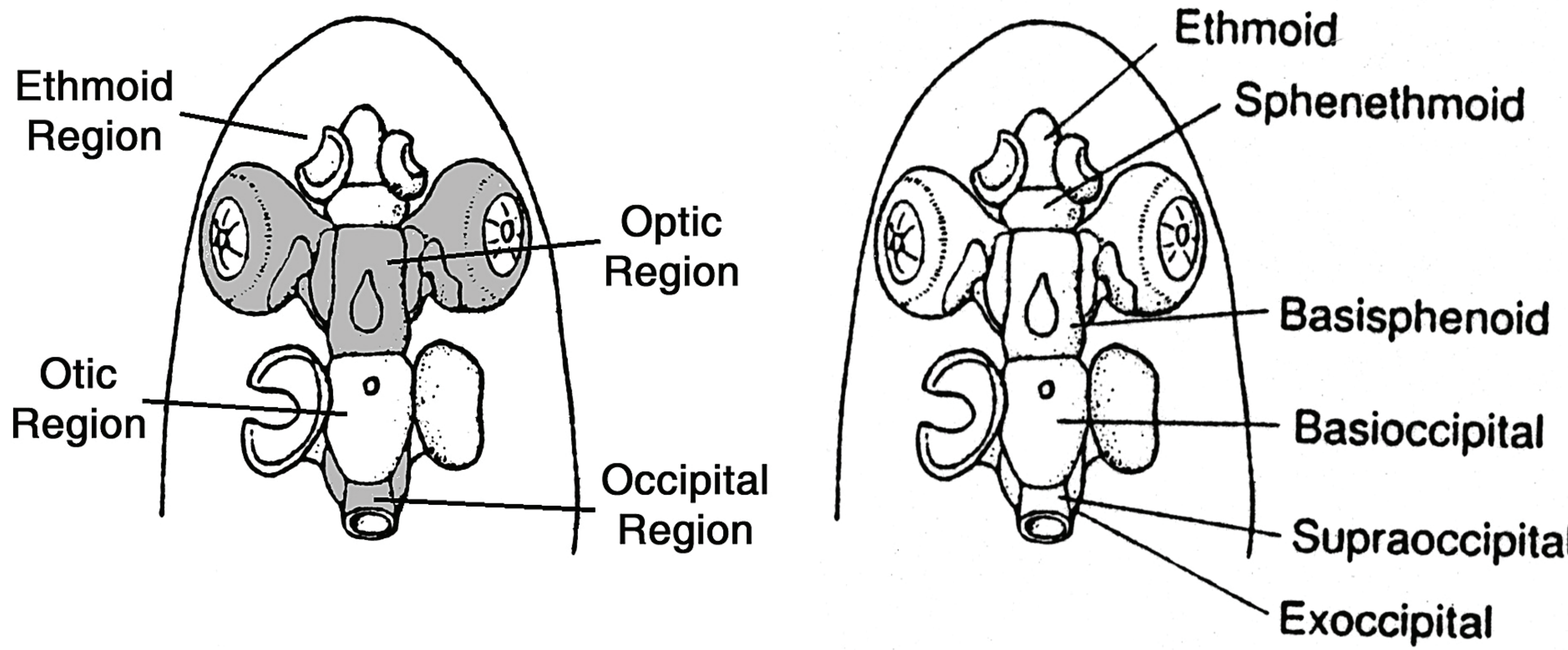

FIGURE 130. Basic anatomy of the shark braincase.

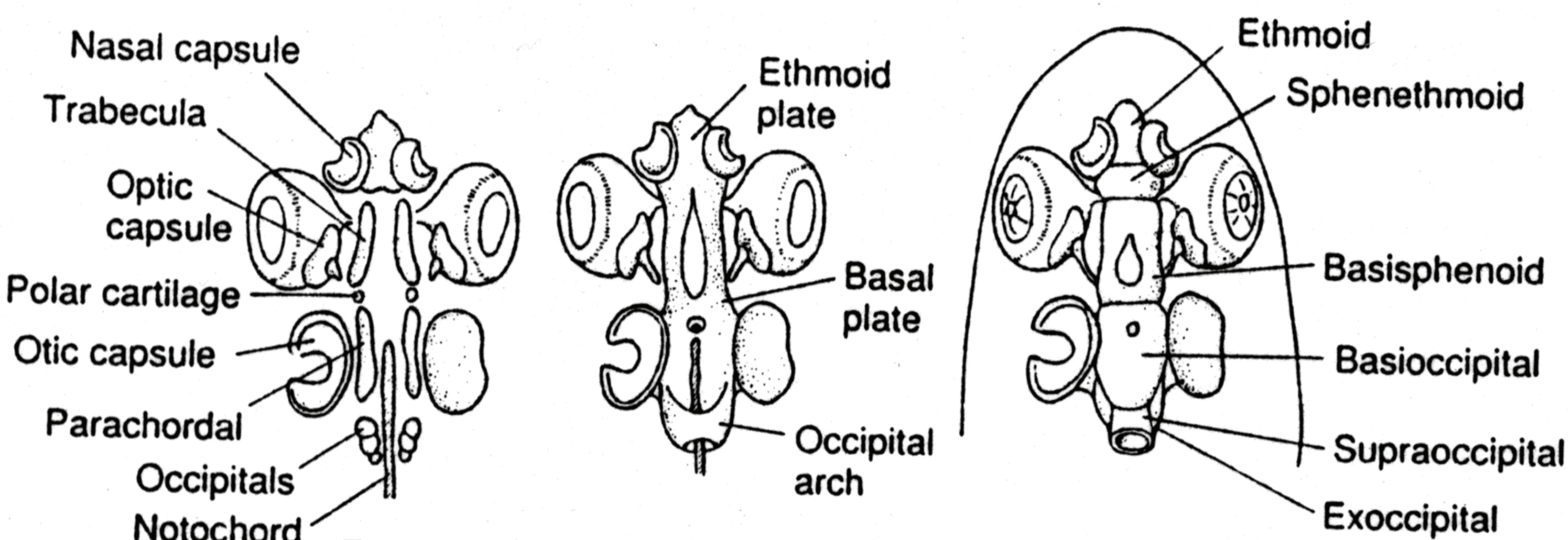

FIGURE 131. Development of the chondracranium.

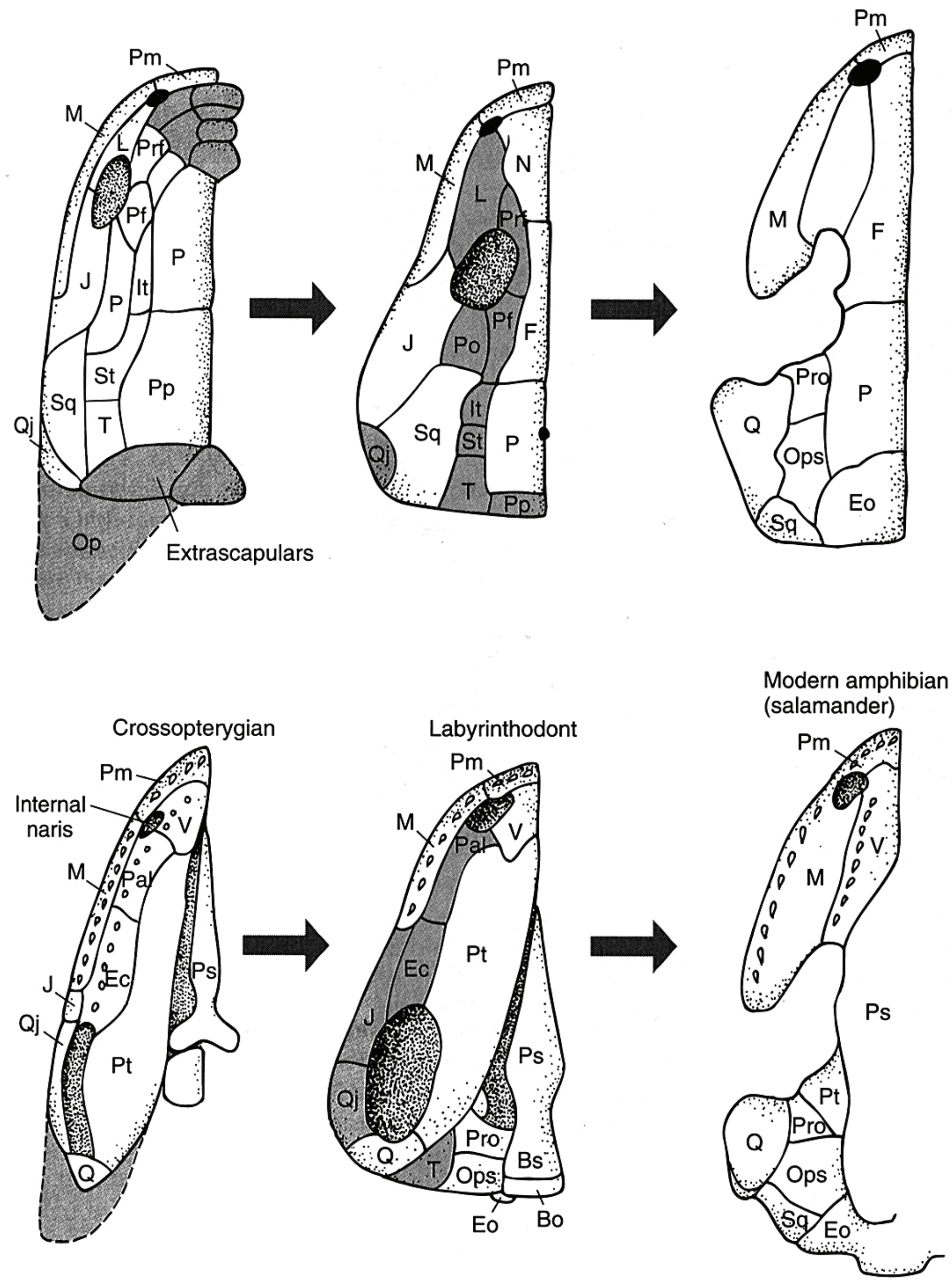

FIGURE 132. **Diagrammatic views of skull modifications from crossopterygian to labyrinthodont to modern amphibian (salamander).** (a) Dorsal views. (b) Ventral (palatal) views. Skull bones lost in the derived group are shaded in the skull of the preceding group. Abbreviations: basioccipital (Bo), basisphenoid (Bs), ectopterygoid (Ec), exoccipital (Eo), frontal (F), intertemporal (It), jugal (J), lacrimal (L), maxilla (M), nasal (N), opercular (Op), opisthotic (Ops), parietal (P), palatine (Pal), postfrontal (Pf), premaxilla (Pm), postorbital (Po), prefrontal (Prf), prootic (Pro), postparietal (Pp), parasphenoid (Ps), pterygoid (Pt), quadrate (Q), quadratojugal (Qj), supratemporal (St), squamosal (Sq), tabular (T), vomer (V).

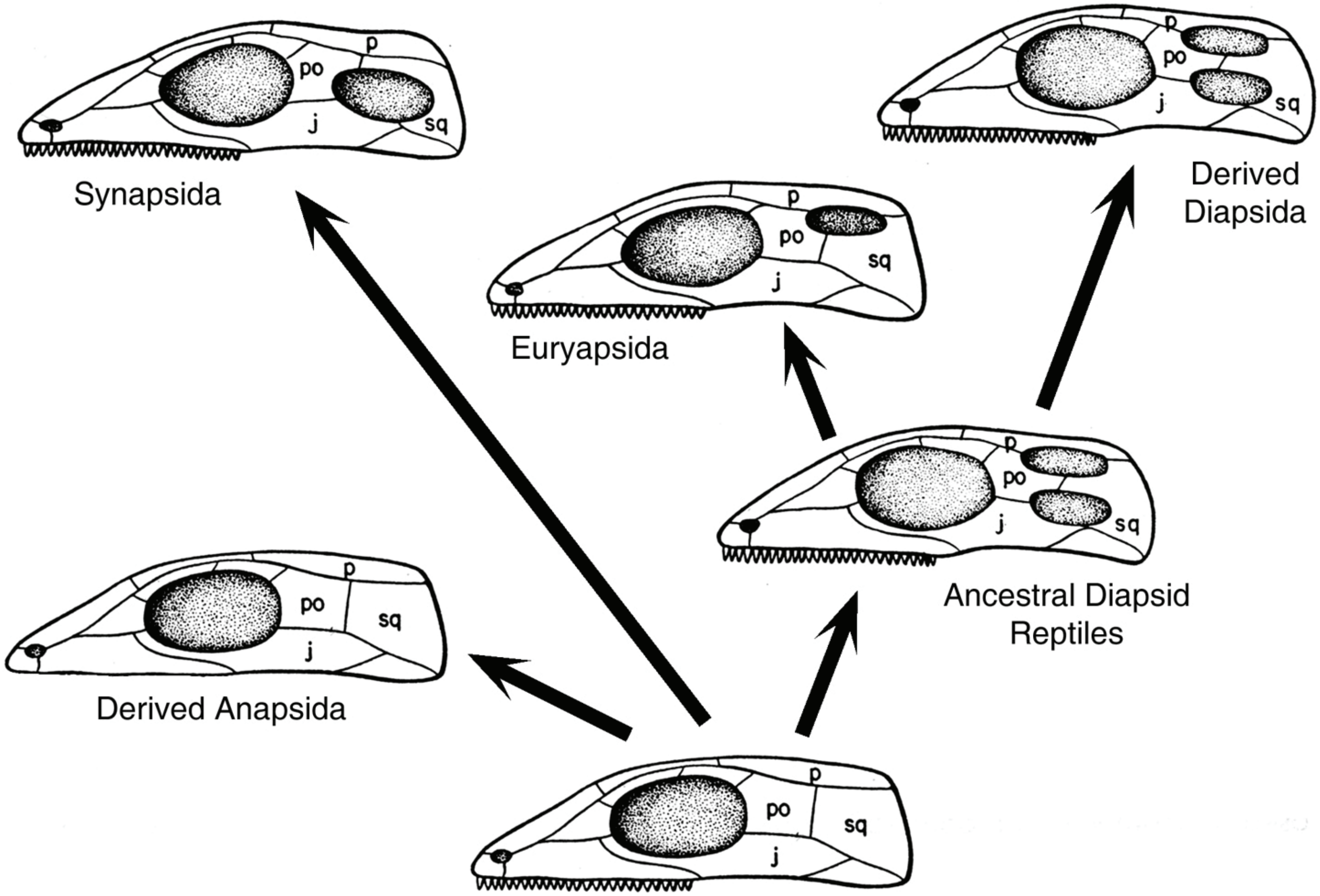

FIGURE 133. Major lineages of skull evolution within the amniotes. The anapsid skull occurs in cotylosaurs and their modern descendants (turtles and tortoises.) Two major groups, the diapsids and synapsids, independently evolved from the anapsid condition. *Sphenodon* and crocodilians retain the primitve diapsid skull but it has been significantly altered in other diapsid derivative groups such as the snakes, modern lizards, and birds. The euryapsid skull is similar to the synapsid skull of modern mammals but is not homologous. Euryapsid skulls represent the evolutionary trend of several extinct sea-going reptiles.
Abbreviations: *j*, jugal; *p*, parietal; *po*, postorbital; *sq*, squamosal.

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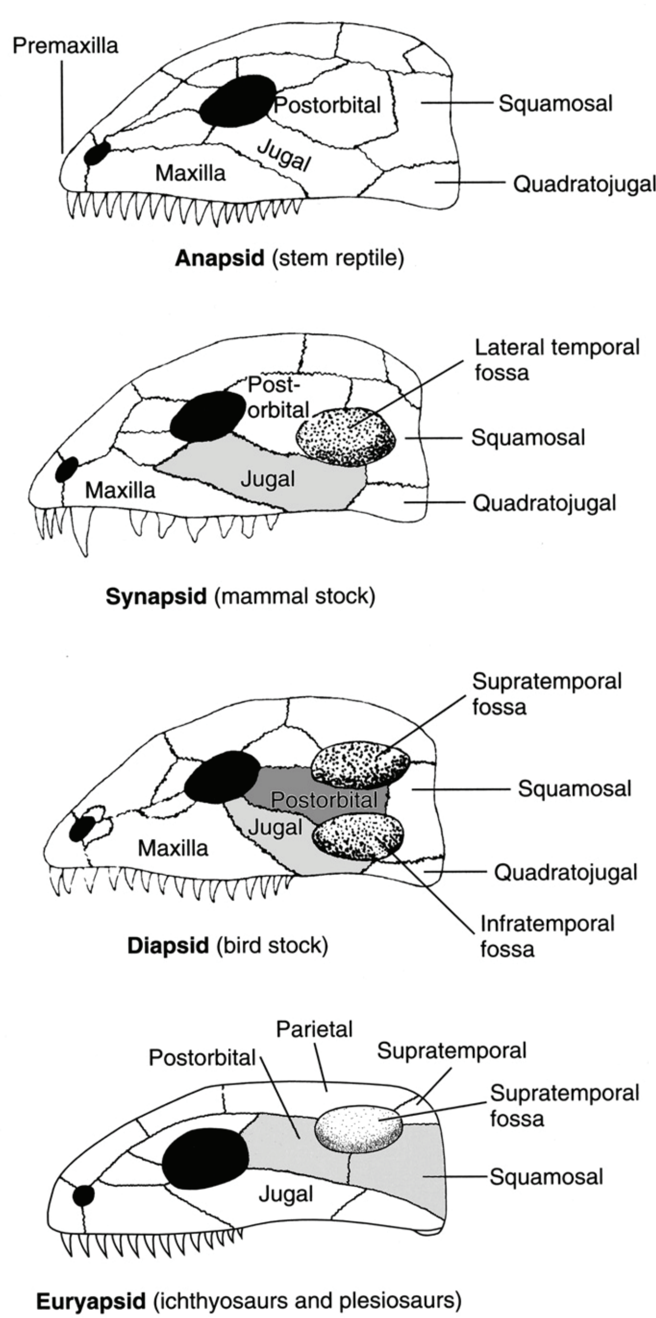


FIGURE 134. **Temporal fossae.** Light shading indicates infratemporal arch component. Dark shading indicates supratemporal arch component. *(After Kent & Miller.)*

[redacted]

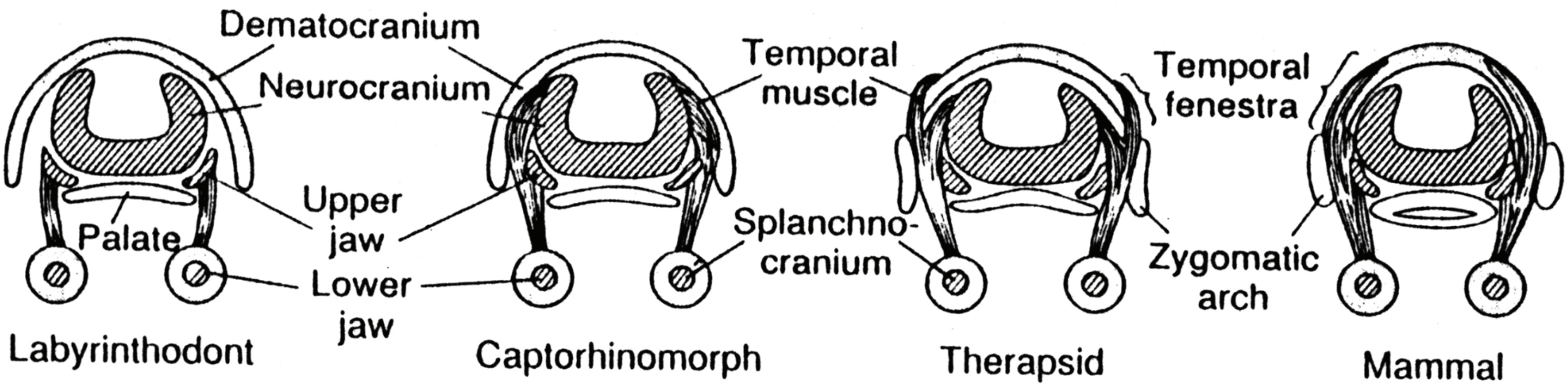


FIGURE 135. Muscle attachment and evolution of temporal fenestrae. The temporal muscles of the jaw run from the upper to lower jaw in primitive tetrapods such as labyrinthodonts (*left*). As these muscles become more prominent their site of origin from the skull expands (*center, right*). *(After Kardong.)*

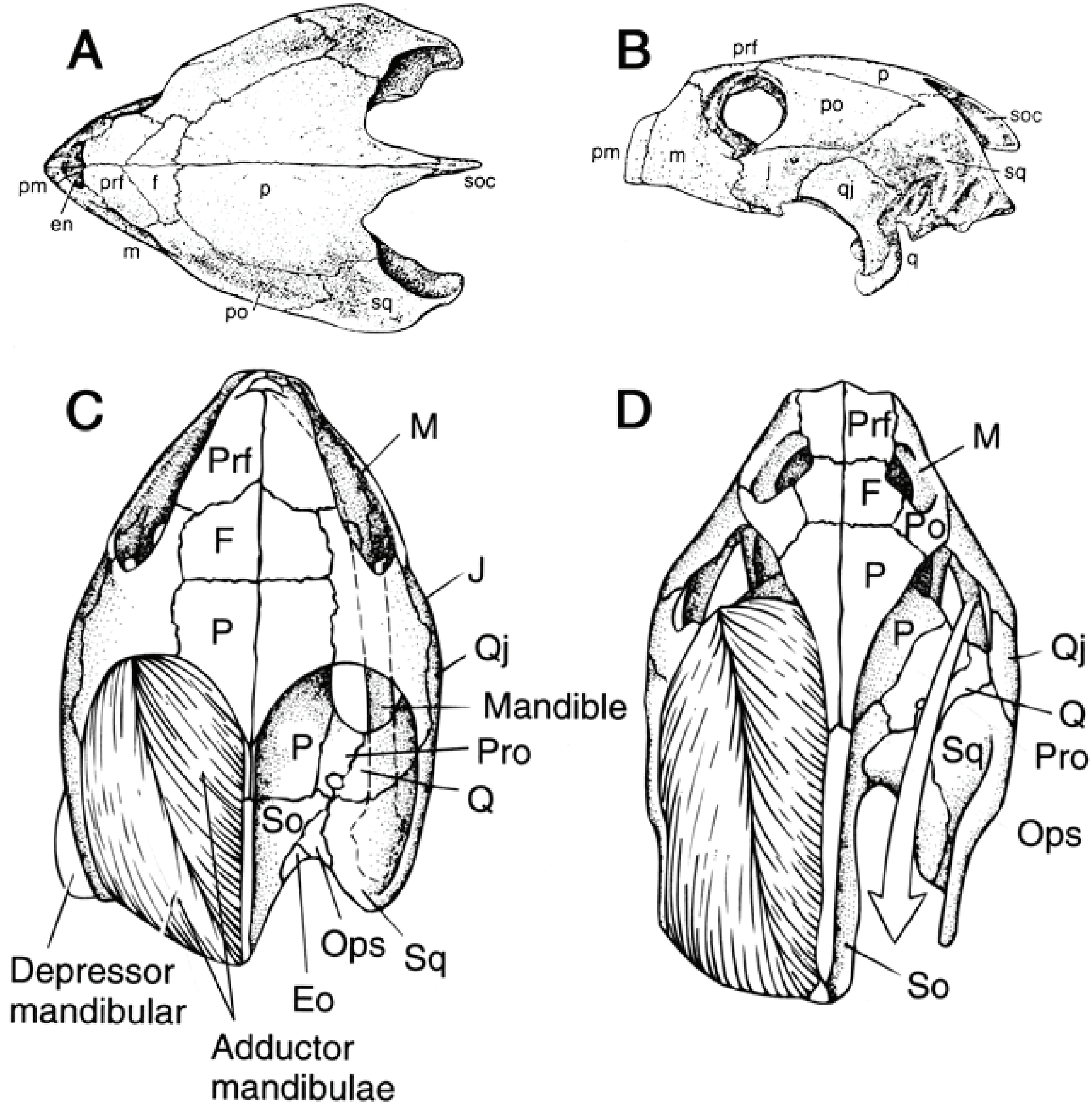


FIGURE 136. Modern anapsid skull structure and function in turtles. **(A, B)** Dorsal and lateral views of the anapsid skull of the sea turtle, *Caretta.* Note the strong emarginations or notches posteriad that house the mandibular adductor muscles. Dorsal views of the European pond turtle, *Emys,* **(C)** and the Western softshelled turtle, *Trionyx,* **(D)** show the placement of the jaw opening (depressor mandibulae) and closing (adductor mandibulae) muscles as well as the line of action of the adductor mandibulae on the lower jaw. *(After Romer, Kardong.)*

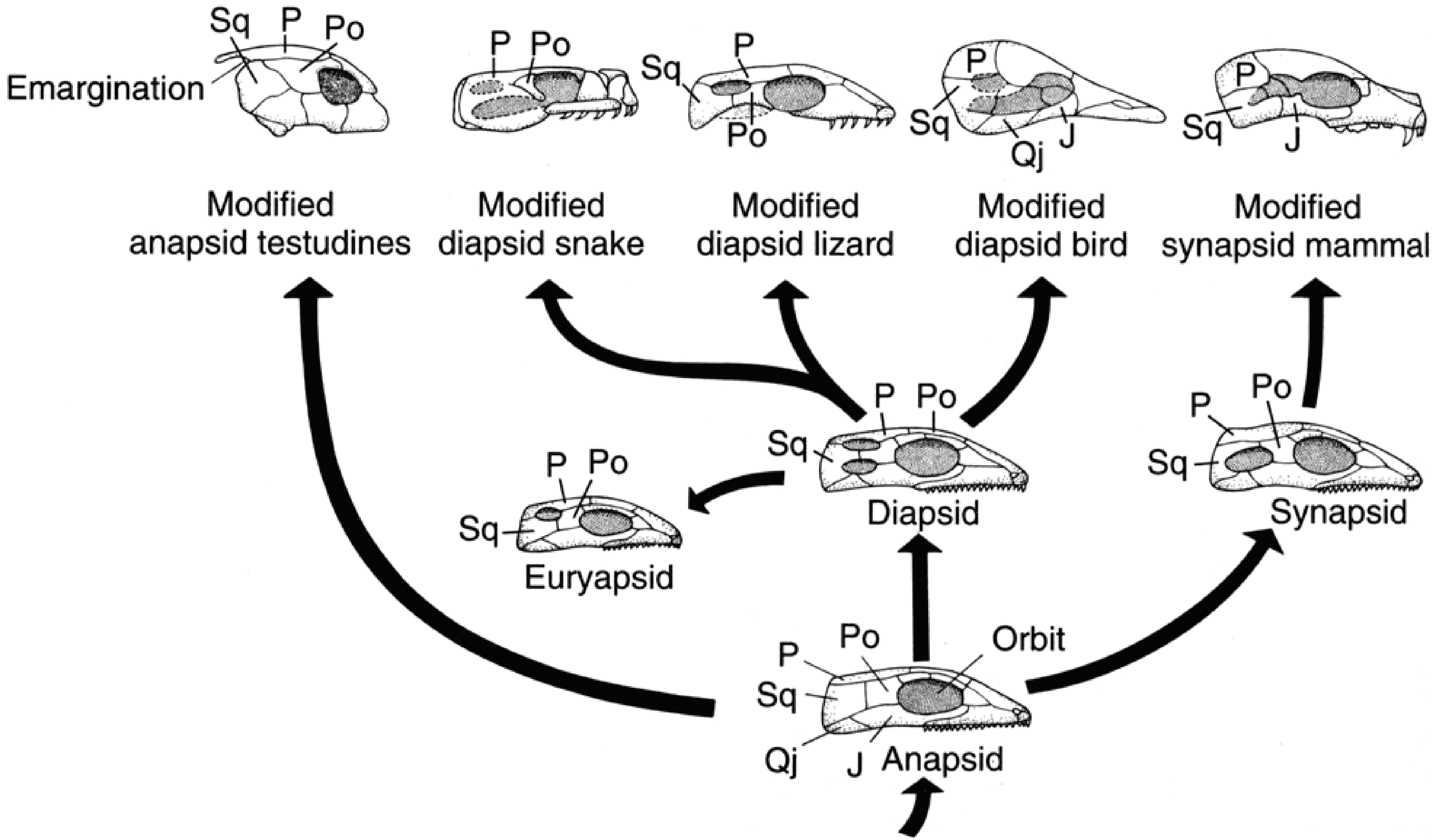


FIGURE 137. Major lineages of dermatocranial evolution within the amniotes. The anapsid skull occurs in cotylosaurs and their modern descendants, turtles and tortoises. Two major groups, the diapsids and synapsids, independently evolved from the anapsid stem reptiles. *Sphenodon* and crocodiles retain the primitive diapsid skull, but it has been modified to form significant diapsid derivative lineages among the snakes, birds, and lizards. Shading indicates positions of temporal fenestrae and orbits. *J*, jugal; *P*, parietal; *Po*, postorbital; *Qj*, quadratojugal; *Sq*, squamosal. *(After Kardong.)*

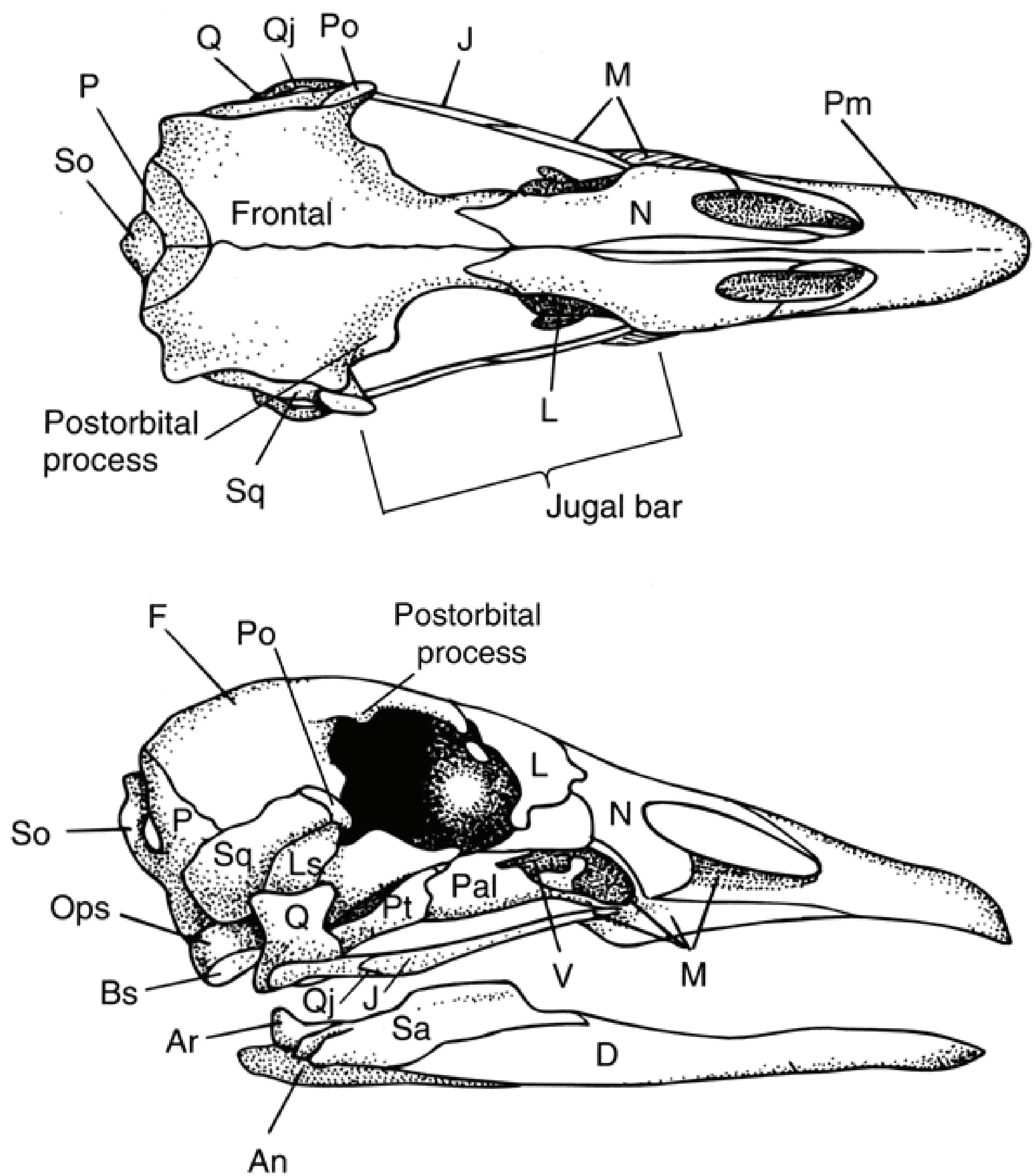


FIGURE 138. Bird skull. In adult birds the sutures between skull bones fuse to obliterte identifiable borders of individual bones. Dorsal (top) and lateral (bottom) views of a young gosling (*Anser*) skull demonstrate unfused, identifiable bony elements. *(modified from Kardong)*

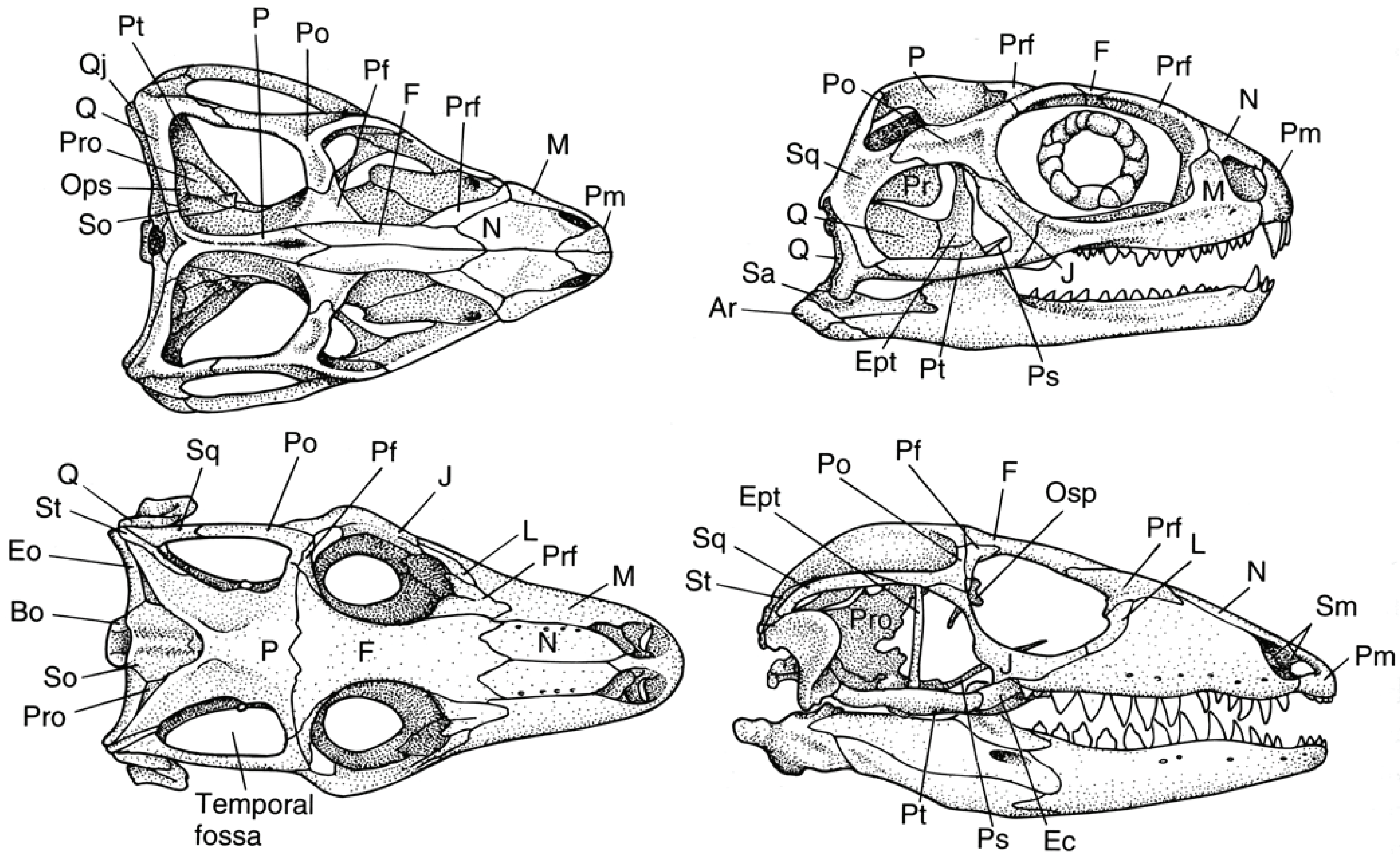


FIGURE 139. Lizard derivations of the diapsid skull pattern. Two temporal fenestrae remain bounded by bone arches in the skull of *Sphenedon*, often considered a living relic of primitive lizards (top: *dorsal*, left; *lateral*, right.) Modern lizards possess a modified diapsid skull (bottom: *dorsal*, left; *lateral*, right.) Two fenestrae are present but the ventral bony border (infratemporal arch) is absent. This loss is part of a series of modifications that serve to increase crainial kinesis. (*after Carroll; Jollie*)

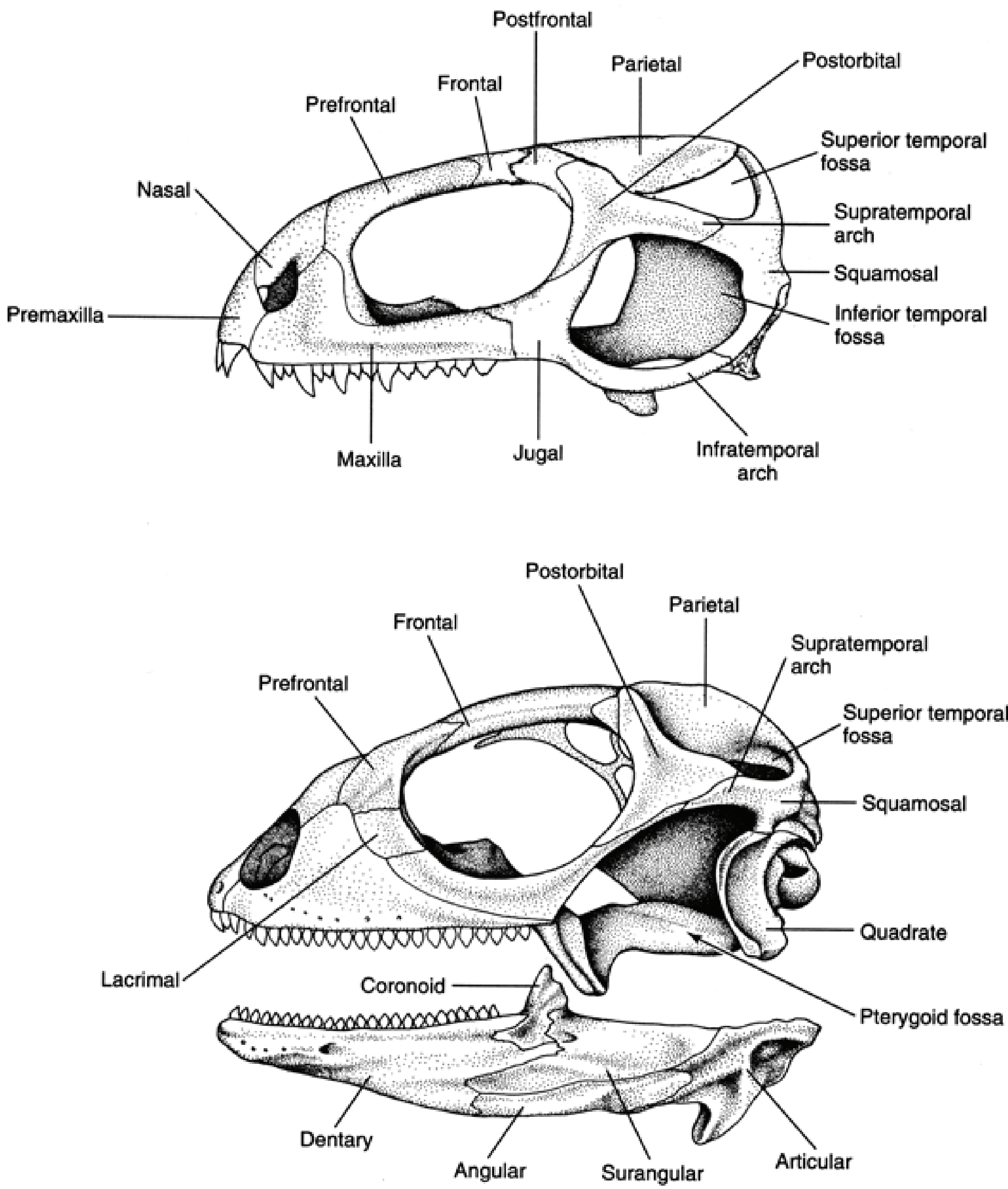


FIGURE 140. Lizard derivations of the diapsid skull pattern. Two temporal fenestrae remain bounded by bone arches in the skull of *Sphenedon*, often considered a living relic of primitive lizards (top.) Modern lizards such as *Iguana* (bottom) possess a modified diapsid skull. Two fenestrae are present but the ventral bony border (infratemporal arch) is absent. (*after Kent & Miller*)

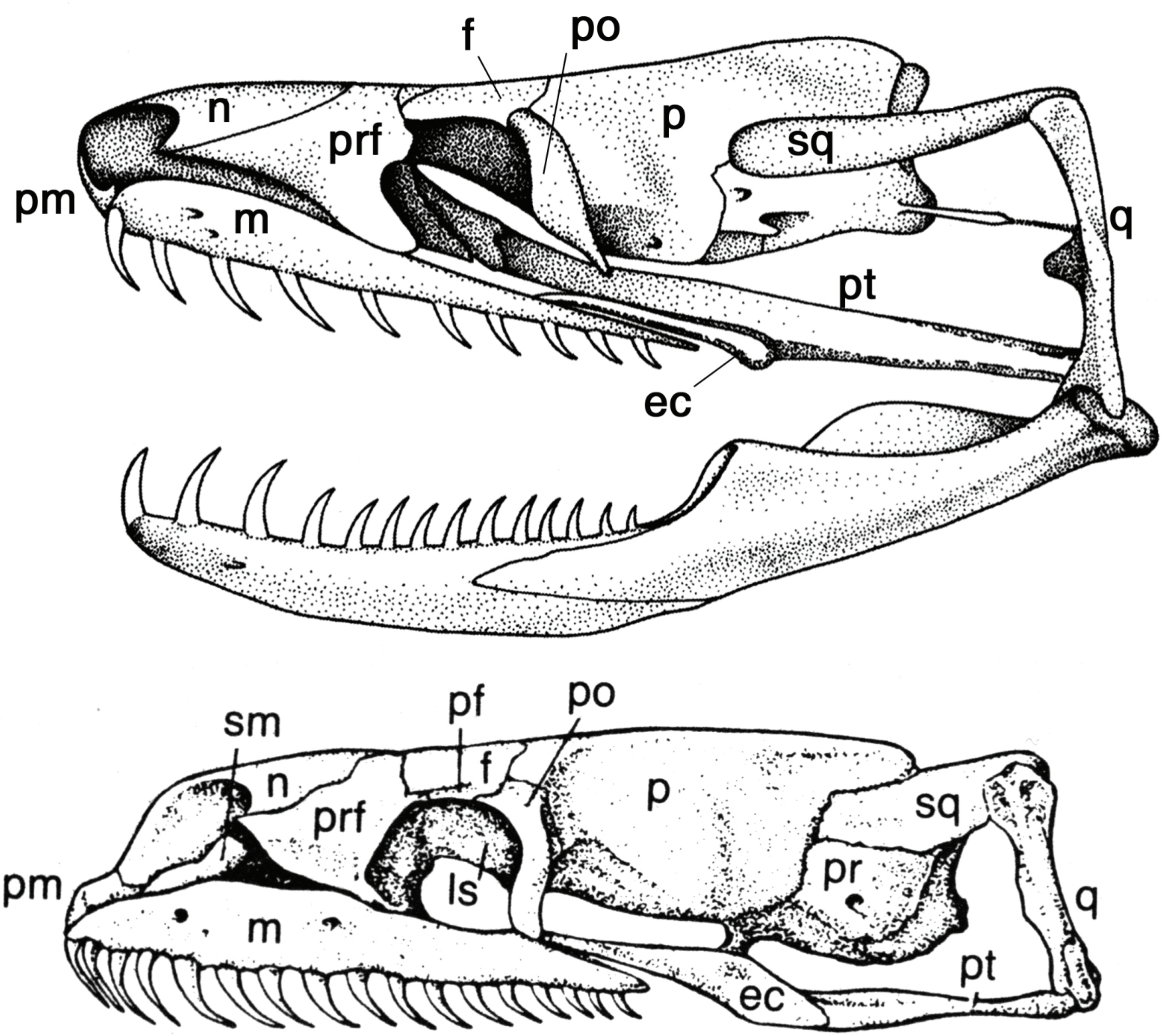


FIGURE 141. Snake derivation of the diapsid skull pattern. Two temporal fenestrae are present in the skull of a modern snake such as *Boa* (top) or *Python* (bottom) but both the supratemporal and infratemporal arches have been lost, increasing cranial kinesis. (*after Kent & Miller; Romer*)

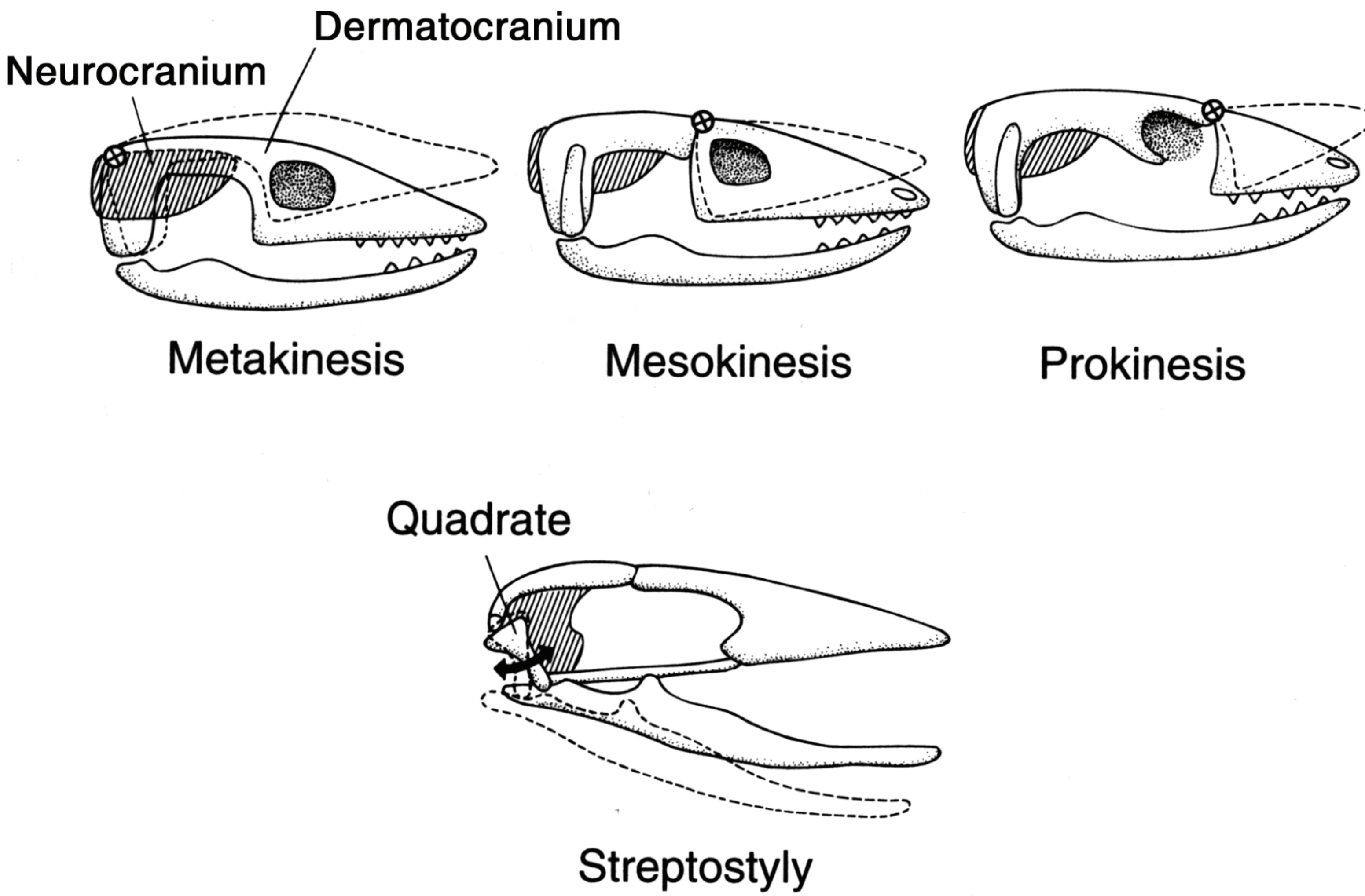
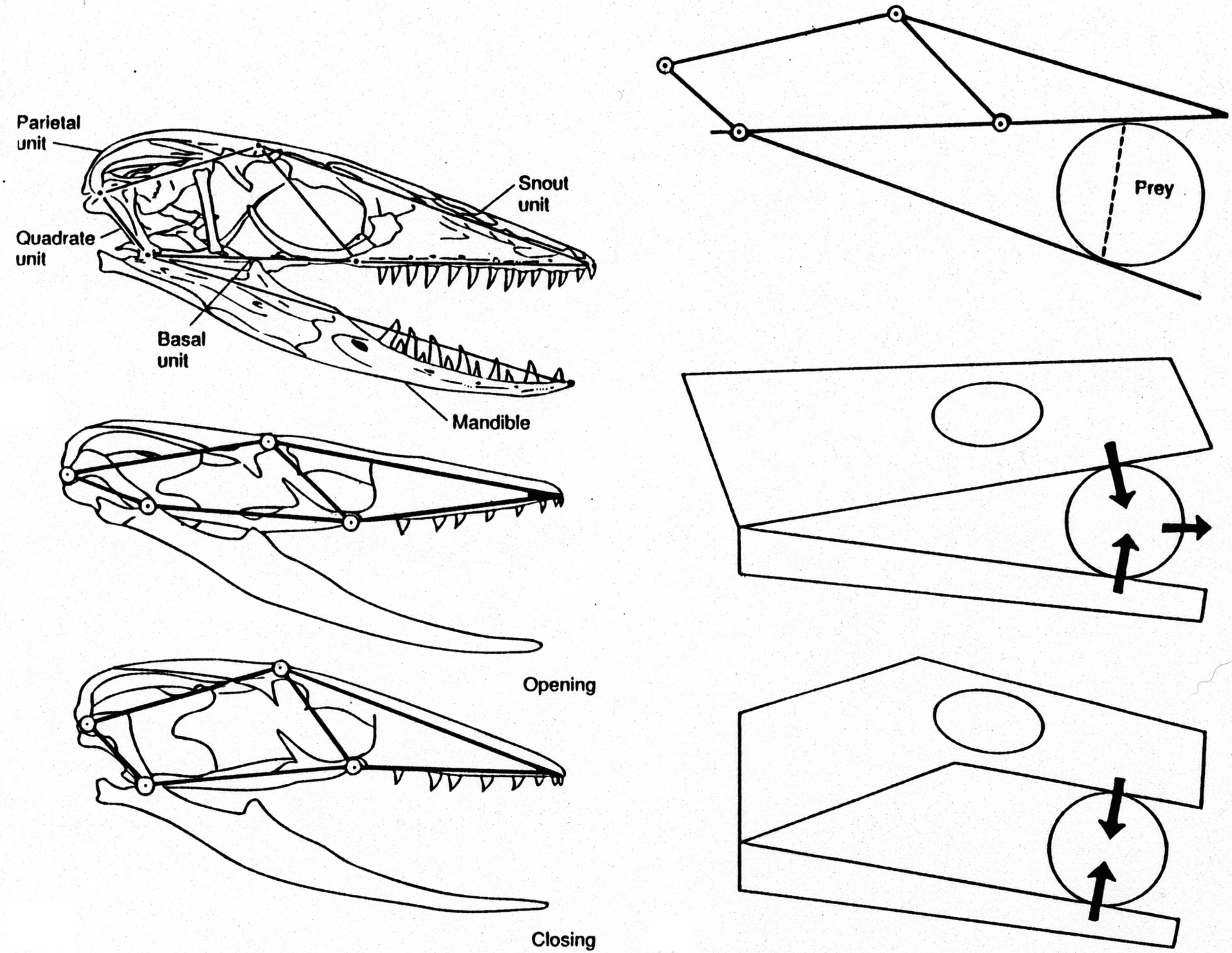
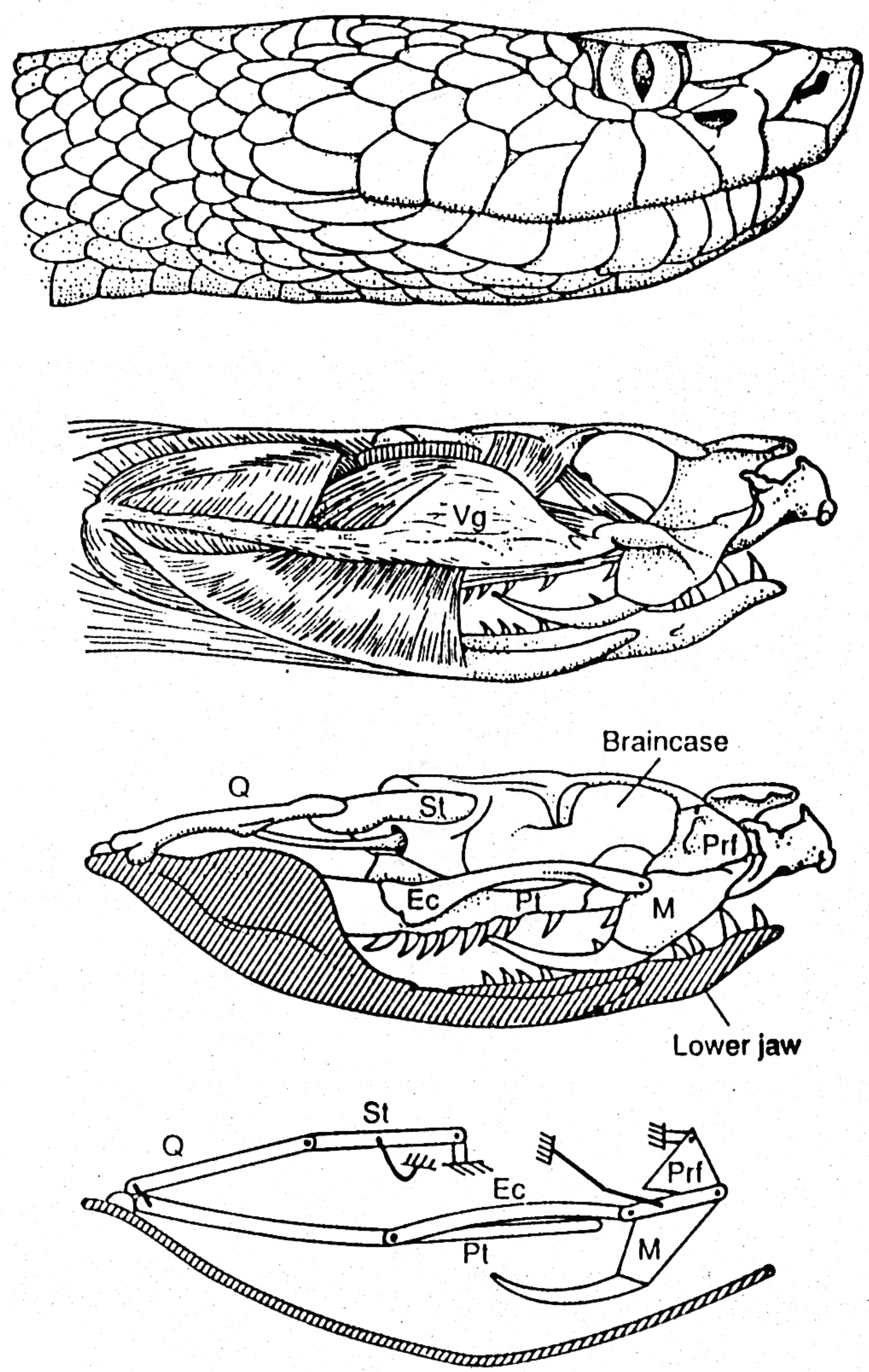
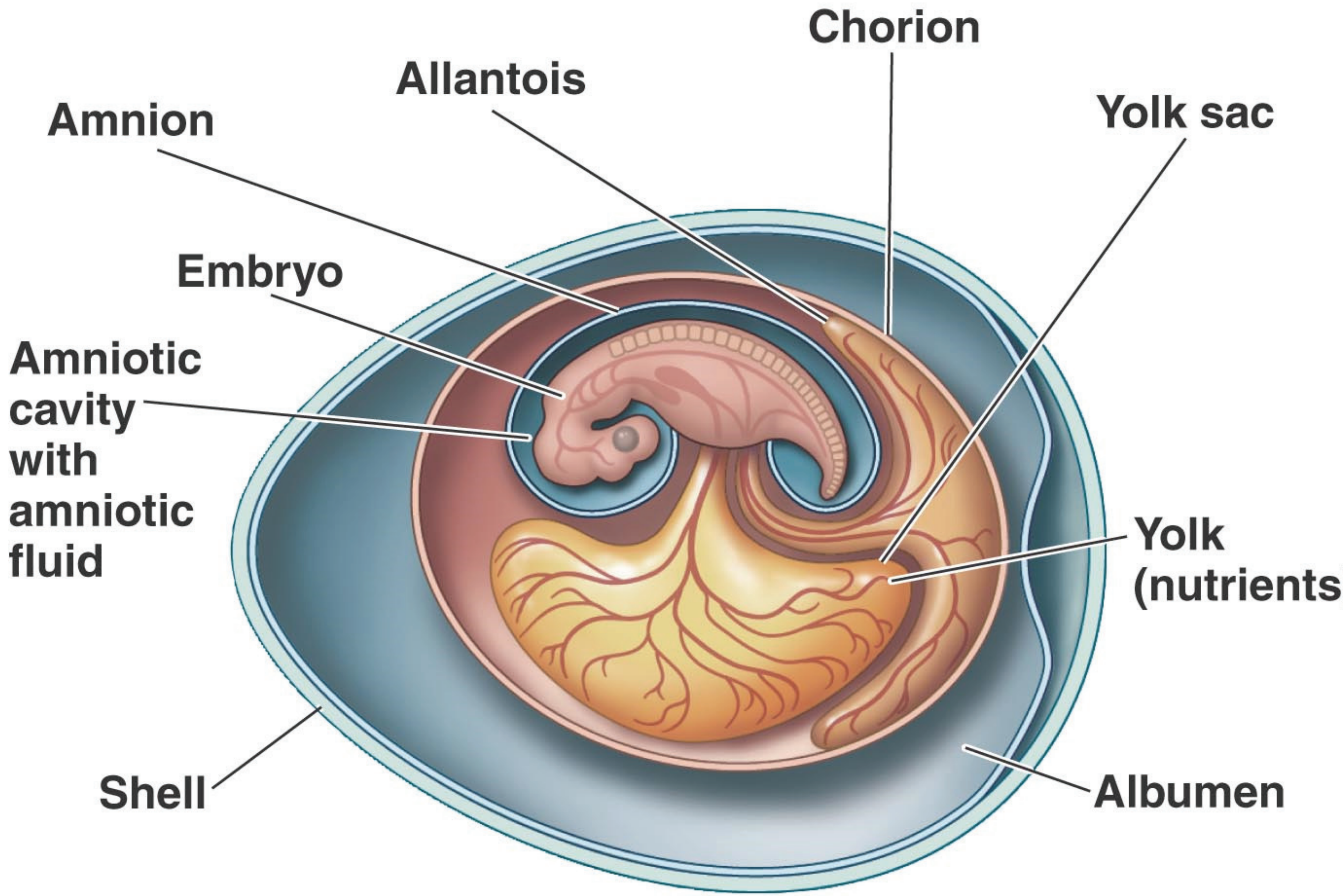


FIGURE 142. Cranial kinesis in reptiles. There are three types of cranial kinesis based largely on the position at which the hinge (X) lies across the top of the skull. The hinge may run across the back of the skull roof (metakinesis), behind the orbit (mesokinesis) or in front of the orbit where the snout or beak articulates (prokinesis.) The top series demonstrates all three kinetic types. Another cranial kinetic phenomenon is streptostyly (bottom). Streptostyly produces parallel movement of the skull in relation to the mandible as a result of the ability of the quadrate to rotate about its dorsal end. (*after Kent & Miller*)


Parietal unit
Snout unit
Quadrate unit
Basal unit
Mandible
Prey
Opening
Closing


Vg
Braincase
Q
St
Prf
Ec
Pt
M
Lower jaw
St
Q
Ec
Prf
Pt
M



Chorion
Allantois
Amnion
Yolk sac
Embryo
Amniotic cavity with amniotic fluid
Yolk (nutrients
Shell
Albumen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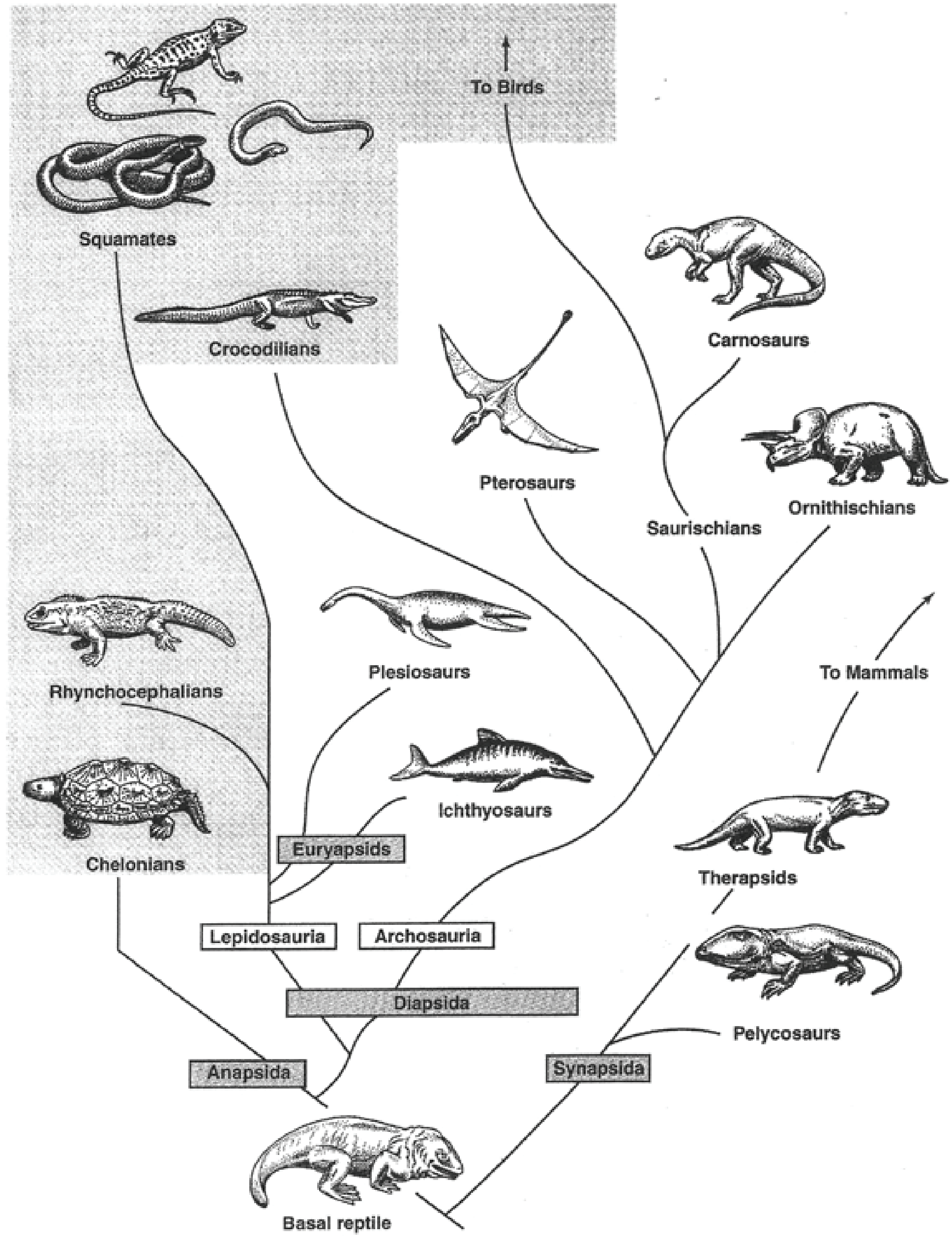
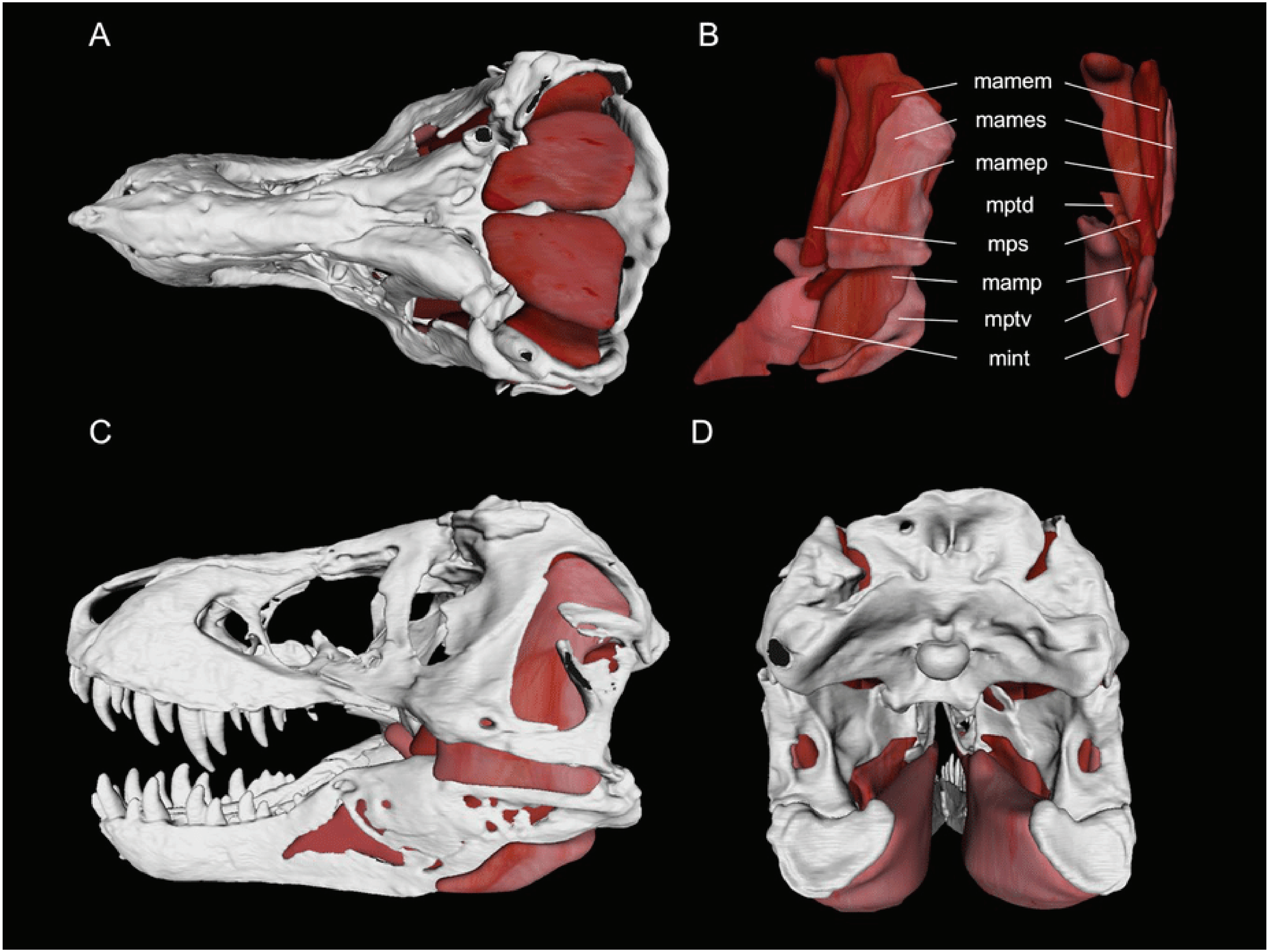
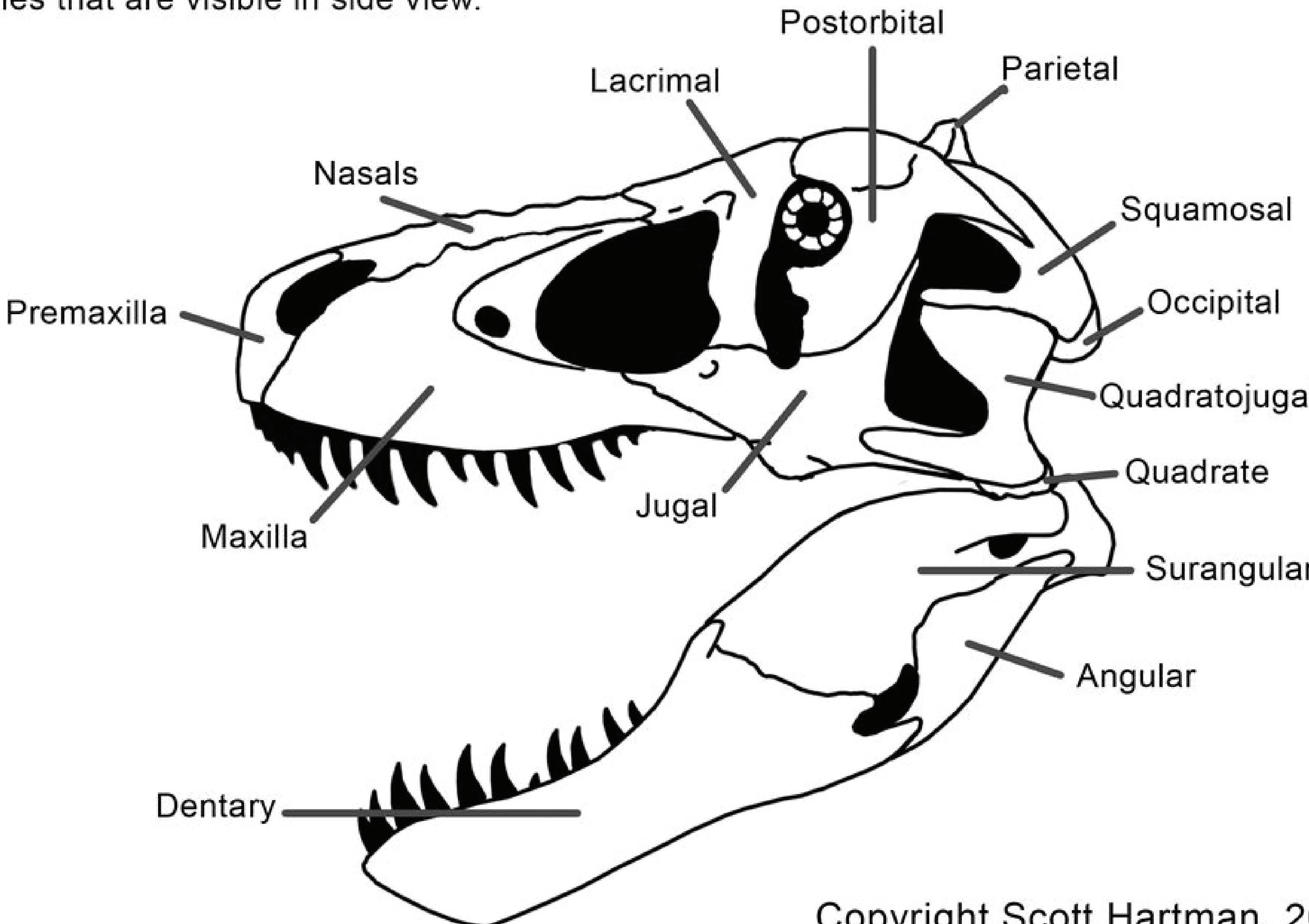


Figure 143. Postulated relationships of selected amniotes. Groupings marked by grey boxes reflect taxa based on the architecture of the temporal region of the skull. Extant reptiles are enclosed in the larger grey box, marking the Sauropsida and including the classes Reptilia and Aves, traditionally classified separately.

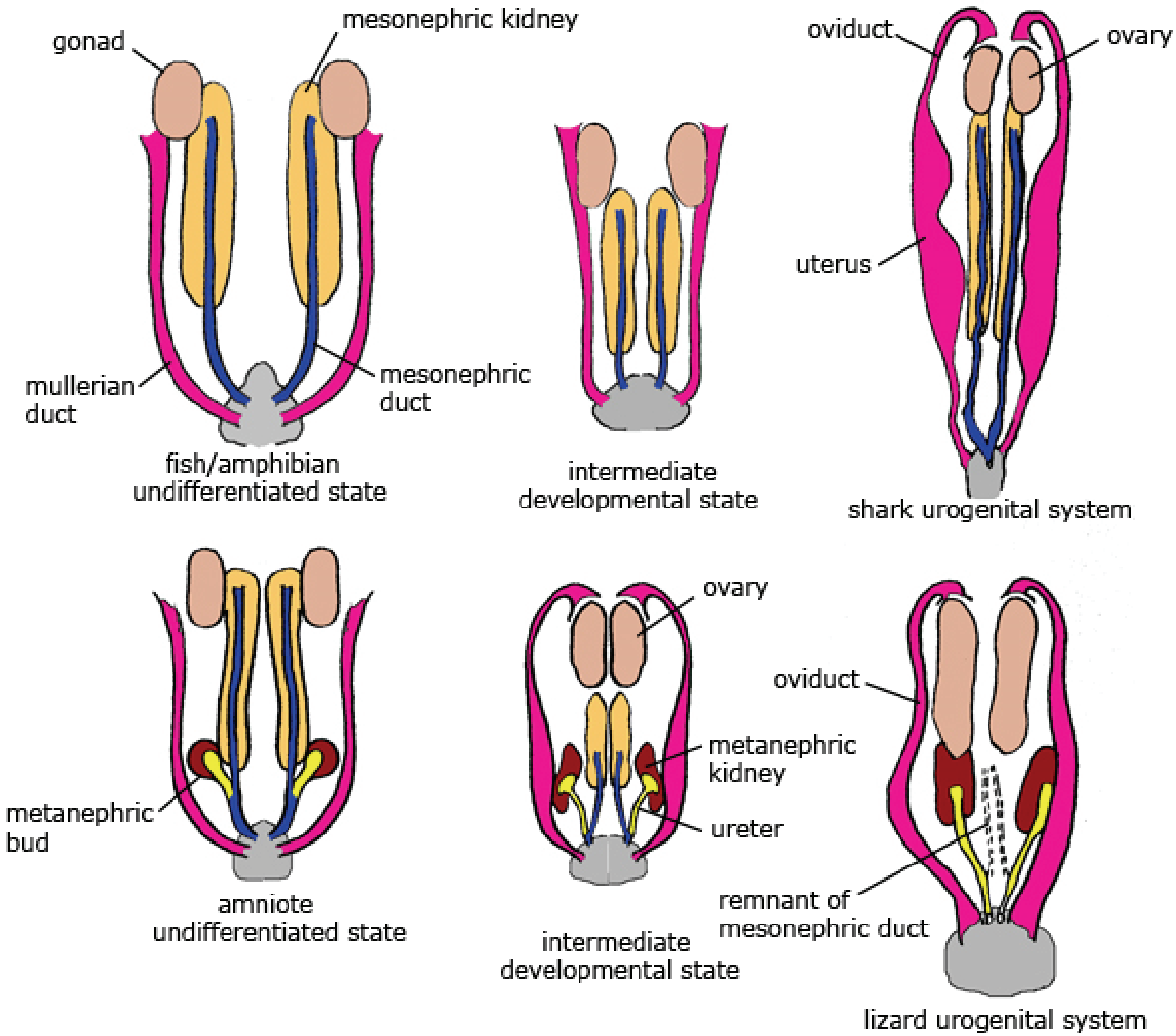

A
B
mamem
mames
mamep
mptd
mps
mamp
mptv
mint
C
D

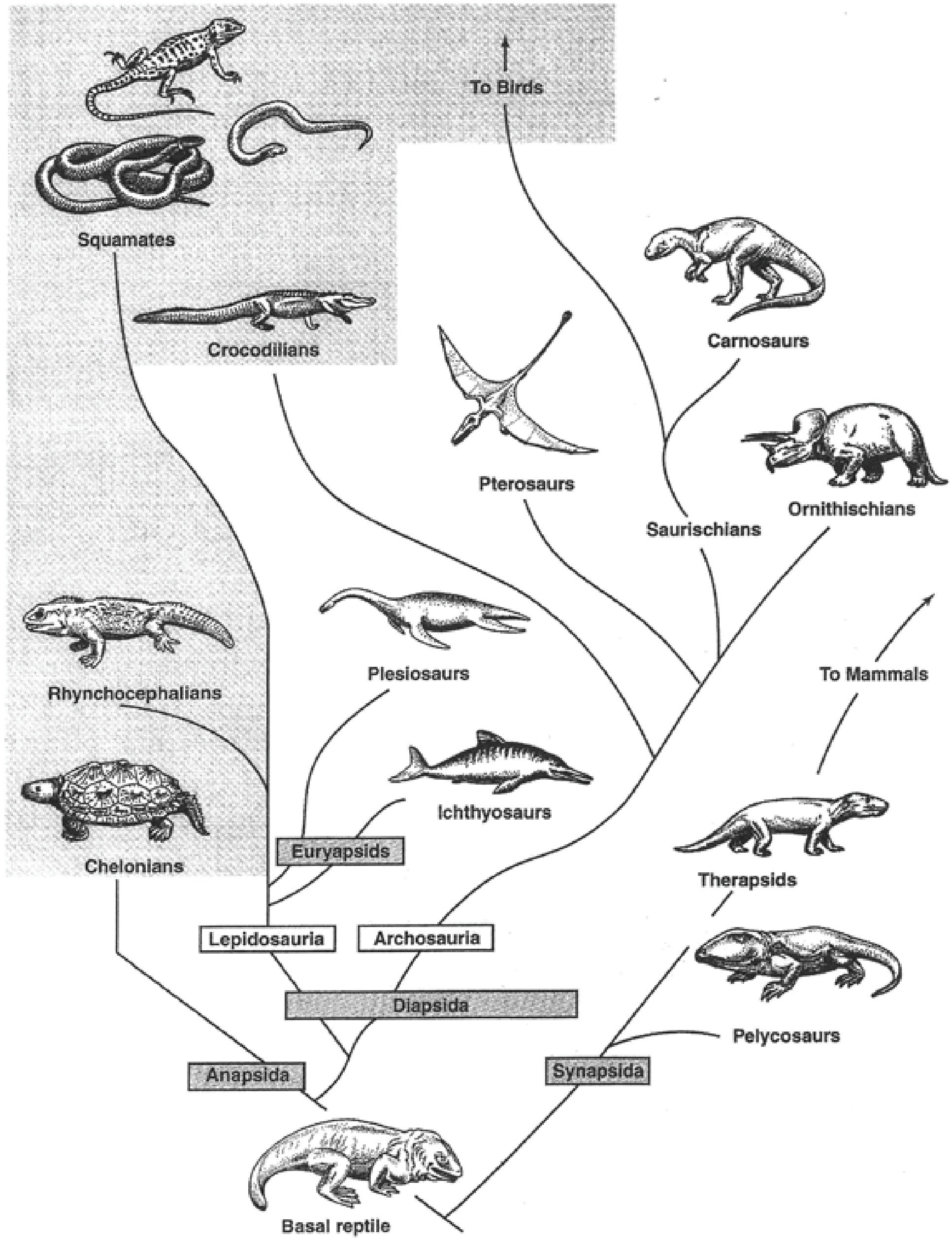
External Bones of the Skull

Like other vertebrates, dinosaur skulls are made up of many bones joined together. Here are the ones that are visible in side view.



Comparison of the development of urogenital organs in fish and amniote vertebrates





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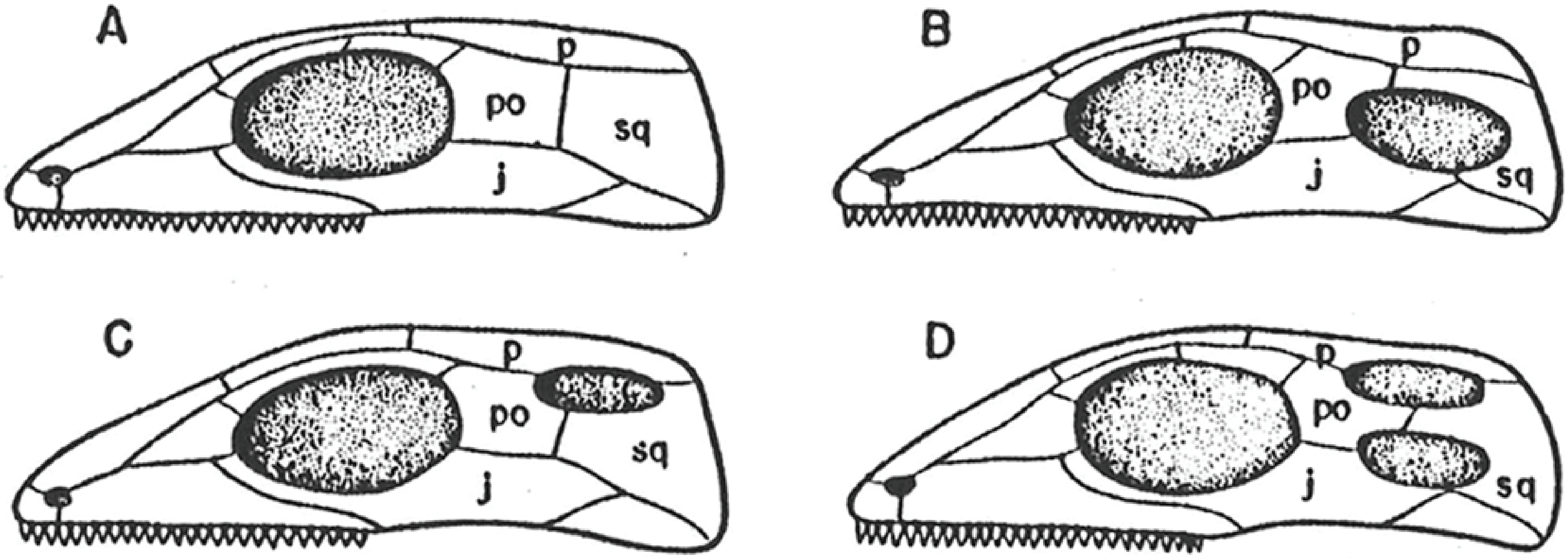


FIGURE 144. Diagrams to show types of temporal fenestra in reptiles. A. Anapsid type skull seen in stem reptiles (Cotylosauria) and turtles. **B.** Synapsid type skull seen in mammal-like reptiles (therapsida) and mammals. **C.** Euryapsid type skull seen in extinct plesiosaurs and ichthyosaurs. **D.** Diapsid type skull seen in rhynchocephalians, archosaurians and lepidosauroians. Lizards and snakes derived by loss of one or both temporal arches. *J, jugal; p, parietal; po, postorbital; sq, squamosal. (After Romer)*

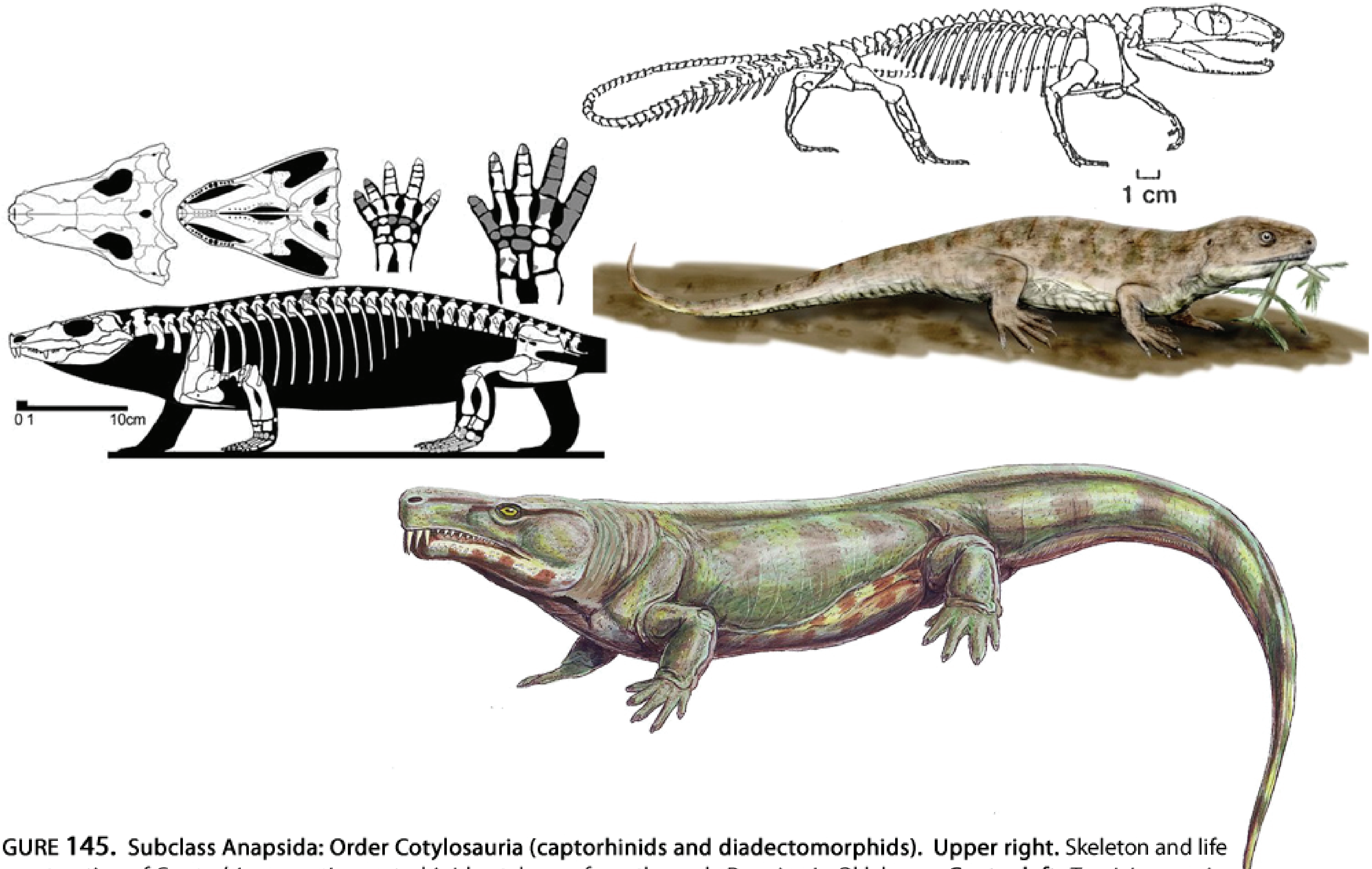


FIGURE 145. Subclass Anapsida: Order Cotylosauria (captorhinids and diadectomorphids). Upper right. Skeleton and life reconstruction of *Captorhinus aguti*, a captorhinid cotylosaur from the early Permian in Oklahoma. **Center left.** *Tseajaia campi,* a diadectomorhid cotylosaur from the early Permian in Montana. **Lower right.** *Limnoscelis paludis*, a diadectomorhid cotylosaurfrom the early Pemian in Texas and New Mexico. Length about 1.5 meters. Life reconstruction by Dmitry Bogdanov.

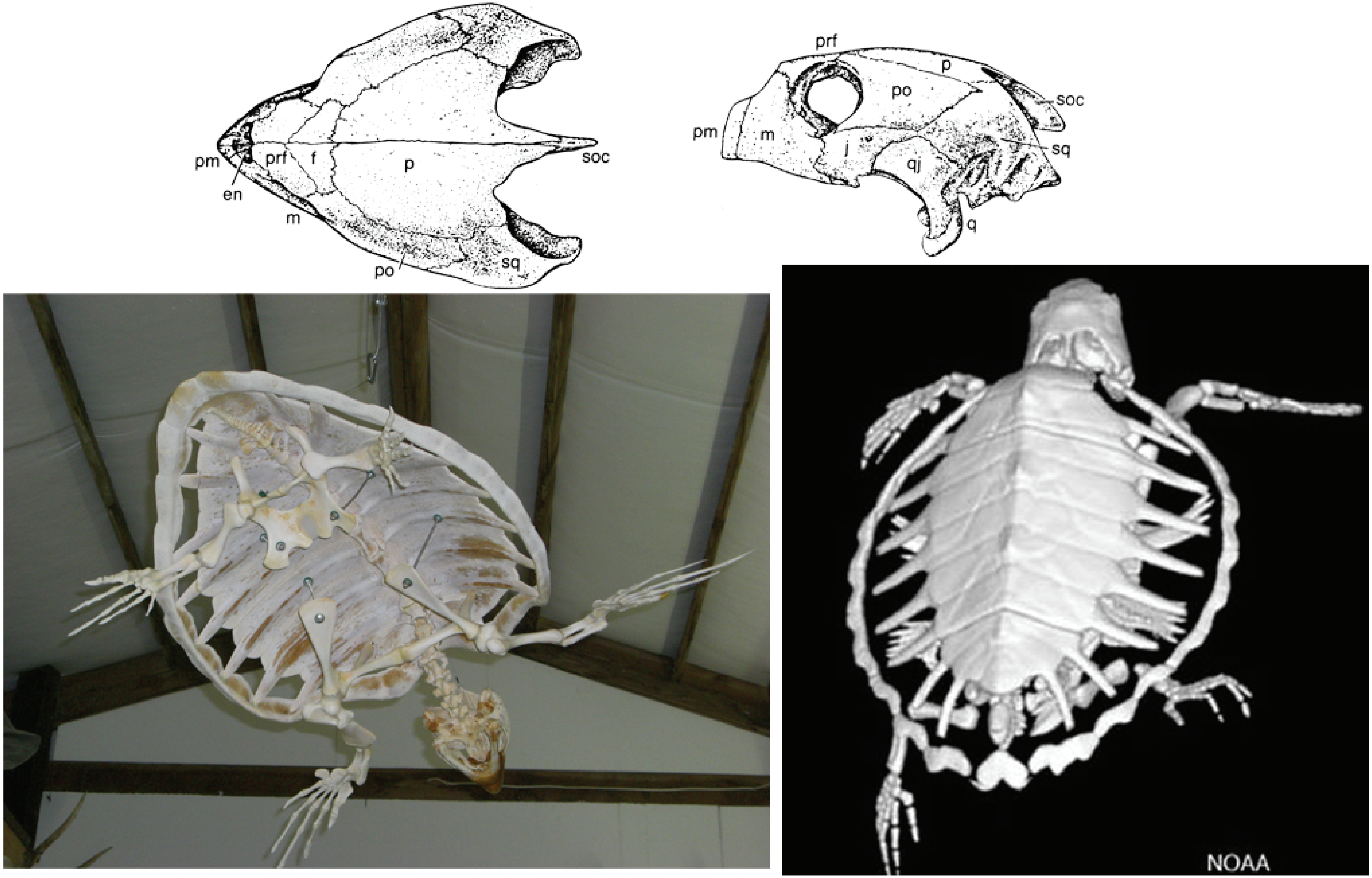
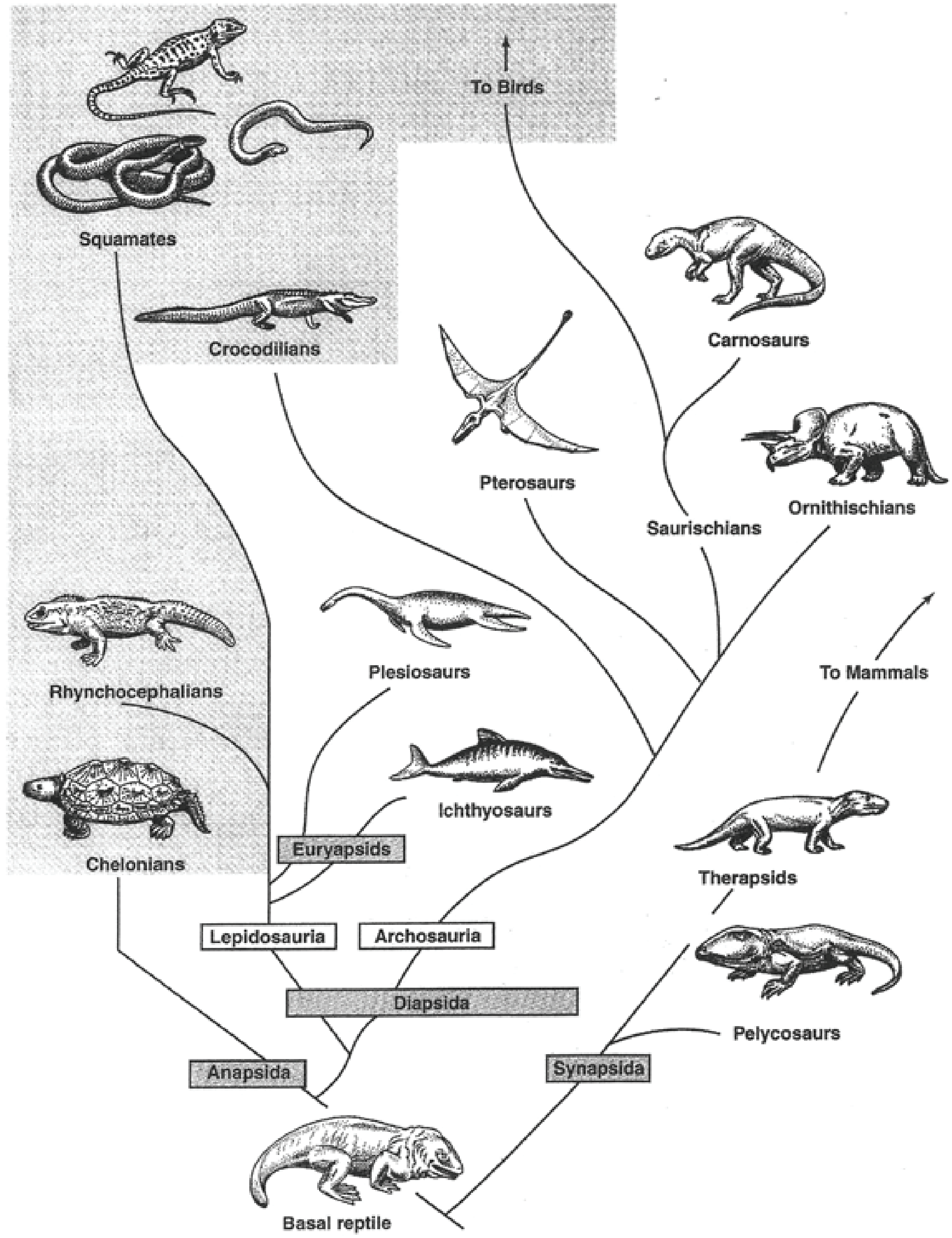


FIGURE 147. Modern anapsid skull and skeletal structure in the sea turtle, *Caretta*. Top. Dorsal and lateral views of the anapsid skull of the sea turtle, *Caretta*. Note the strong emarginations or notches posteriad that house the mandibular adductor muscles. **Bottom.** Ventral and dorsal views of the full articulated skeleton of *Caretta*. Note ribs and vertebrae expanded to form expanded scutes of shell. Note pelvic and pectoral girdles are placed inside the ribcage of scutes. F, frontal; J, jugal; M, maxilla; P, parietal; Po, postorbital; Prf, prefrontal; Pm, premaxilla; Qj, quadratojugal; Soc, supraoccipital; Sq, squamosal.



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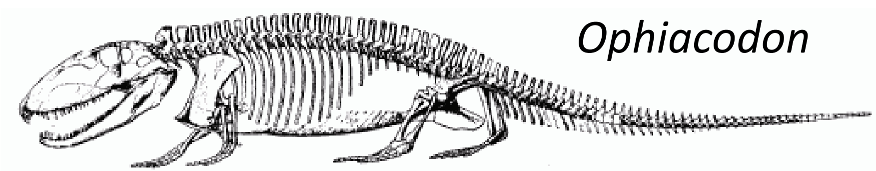
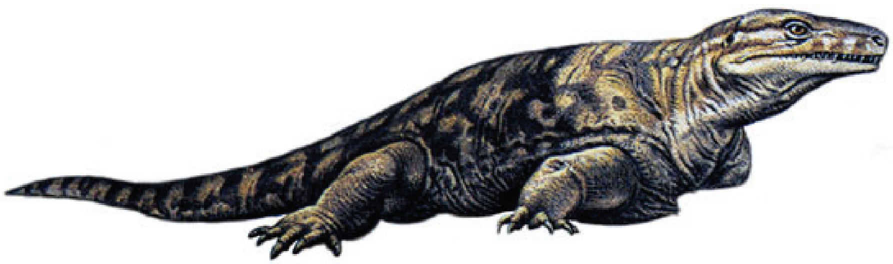
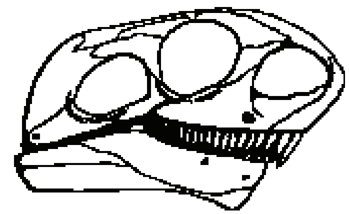
PELYCOSAURIA   Ophiacodontidae

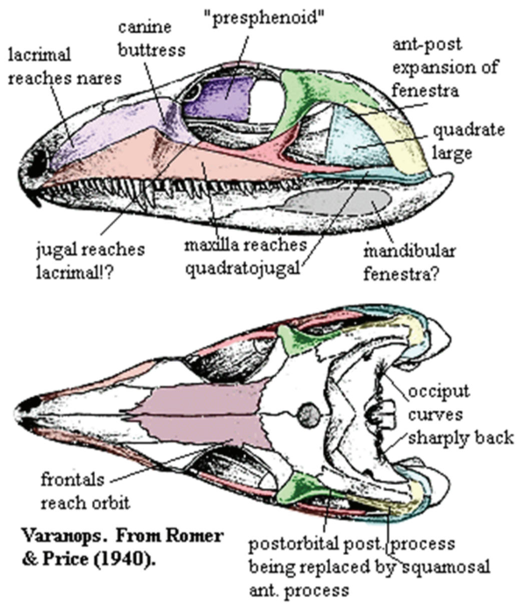


Ophiacodon

PELYCOSAURIA - Varanopseidae



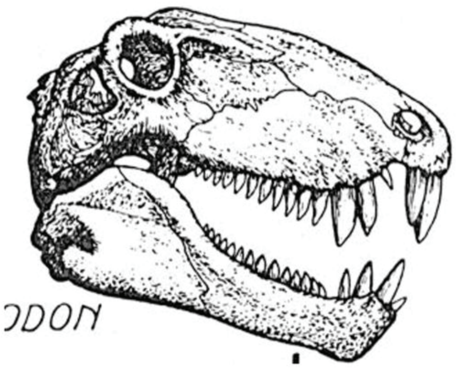


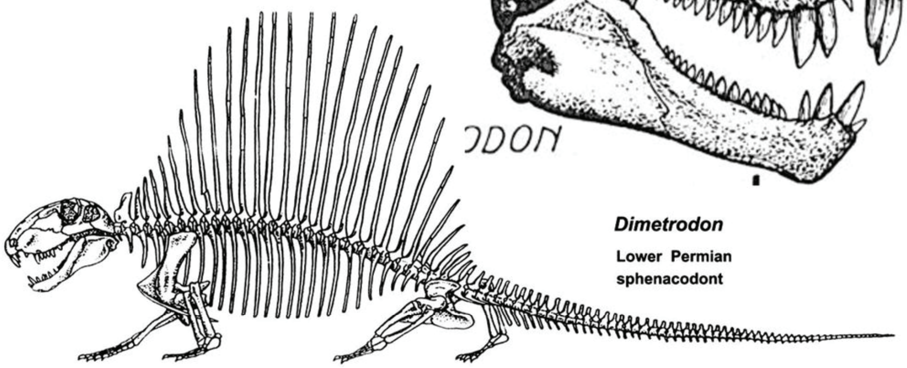


Varanops. From Romer & Price (1940).

Pelycosauria - Sphenacodontidae

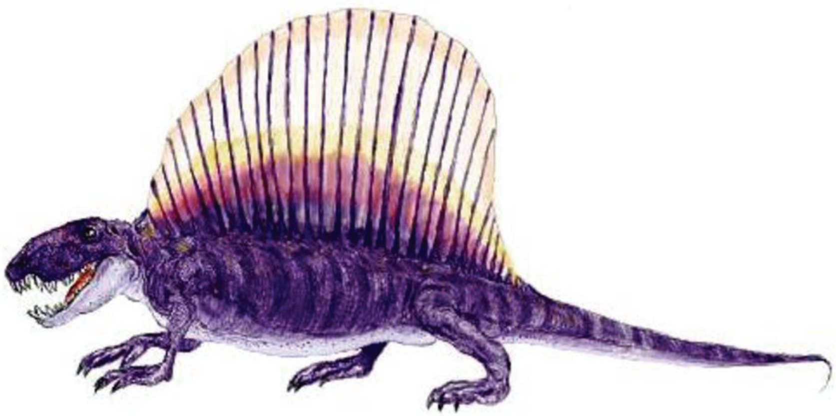
Dimetrodon



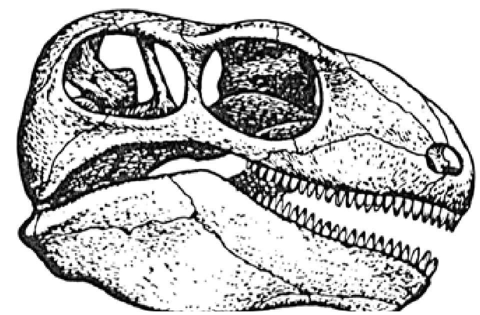


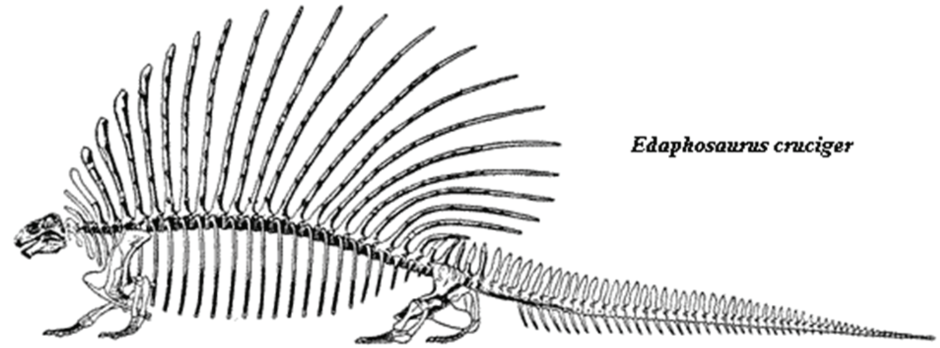
Dimetrodon

Lower Permian sphenacodont



Pelycosauria - Edaphodauridae

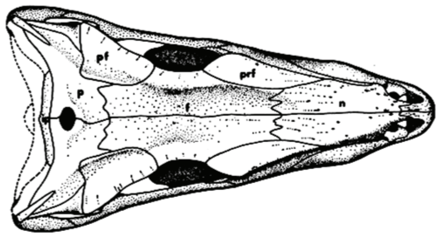


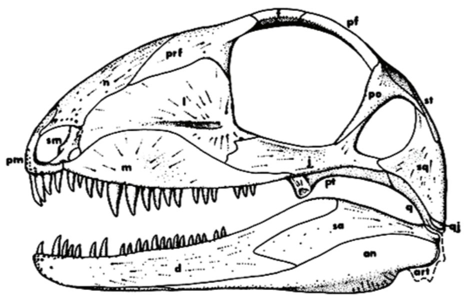


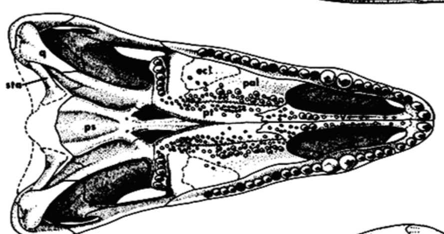
Edaphosaurus cruciger

Pelycosauria - Sphenacodontidae

Haptodus -- probable therapsid ancestor







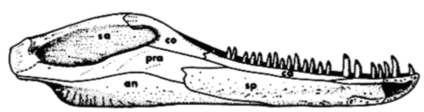
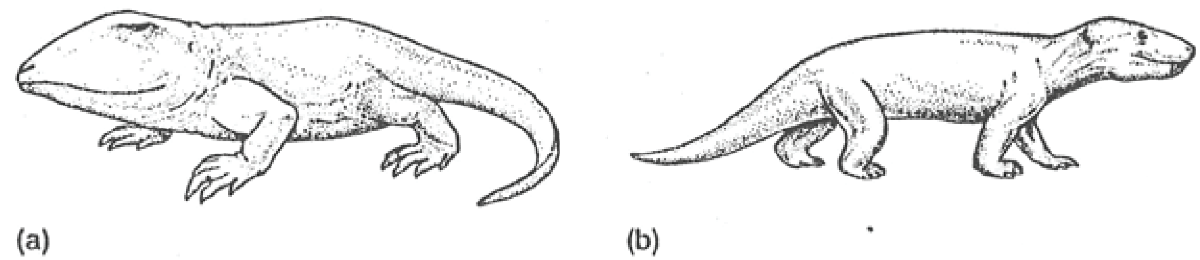


FIGURE 4.26

(*a*) Pelycosaur, a Carboniferous synapsid.
(*b*) A Triassic therapsid about the size of a large dog. Nothing is known of the skin.



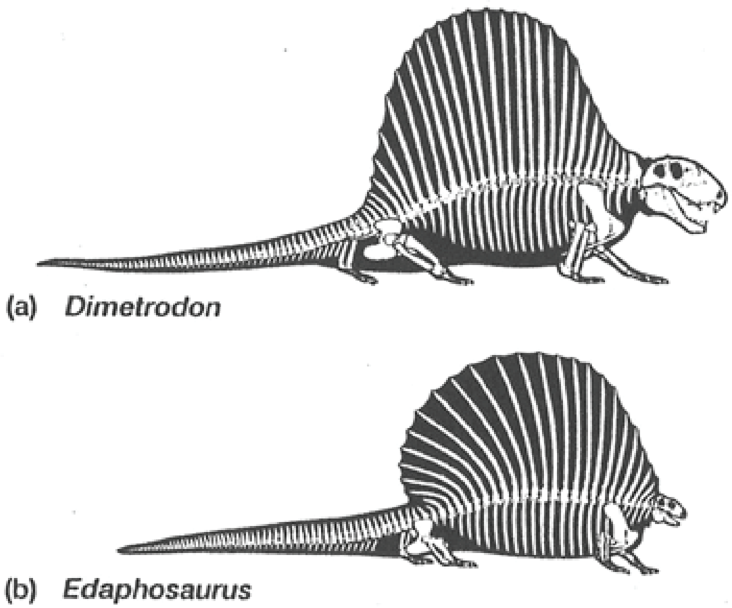


Figure 3.32 Pelycosaurs. (a) *Dimetrodon*, a predator, reached 3 m in length (Lower Permian of Texas). (b) *Edaphosaurus*, a herbivore (late Carboniferous and early Permian) was about 3 m long.

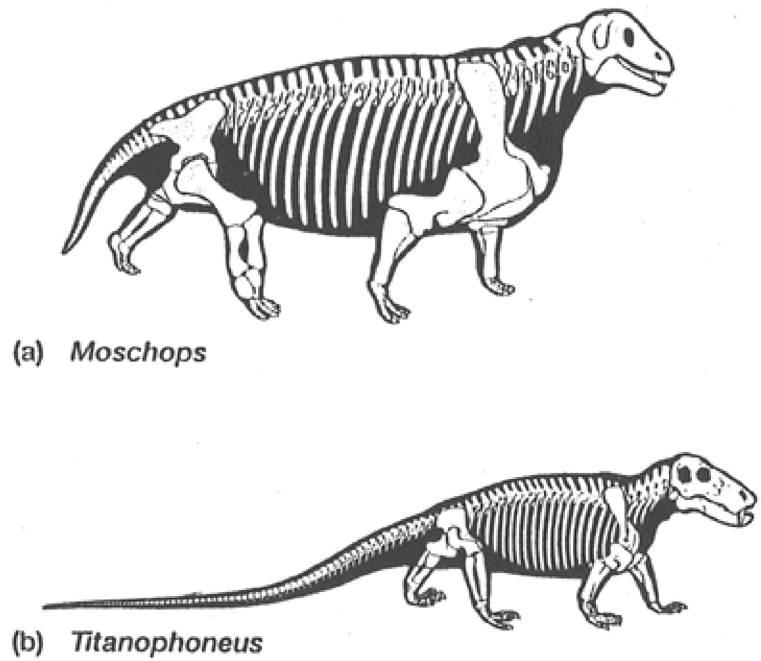
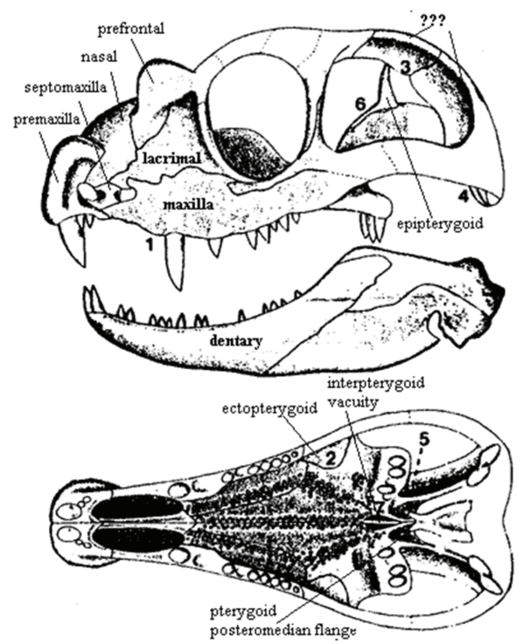


Figure 3.33 Therapsids. (a) *Moschops*, about 5 m in length. (b) *Titanophoneus*, about 2 m.

THERAPSIDA

Tetraceratops -- earliest Therapsid



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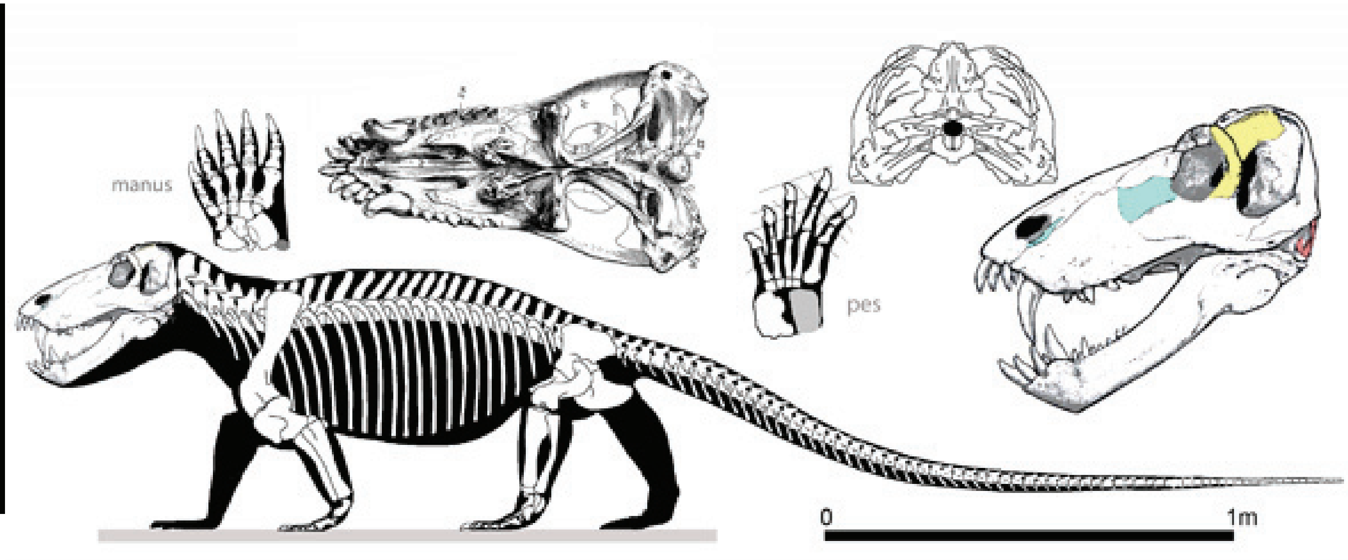
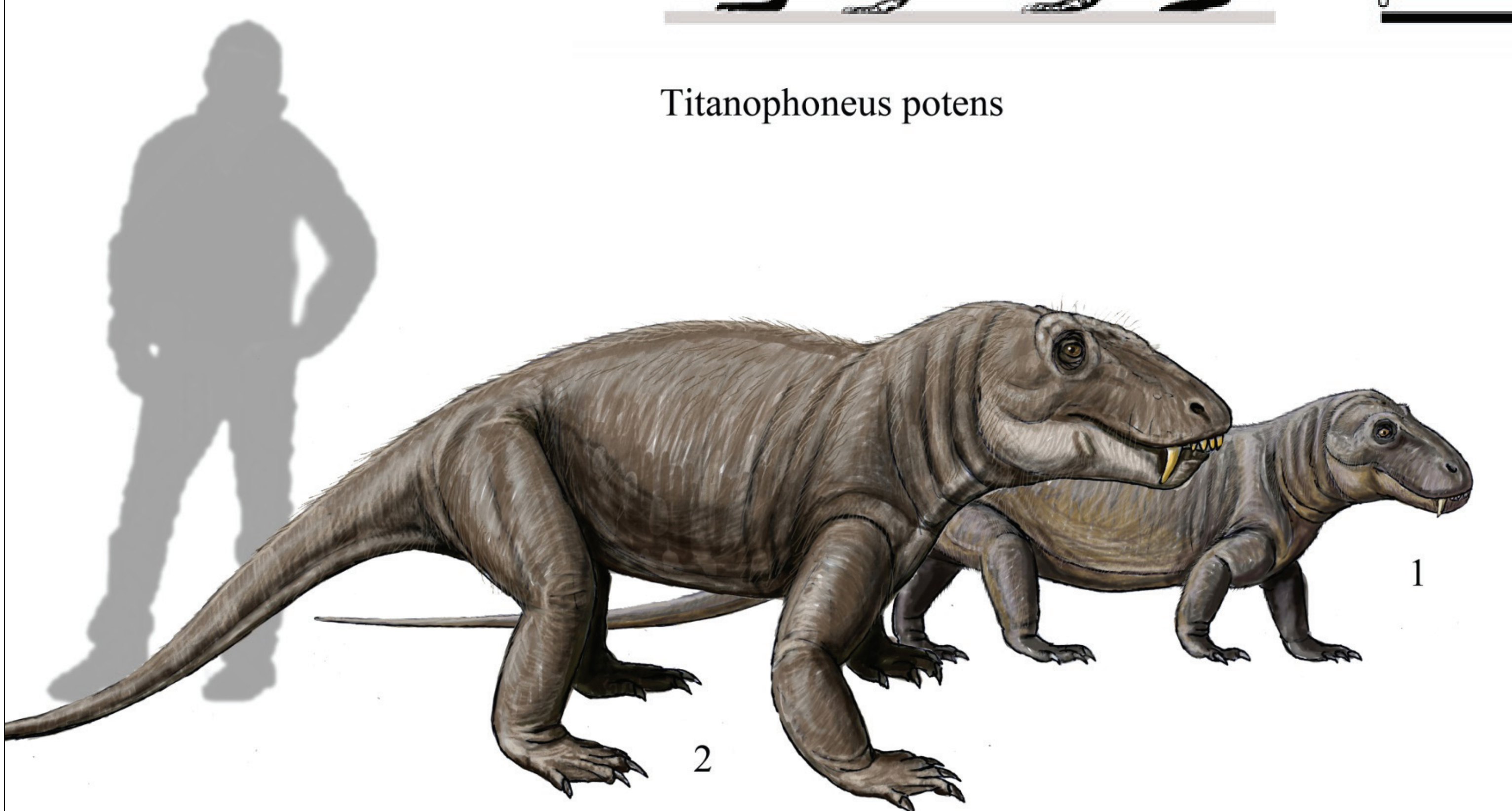


Titanophoneus potens



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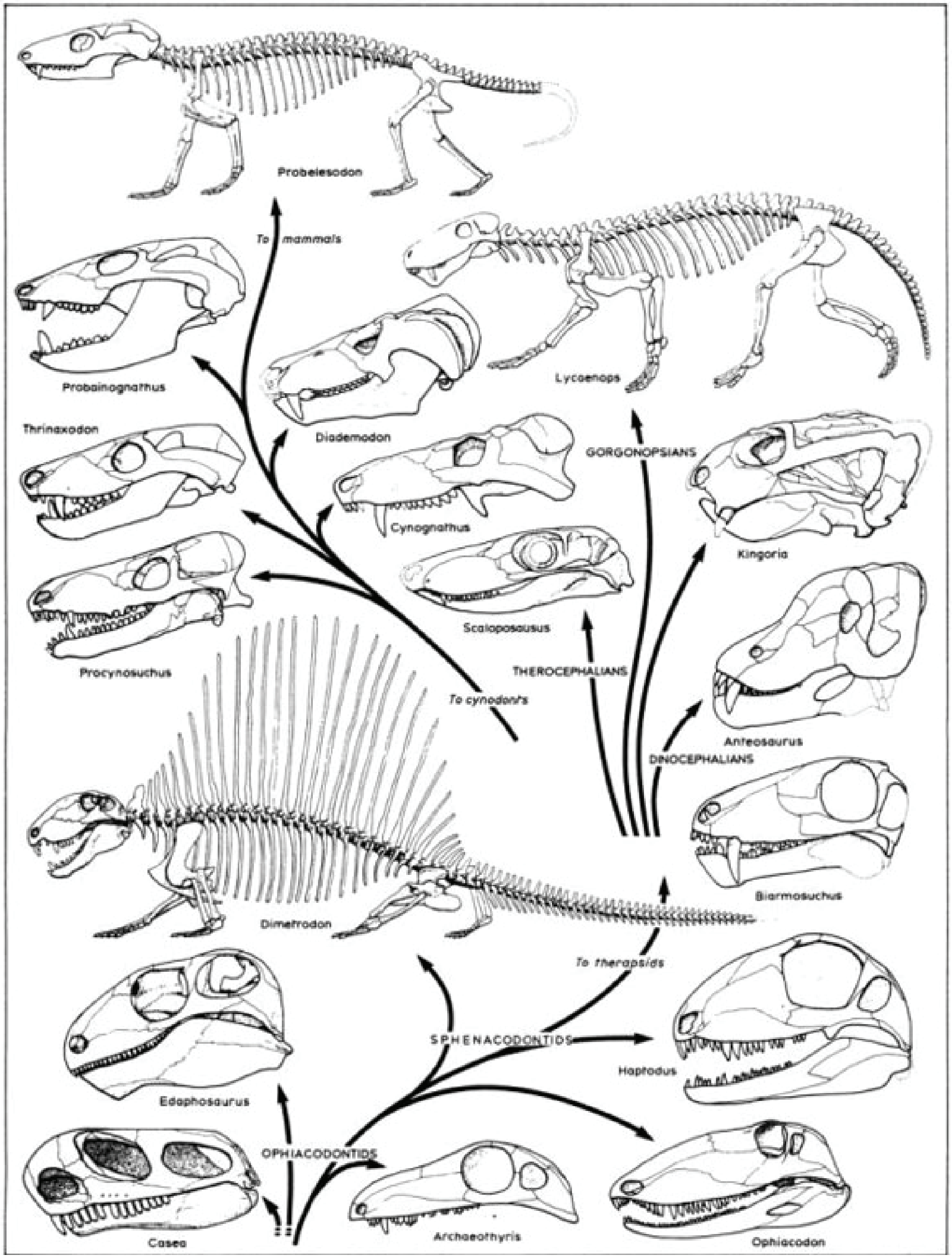
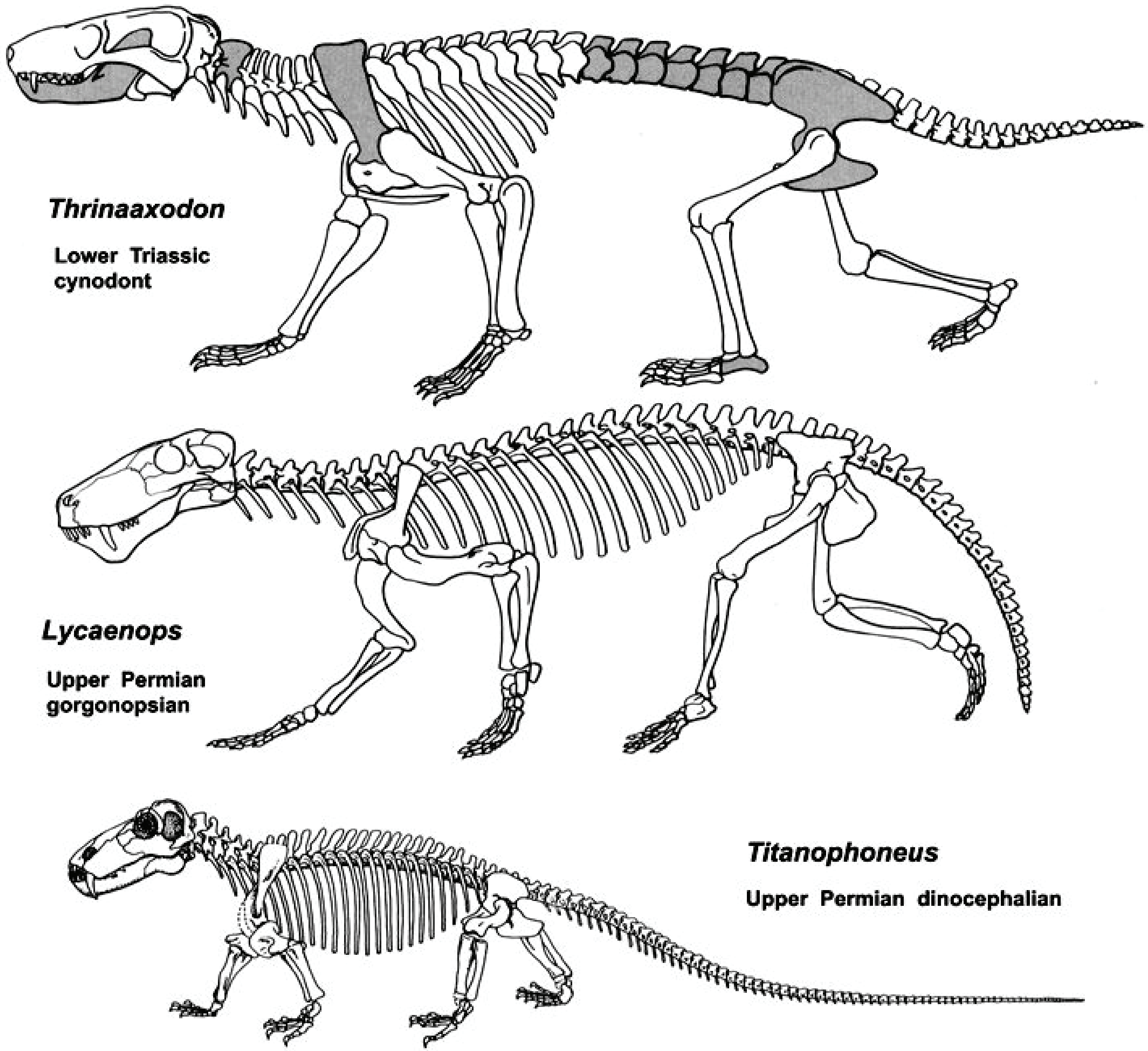


Probelesodon
To mammals
Lycaenops
Probainognathus
Diademodon
Thrinaxodon
GORGONOPSIANS
Cynognathus
Kingoria
Procynosuchus
Scaloposaurus
THEROCEPHALIANS
To cynodonts
Anteosaurus
DINOCEPHALIANS
Dimetrodon
Biarmosuchus
To therapsids
SPHENACODONTIDS
Haptodus
Edaphosaurus
OPHIACODONTIDS
Casea
Archaeothyris
Ophiacodon


Thrinaaxodon
Lower Triassic
cynodont
Lycaenops
Upper Permian
gorgonopsian
Titanophoneus
Upper Permian dinocephalian

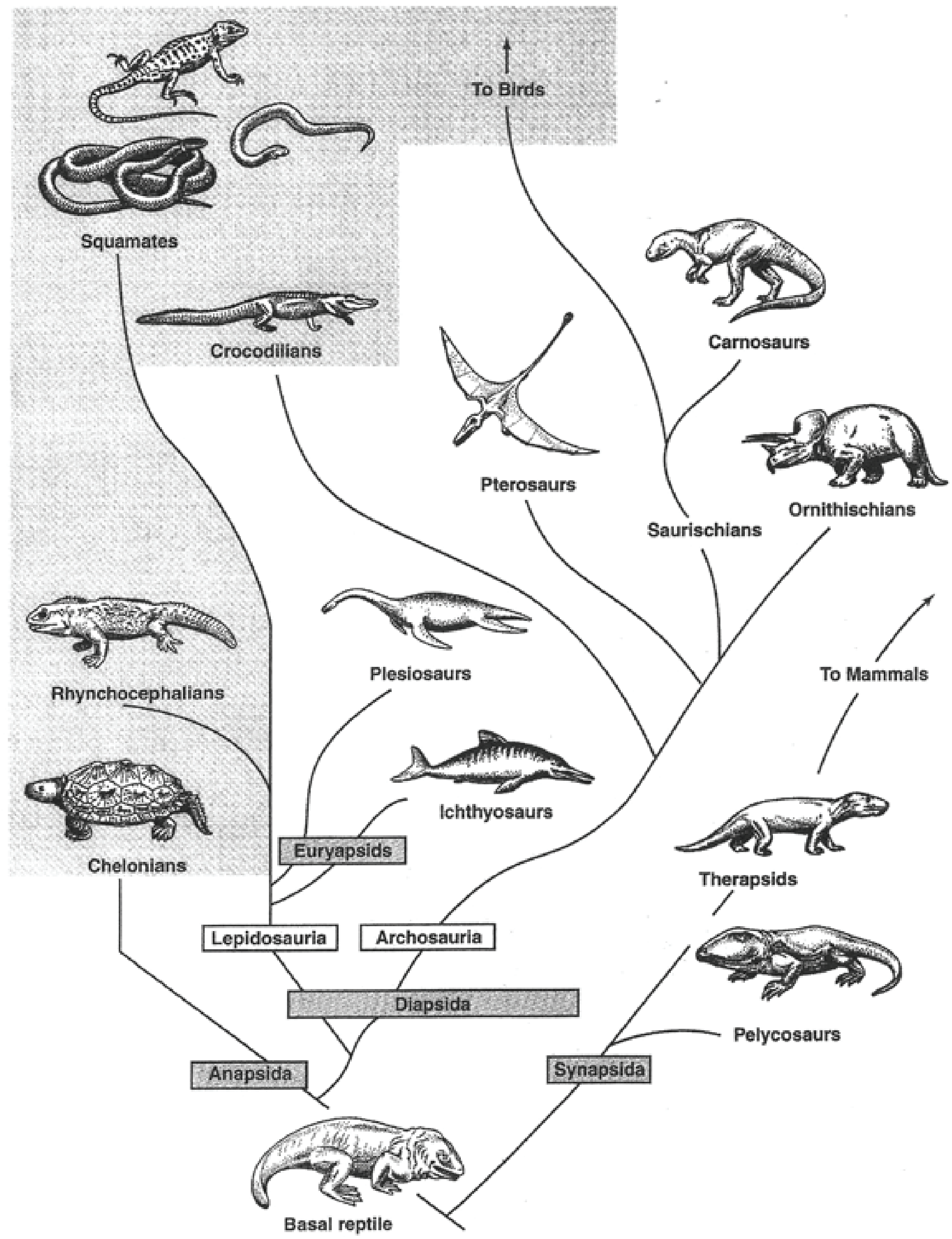
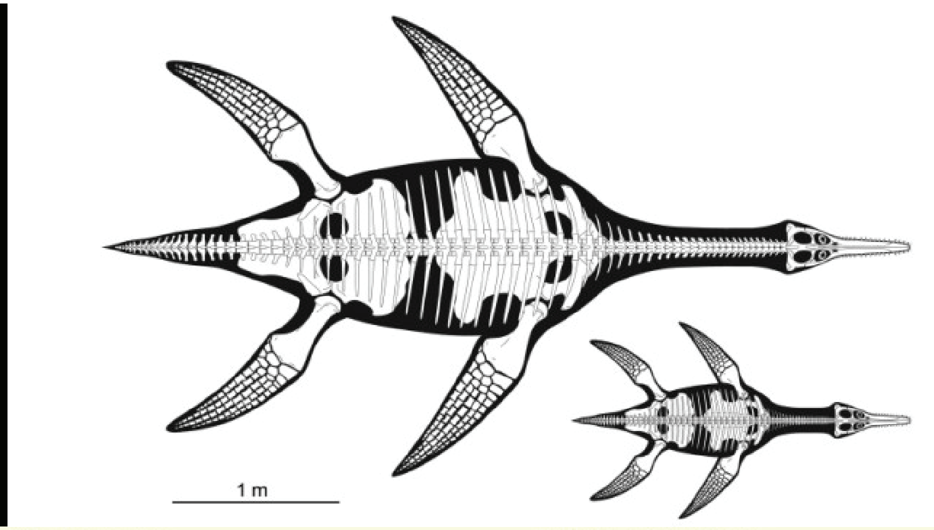
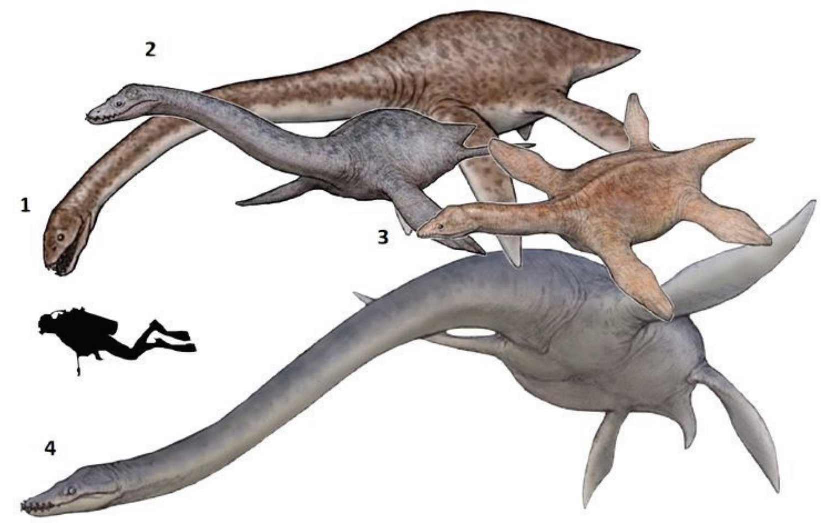
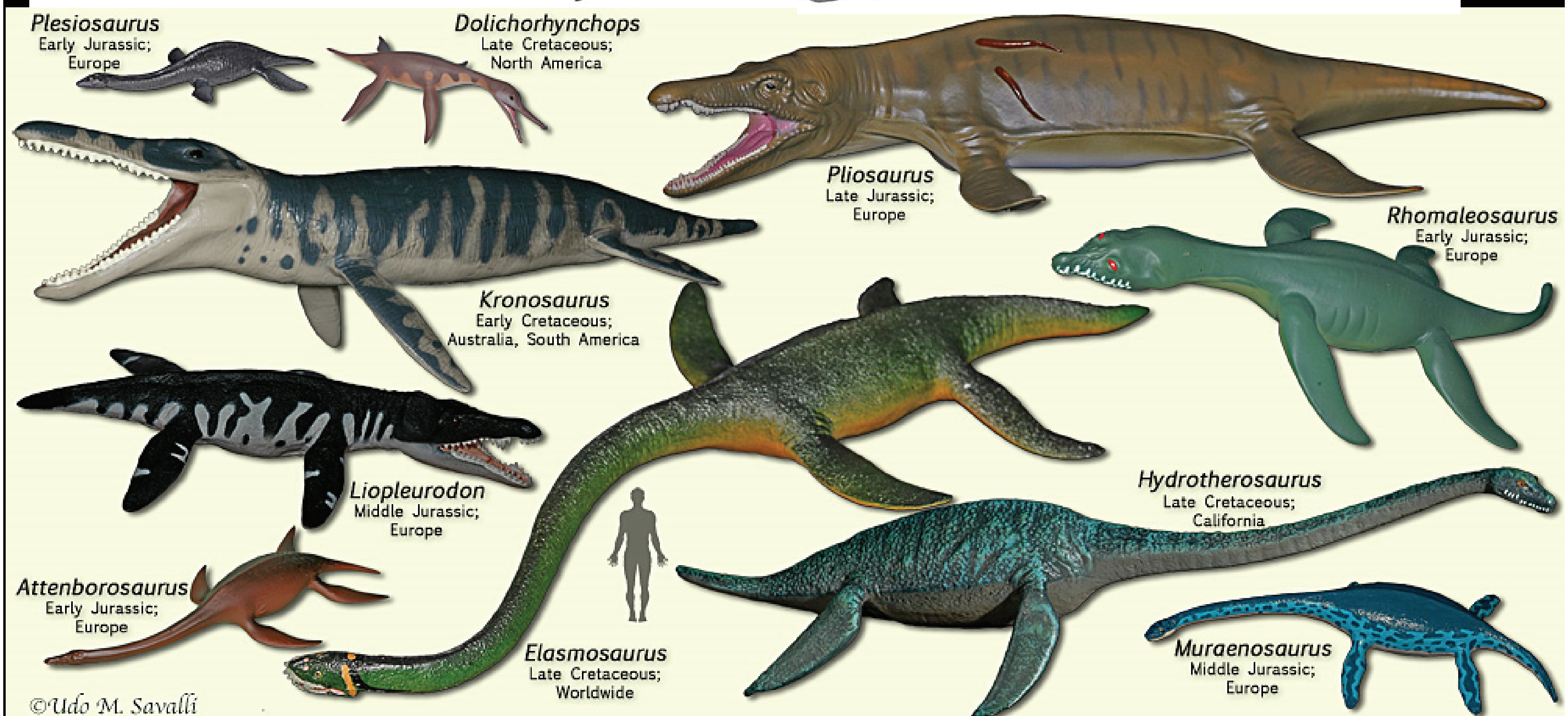
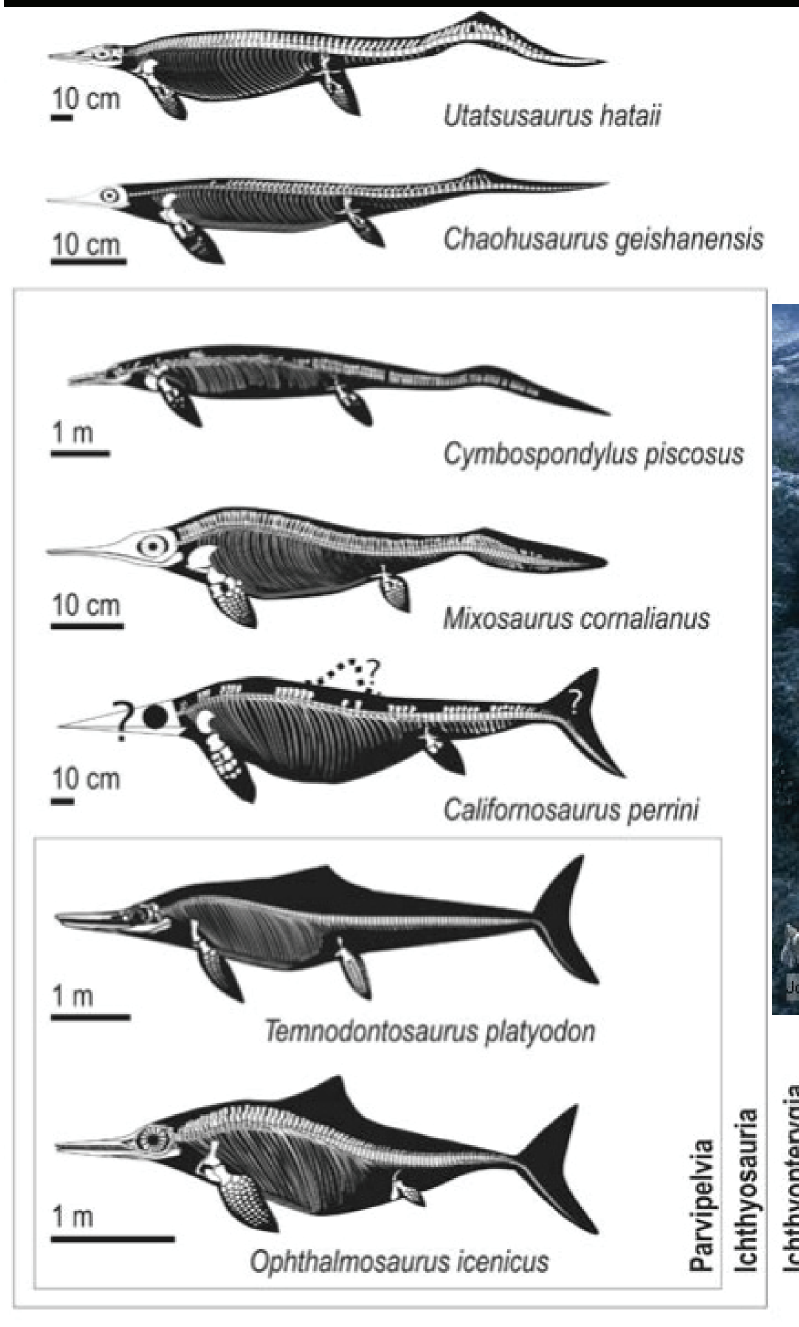


Figure 143. Postulated relationships of selected amniotes. Groupings marked by grey boxes reflect taxa based on the architecture of the temporal region of the skull. Extant reptiles are enclosed in the larger grey box, marking the Sauropsida and including the classes Reptilia and Aves, traditionally classified separately.

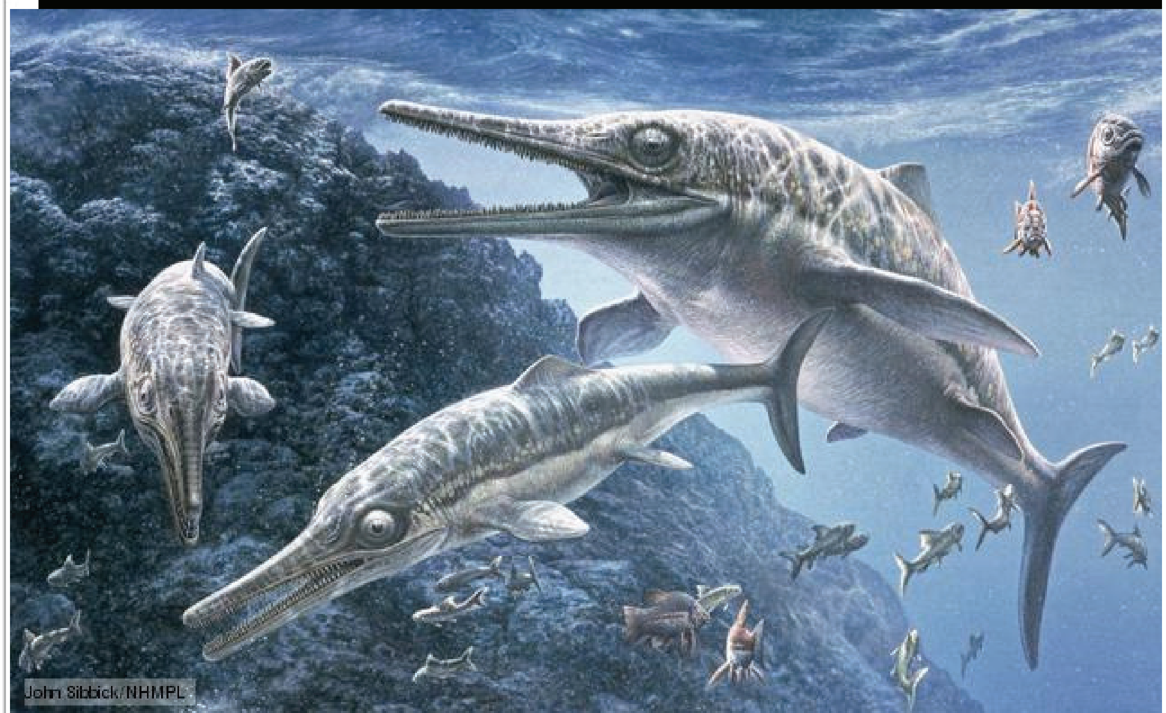

1 m


1
2
3
4


Plesiosaurus
Early Jurassic;
Europe
Dolichorhynchops
Late Cretaceous;
North America
Pliosaurus
Late Jurassic;
Europe
Rhomaleosaurus
Early Jurassic;
Europe
Kronosaurus
Early Cretaceous;
Australia, South America
Liopleurodon
Middle Jurassic;
Europe
Hydrotherosaurus
Late Cretaceous;
California
Attenborosaurus
Early Jurassic;
Europe
Elasmosaurus
Late Cretaceous;
Worldwide
Muraenosaurus
Middle Jurassic;
Europe
©Udo M. Savalli



10 cm
Utatsusaurus hataii
10 cm
Chaohusaurus geishanensis
1 m
Cymbospondylus piscosus
10 cm
Mixosaurus cornalianus
10 cm
Californosaurus perrini
1 m
Temnodontosaurus platyodon
1 m
Ophthalmosaurus icenicus
Parvipelvia
Ichthyosauria
Ichthyopterygia



John Sibbick/NHMPL

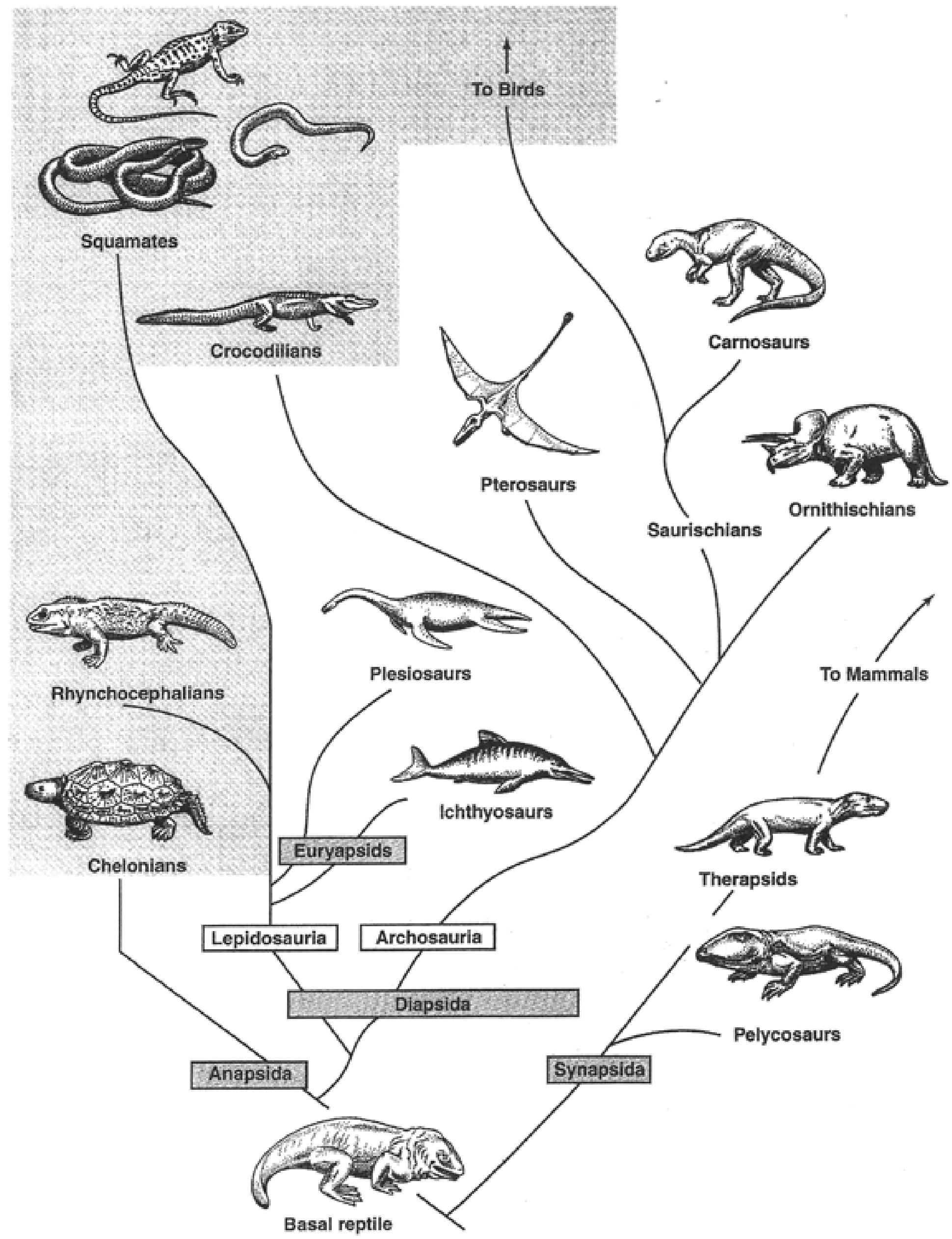
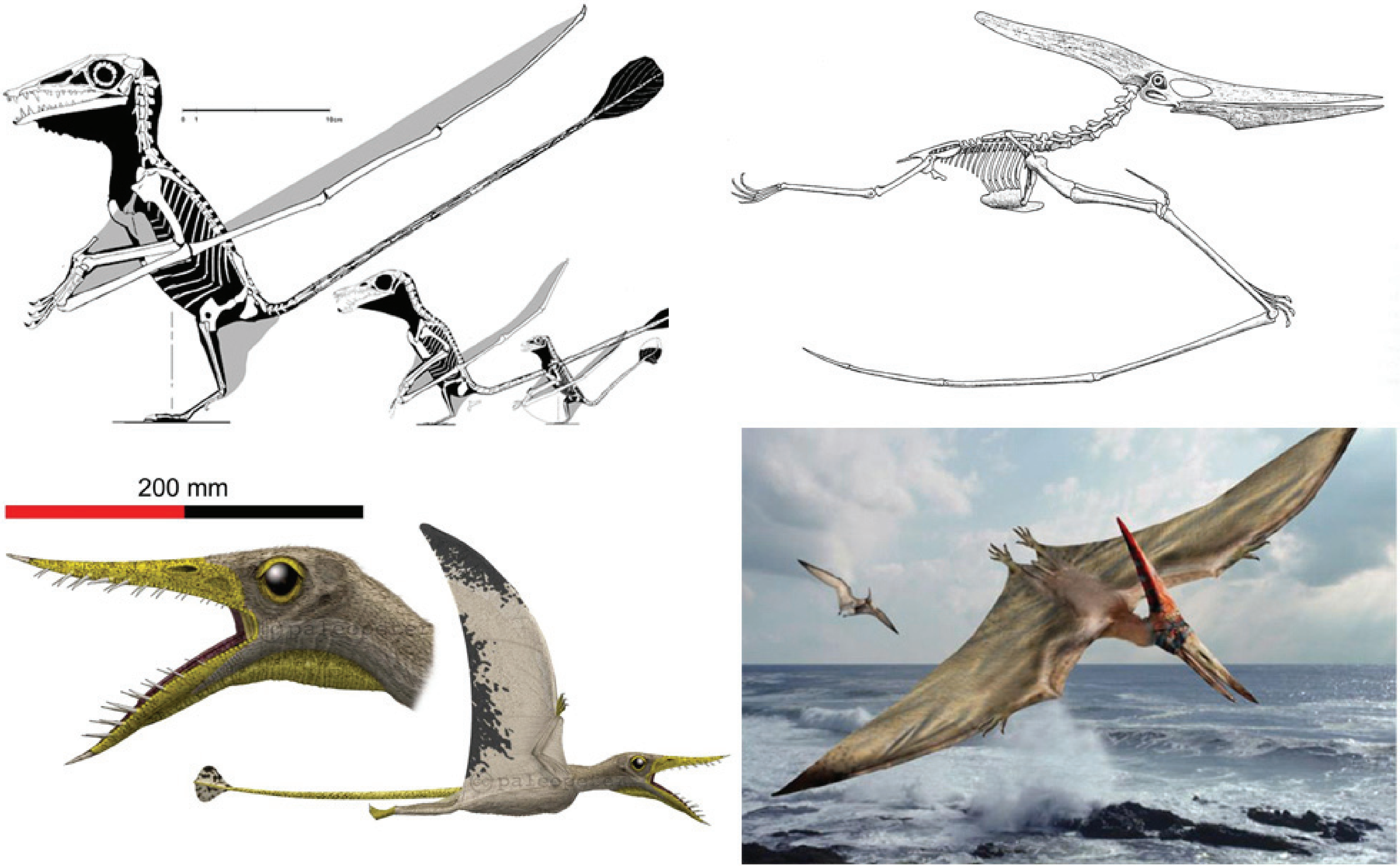


Figure 143. Postulated relationships of selected amniotes. Groupings marked by grey boxes reflect taxa based on the architecture of the temporal region of the skull. Extant reptiles are enclosed in the larger grey box, marking the Sauropsida and including the classes Reptilia and Aves, traditionally classified separately.

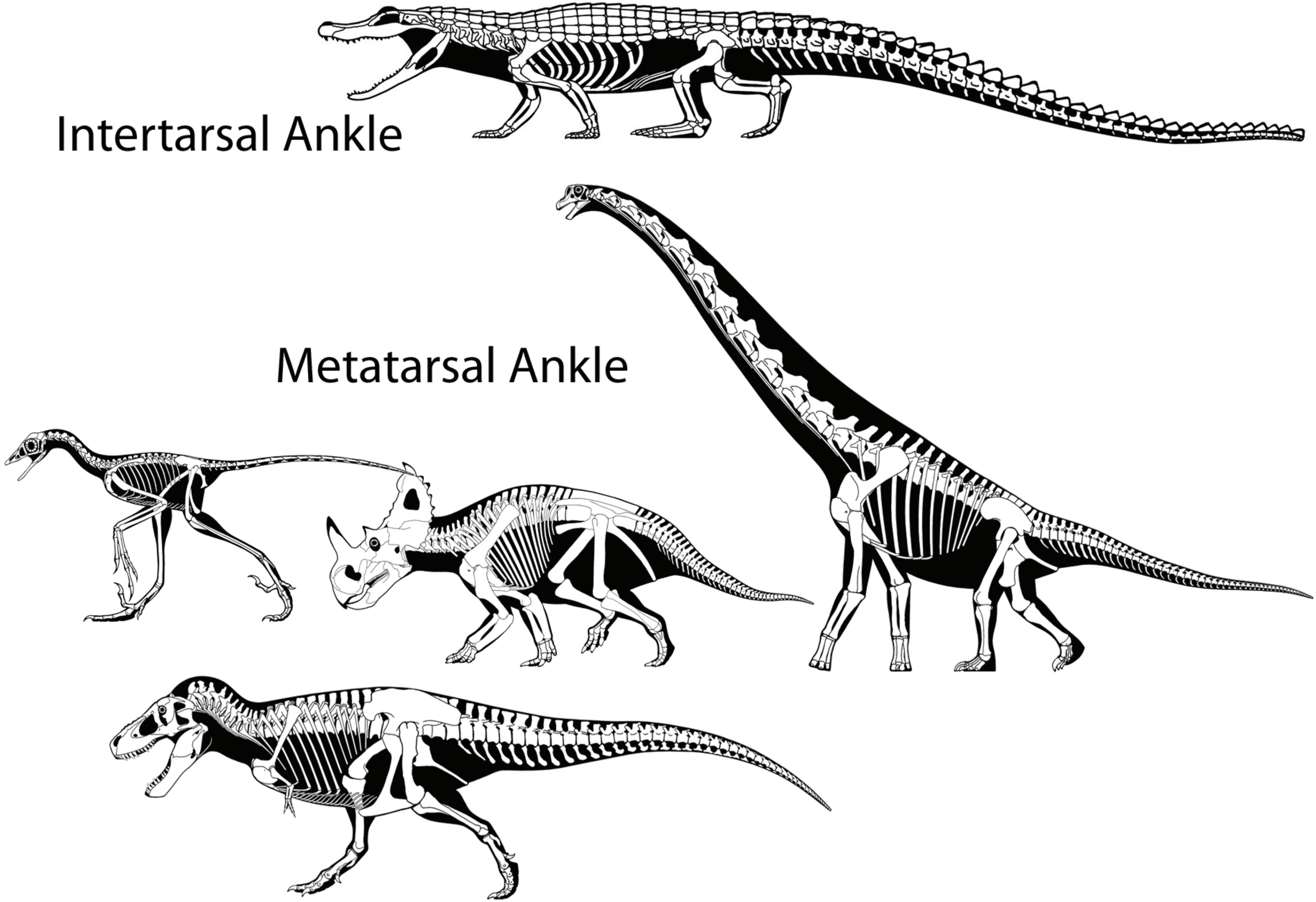


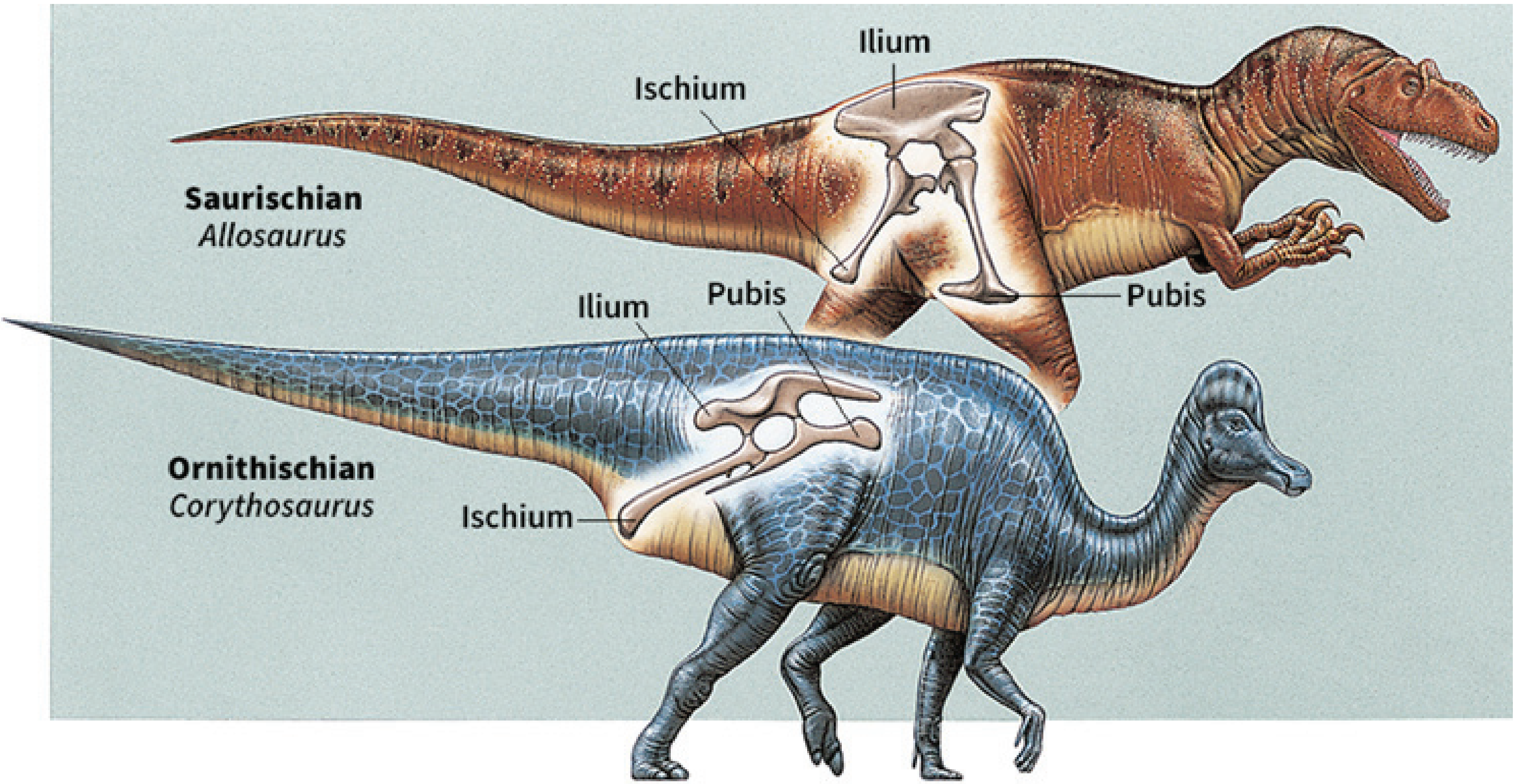
Rhamphorhynchus muensteri

Pteranodon longiceps

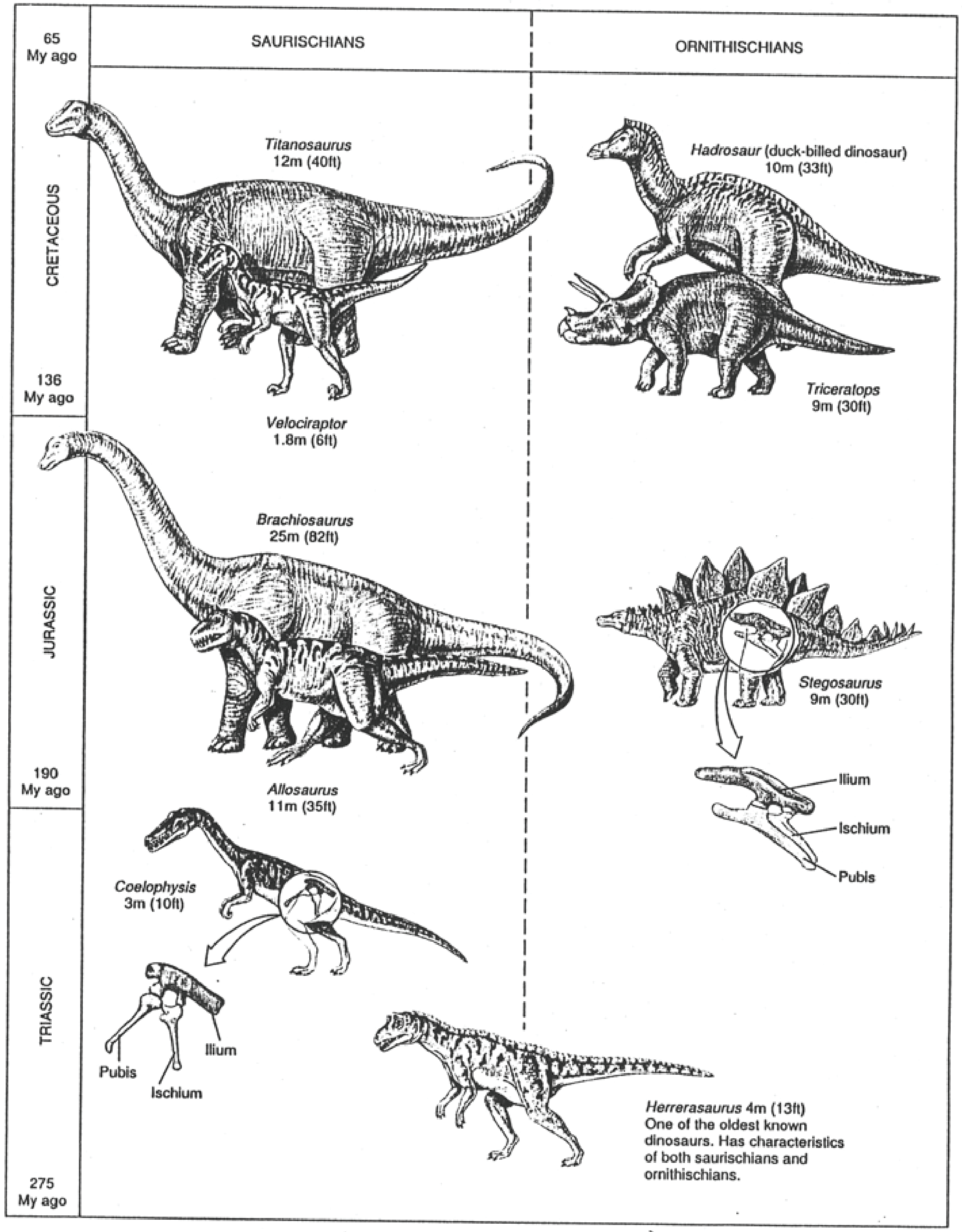
FIGURE 1XX. Superorder Archosauria: Pterosauria. Left. Rhamphorhynchoid pterosaurs. Note short neck and long, kite like balancing tail. **Right.** Pterodactyloid pterosaurs. Note longer neck, lack of tail, crainial rudder crest.

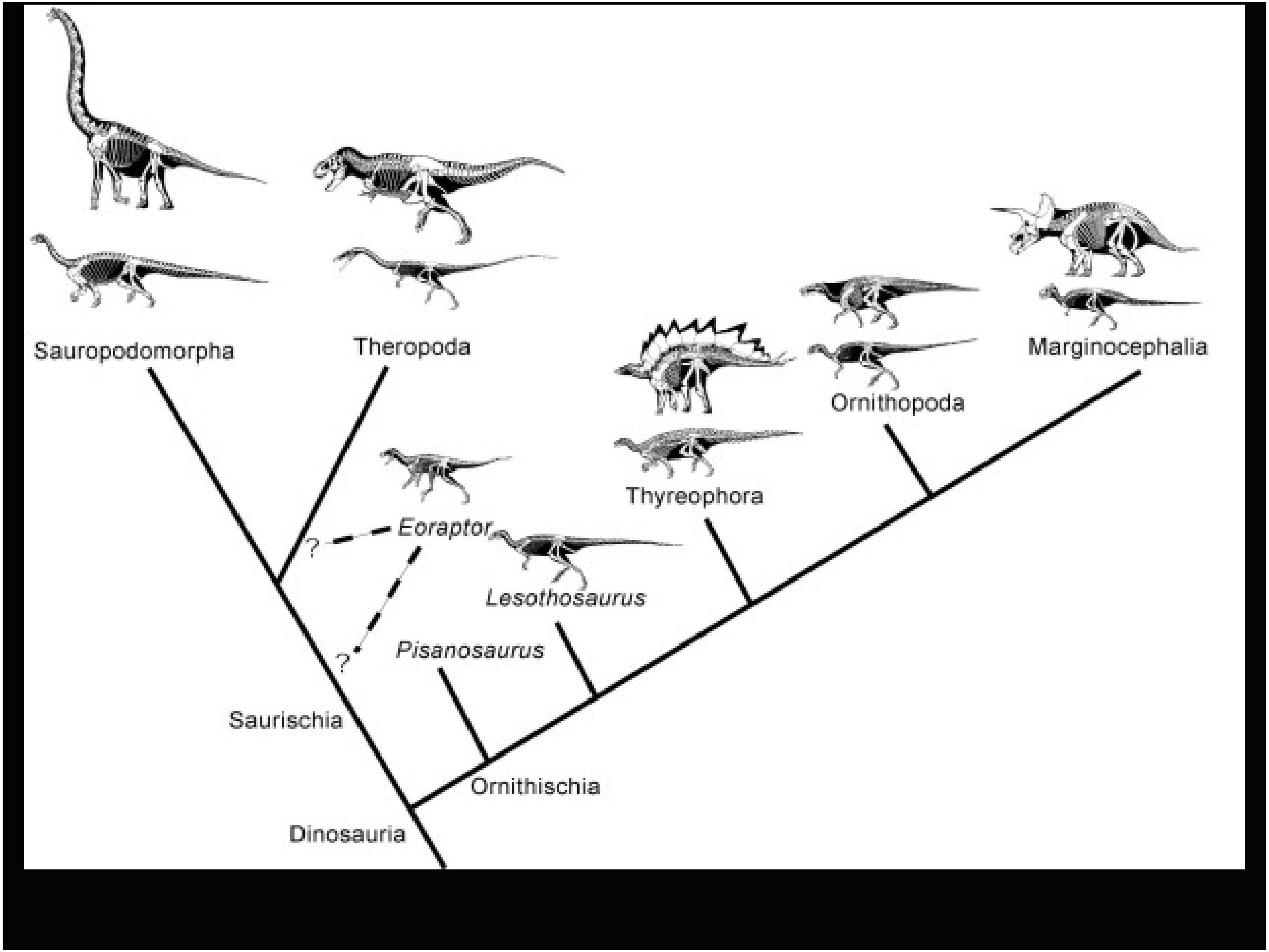
Quetzalcoathus northropi


Intertarsal Ankle
Metatarsal Ankle

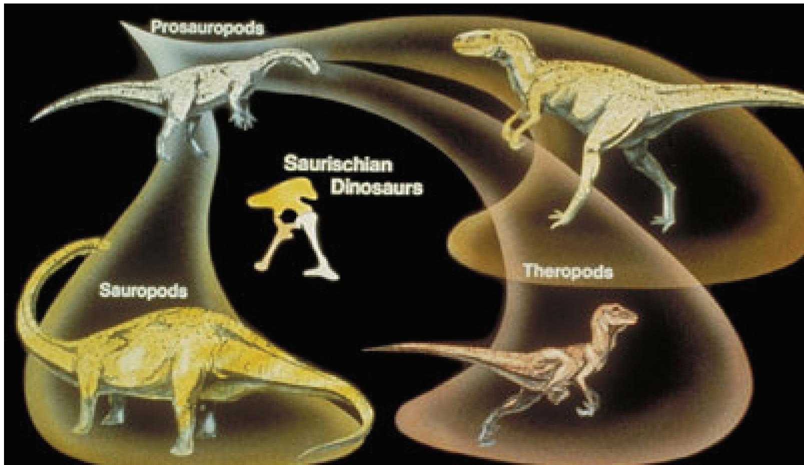

Ilium
Ischium
Saurischian
Allosaurus
Pubis
Ilium
Pubis
Ornithischian
Corythosaurus
Ischium

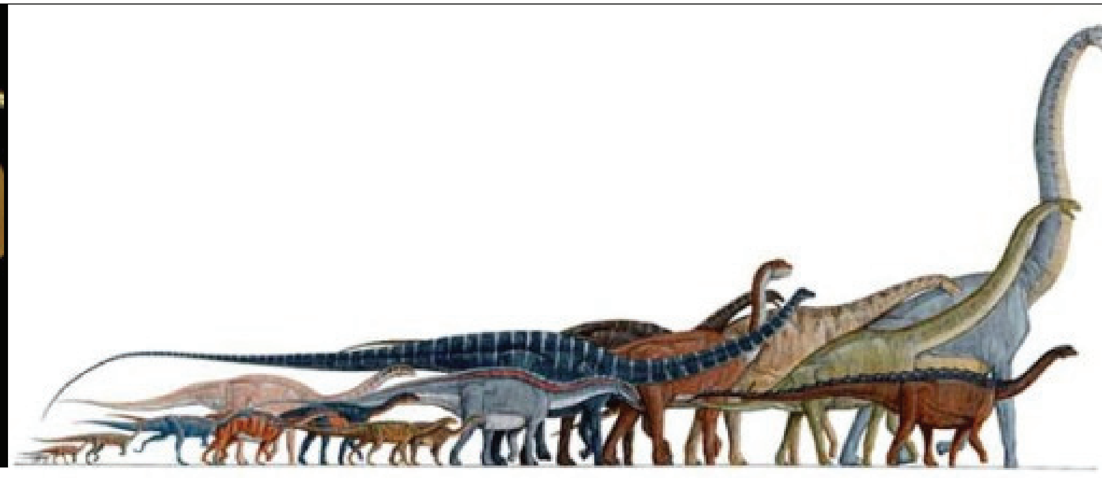
[redacted]

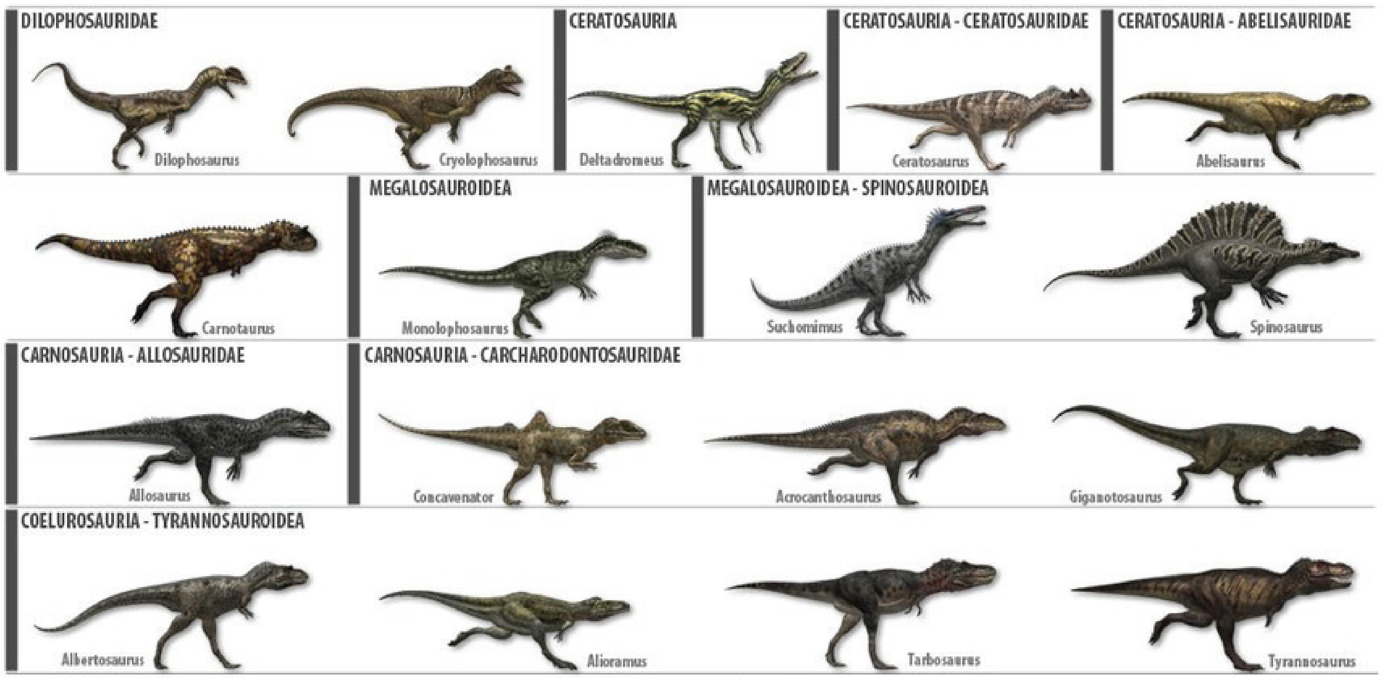

65
My ago
SAURISCHIANS
ORNITHISCHIANS
CRETACEOUS
Titanosaurus
12m (40ft)
Hadrosaur (duck-billed dinosaur)
10m (33ft)
Triceratops
9m (30ft)
136
My ago
Velociraptor
1.8m (6ft)
JURASSIC
Brachiosaurus
25m (82ft)
Stegosaurus
9m (30ft)
Ilium
Ischium
Pubis
190
My ago
Allosaurus
11m (35ft)
TRIASSIC
Coelophysis
3m (10ft)
Ilium
Pubis
Ischium
Herrerasaurus 4m (13ft)
One of the oldest known
dinosaurs. Has characteristics
of both saurischians and
ornithischians.
275
My ago

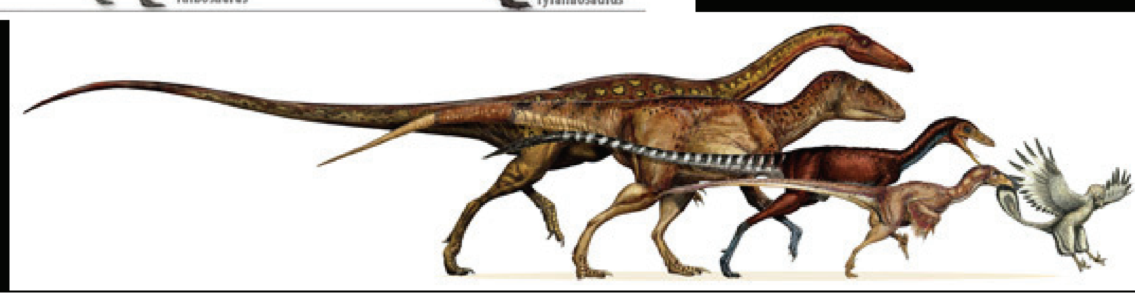


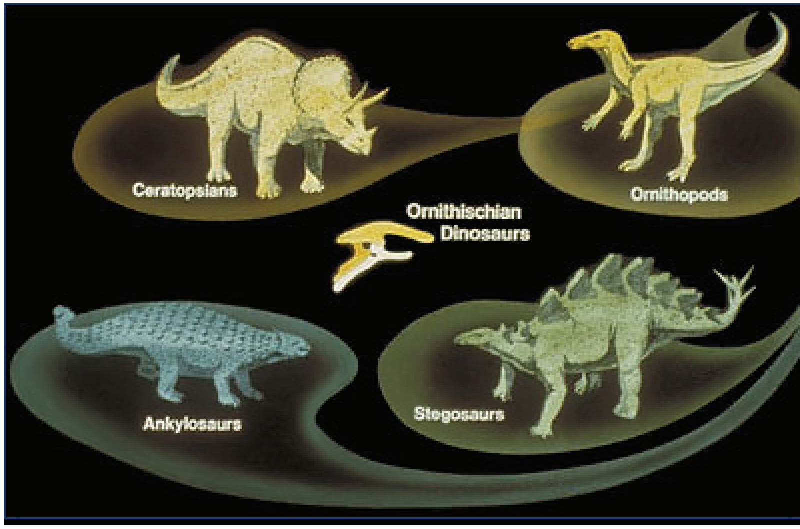
Sauropodomorpha
Theropoda
Marginocephalia
Ornithopoda
Thyreophora
Eoraptor
?
?
Lesothosaurus
Pisanosaurus
Saurischia
Ornithischia
Dinosauria

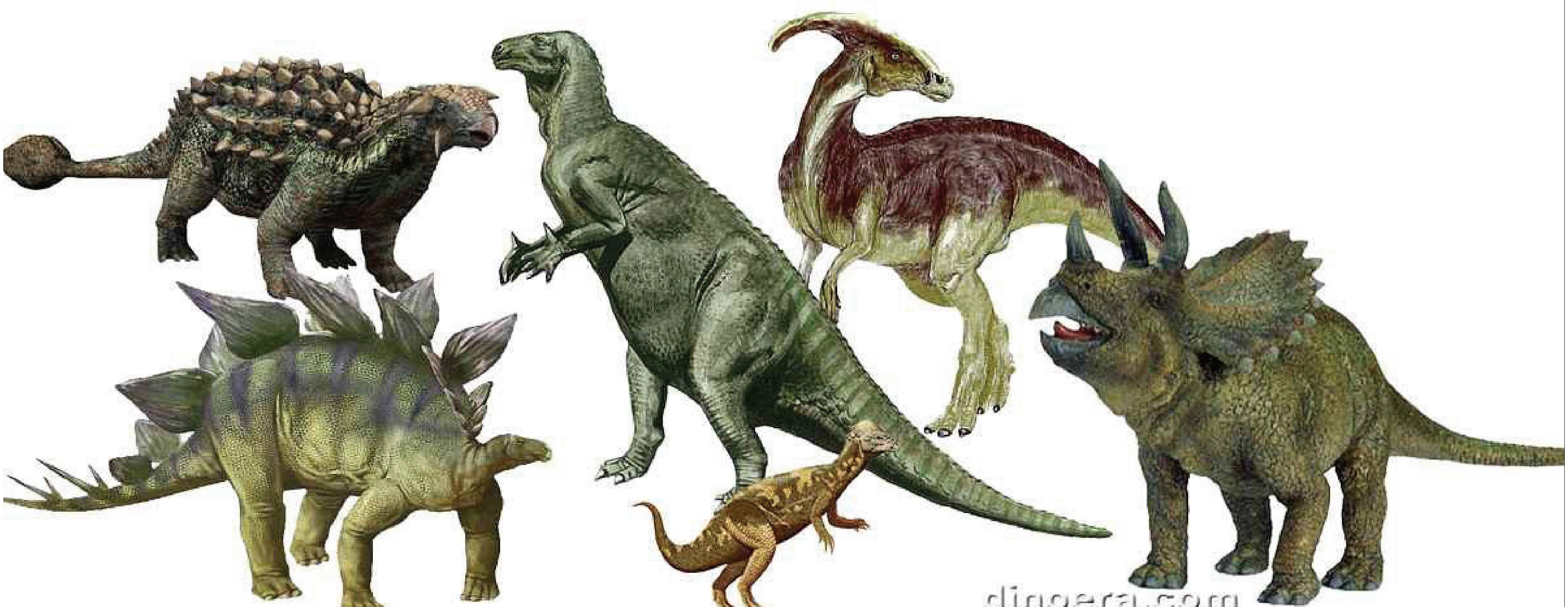

Prosauropods
Saurischian Dinosaurs
Theropods
Sauropods




DILOPHOSAURIDAE
Dilophosaurus
Cryolophosaurus
CERATOSAURIA
Deltadromeus
CERATOSAURIA - CERATOSAURIDAE
Ceratosaurus
CERATOSAURIA - ABELISAURIDAE
Abelisaurus
Carnotaurus
MEGALOSAUROIDEA
Monolophosaurus
MEGALOSAUROIDEA - SPINOSAUROIDEA
Suchomimus
Spinosaurus
CARNOSAURIA - ALLOSAURIDAE
Allosaurus
CARNOSAURIA - CARCHARODONTOSAURIDAE
Concavenator
Acrocanthosaurus
Giganotosaurus
COELUROSAURIA - TYRANNOSAUROIDEA
Albertosaurus
Alioramus
Tarbosaurus
Tyrannosaurus




Ceratopsians
Ornithopods
Ornithischian Dinosaurs
Ankylosaurs
Stegosaurs


dinoera.com

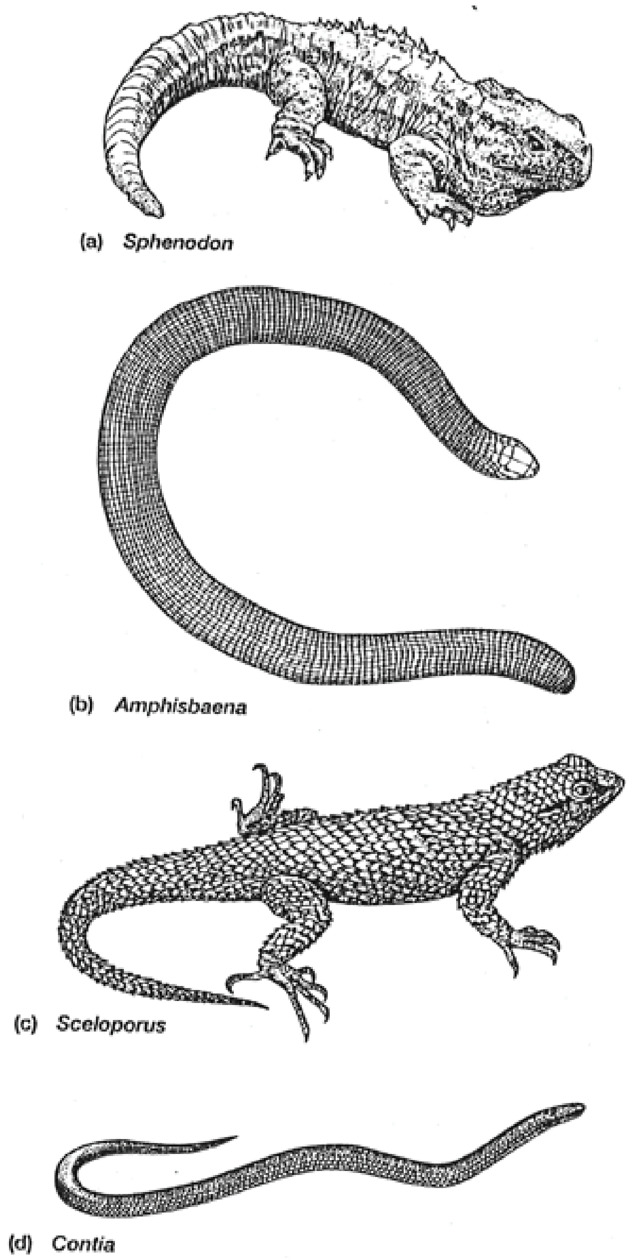
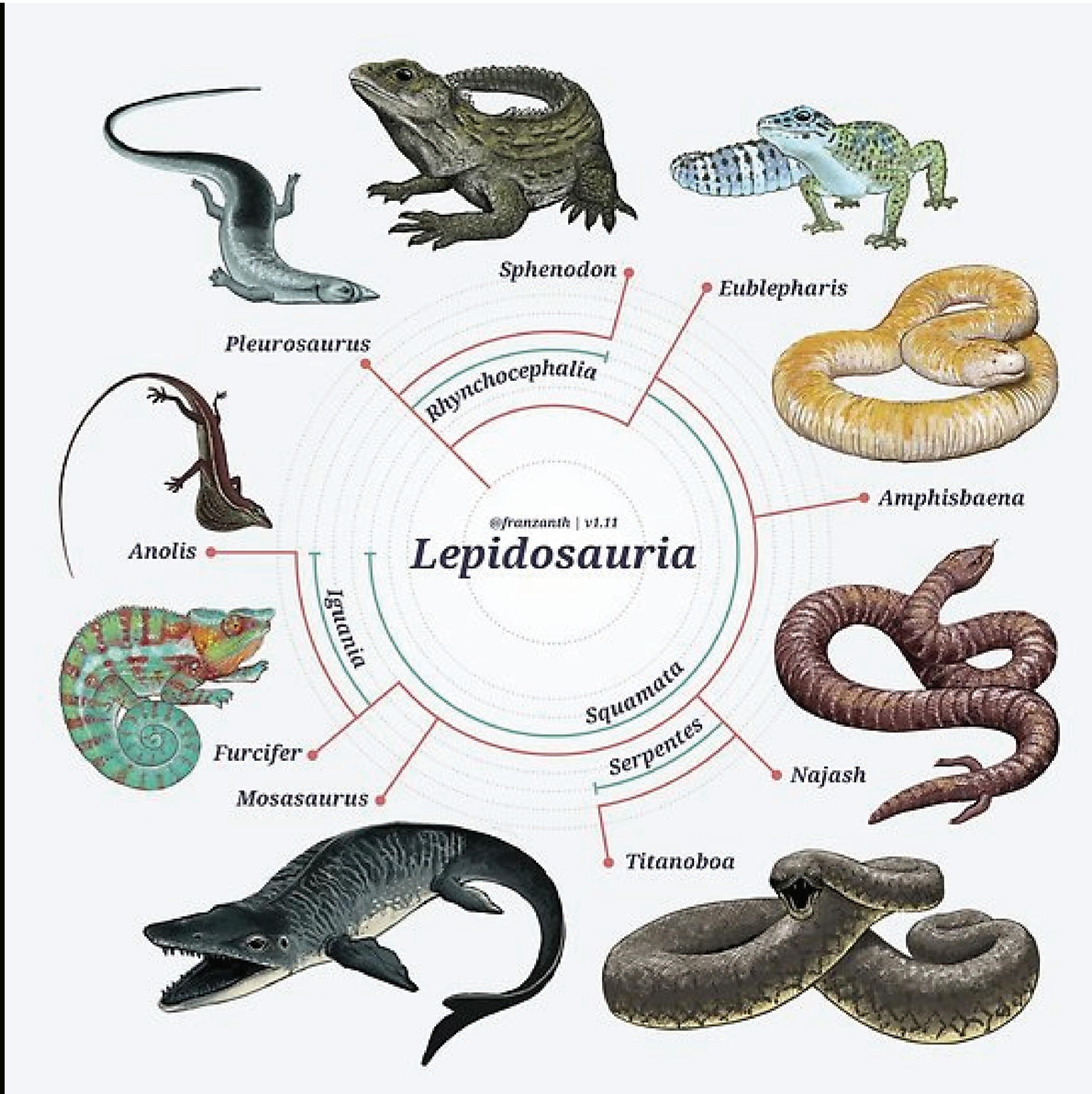
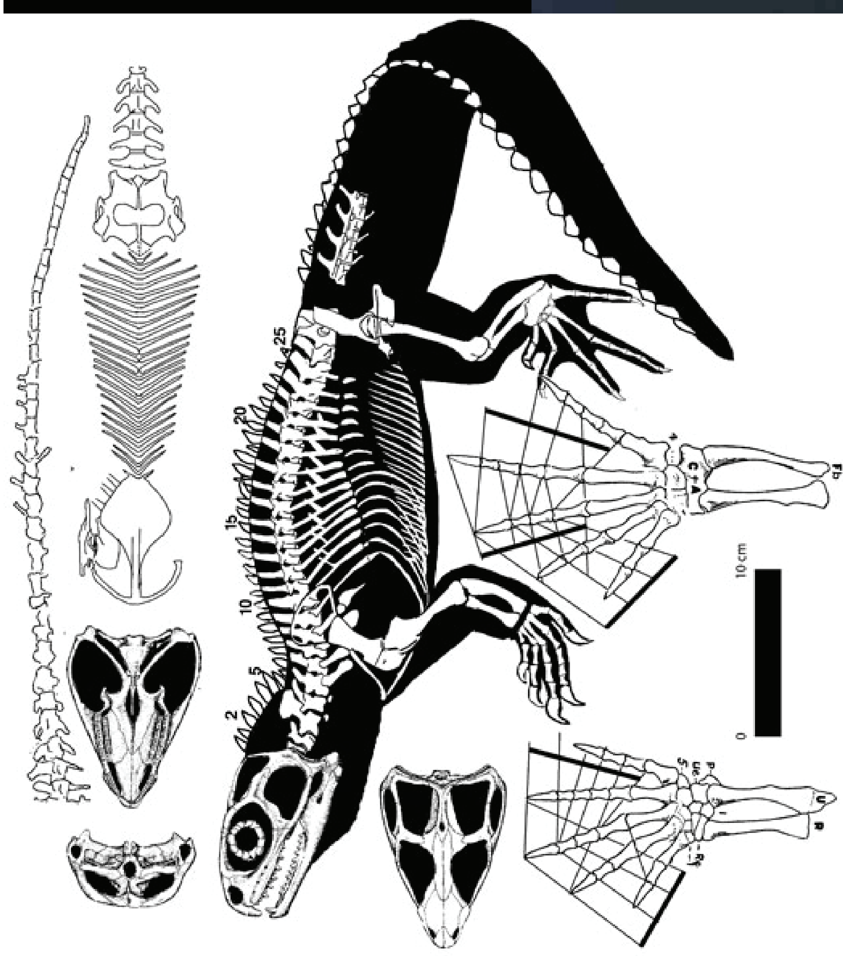


Figure 3.27 Lepidosaurs. (a) *Sphenodon*. (b) Amphisbaenian, a burrowing lepidosaur. (c) Lizard (*Sceloporus*). (d) Snake (*Contia*).


@franzanth | v1.11
Lepidosauria
Sphenodon
Eublepharis
Pleurosaurus
Rhynchocephalia
Amphisbaena
Anolis
Iguania
Squamata
Serpentes
Furcifer
Najash
Mosasaurus
Titanoboa


10 cm
0
2
5
10
15
20
25
Fb
U
R

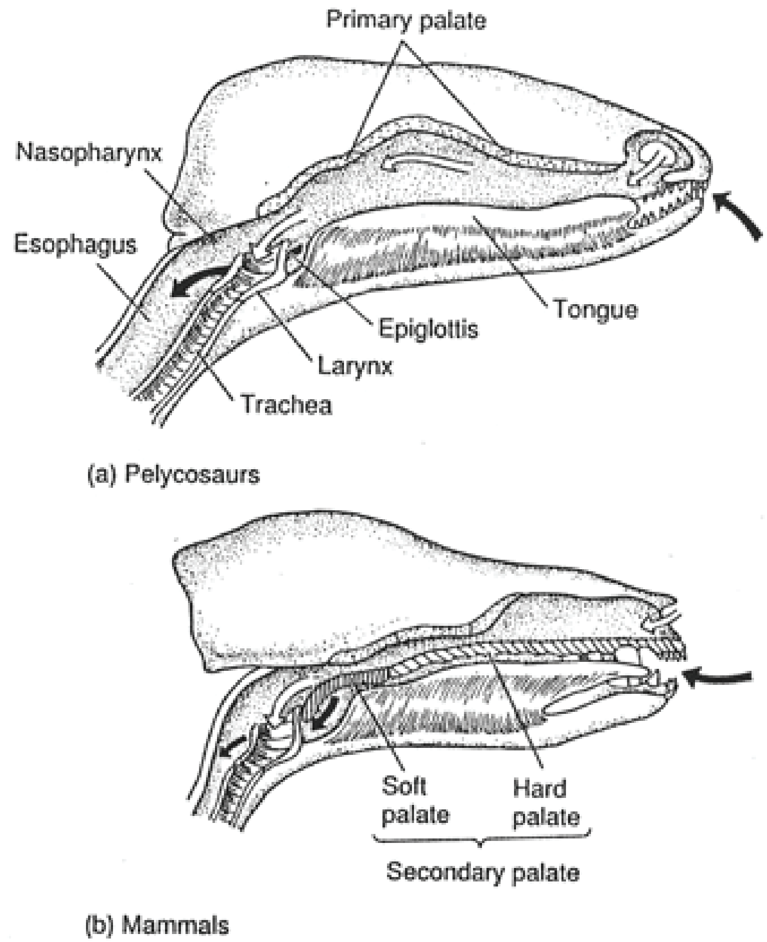


Figure 7.57 Secondary palate. (a) In most reptiles, air entering the nostrils and food entering the front of the mouth share a common passage, although each exits differently at the back. Air moves down the trachea and food travels down the esophagus. (b) In mammals, the routes of air and food are separated from the beginning of their travel by the secondary palate, a structure of bone (hard palate) and soft tissue (soft palate). White arrows indicate the path of air; dark arrows indicate the path of food.

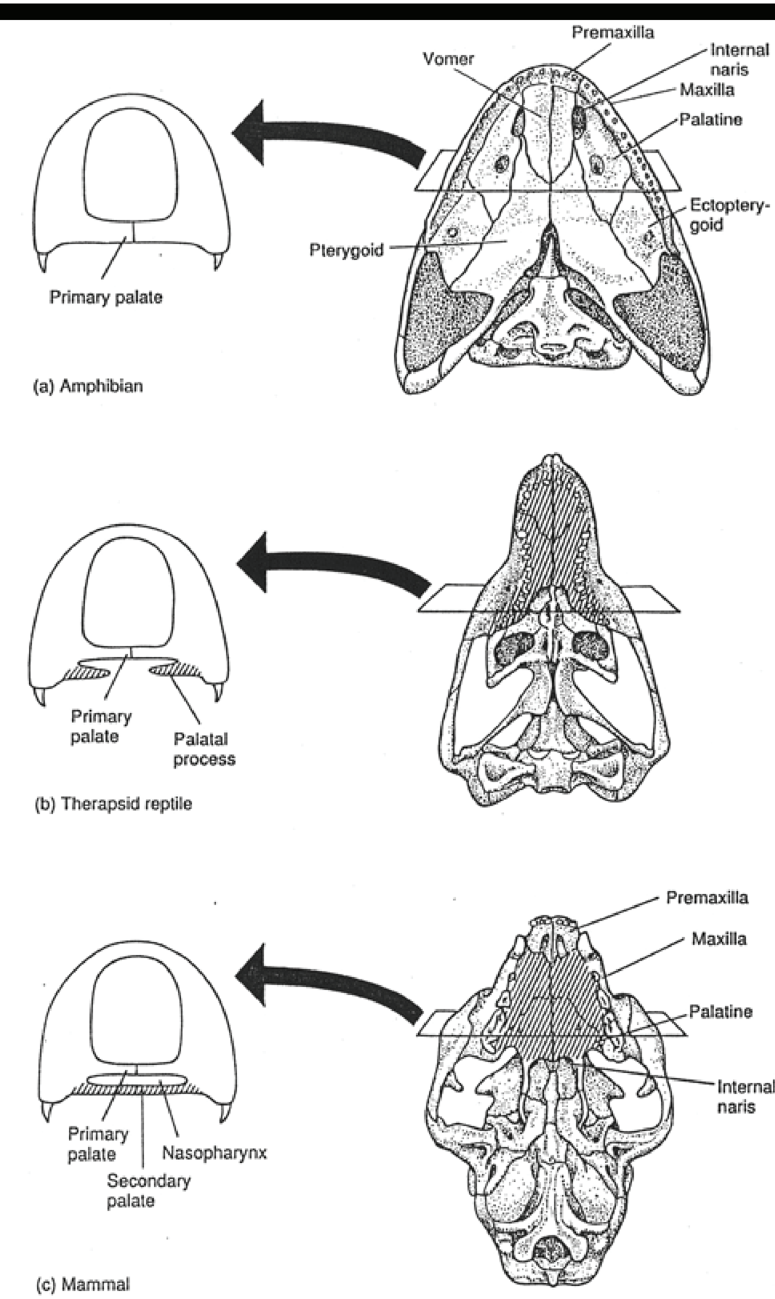


Figure 7.58 Evolution of the secondary palate. (a) Amphibian with a primary palate in cross section (left) and ventral (right) views. (b) Therapsid-reptile with a partial secondary palate formed by the medial extension of the premaxilla and maxilla. (c) Mammal with a secondary palate that, in addition to extensions of the premaxilla and maxilla, includes part of the palatine bone.

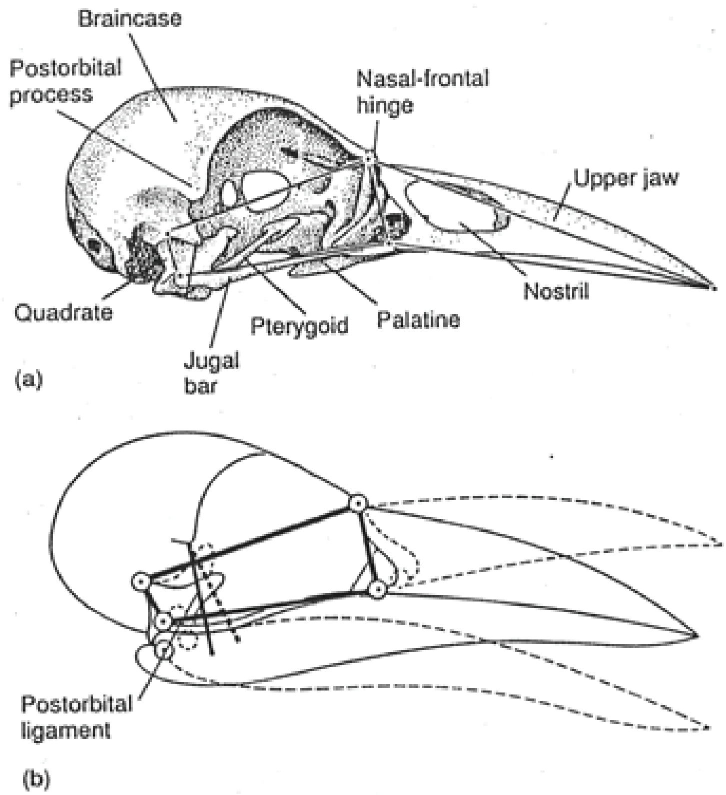
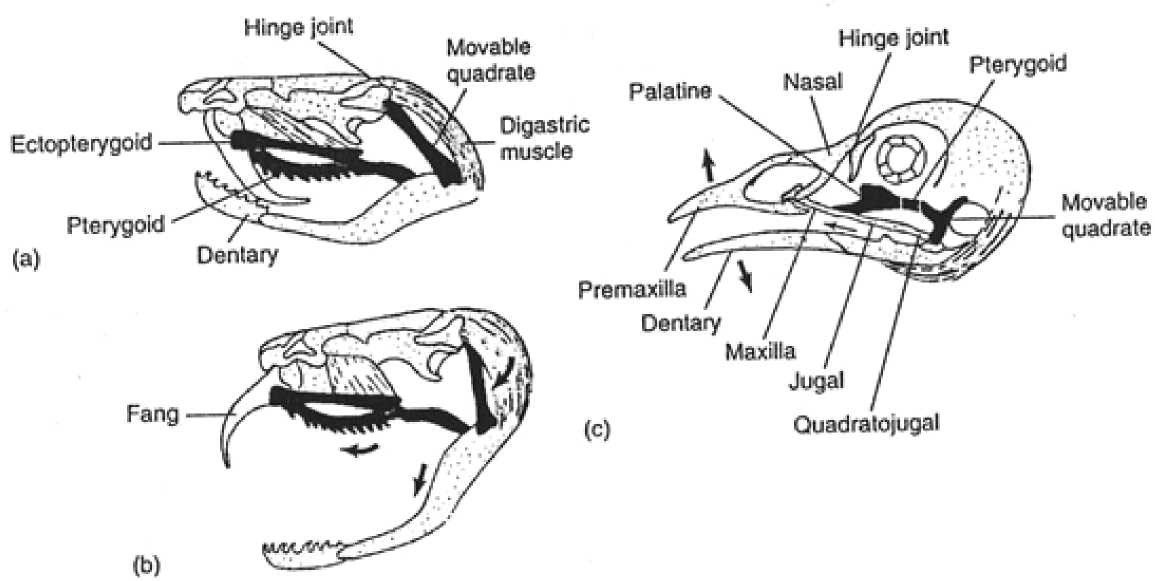


Figure 7.47 Cranial kinesis in the crow skull (*Corvus*). (a) Skull with lower jaw removed. Flexion of the beak occurs at its base with the skull. (b) Kinematic model that represents the major mechanical elements of the skull with linkages. The lower jaw is in place showing the postorbital ligament and points of rotation. The strong postorbital ligament helps control kinesis and opening of the lower jaw by forcing the lower jaw to swing forward and up. The connected jugal imparts this motion to the beak, resulting in its upward rotation about the prokinetic joint (nasofrontal hinge).



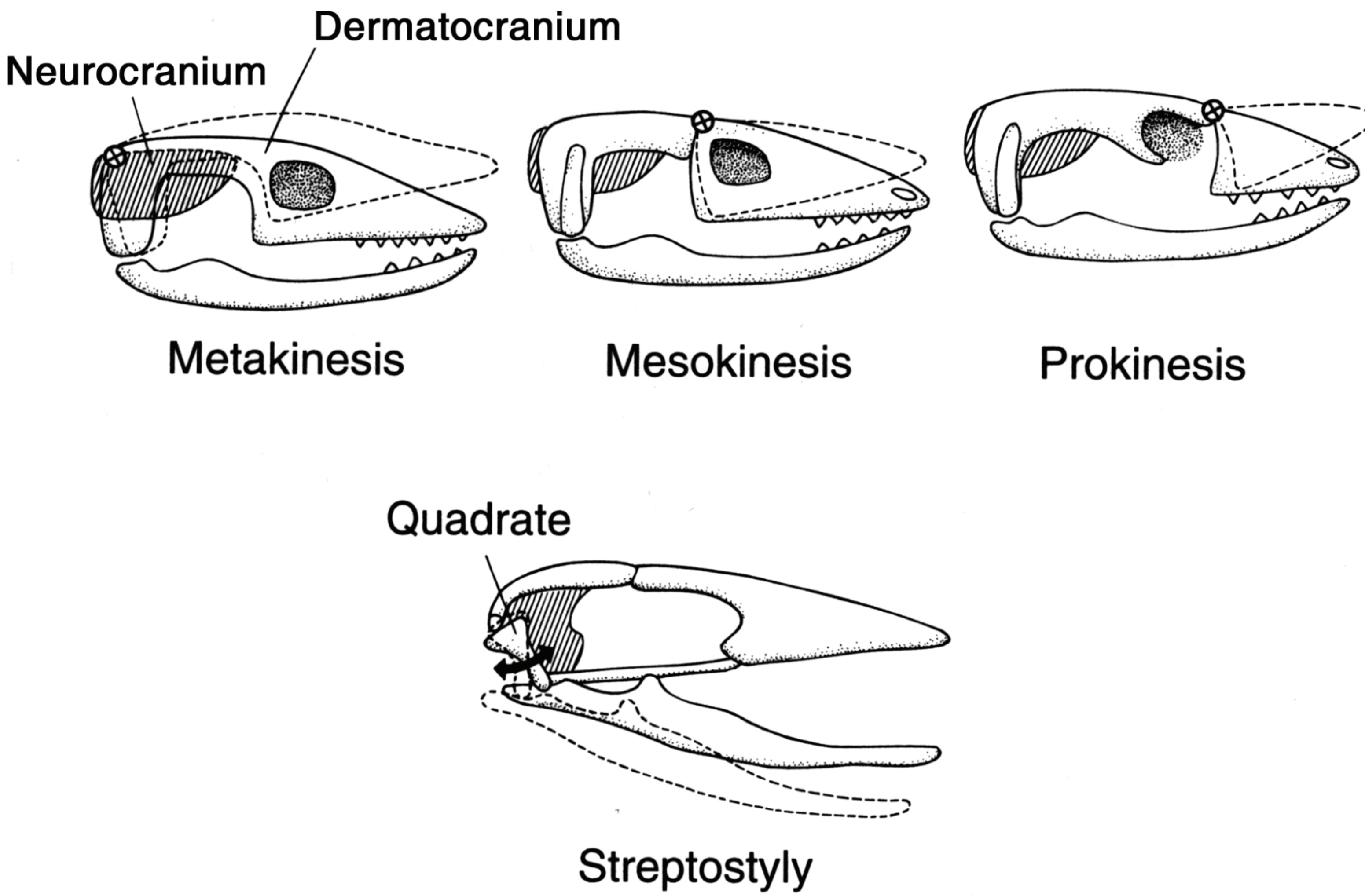
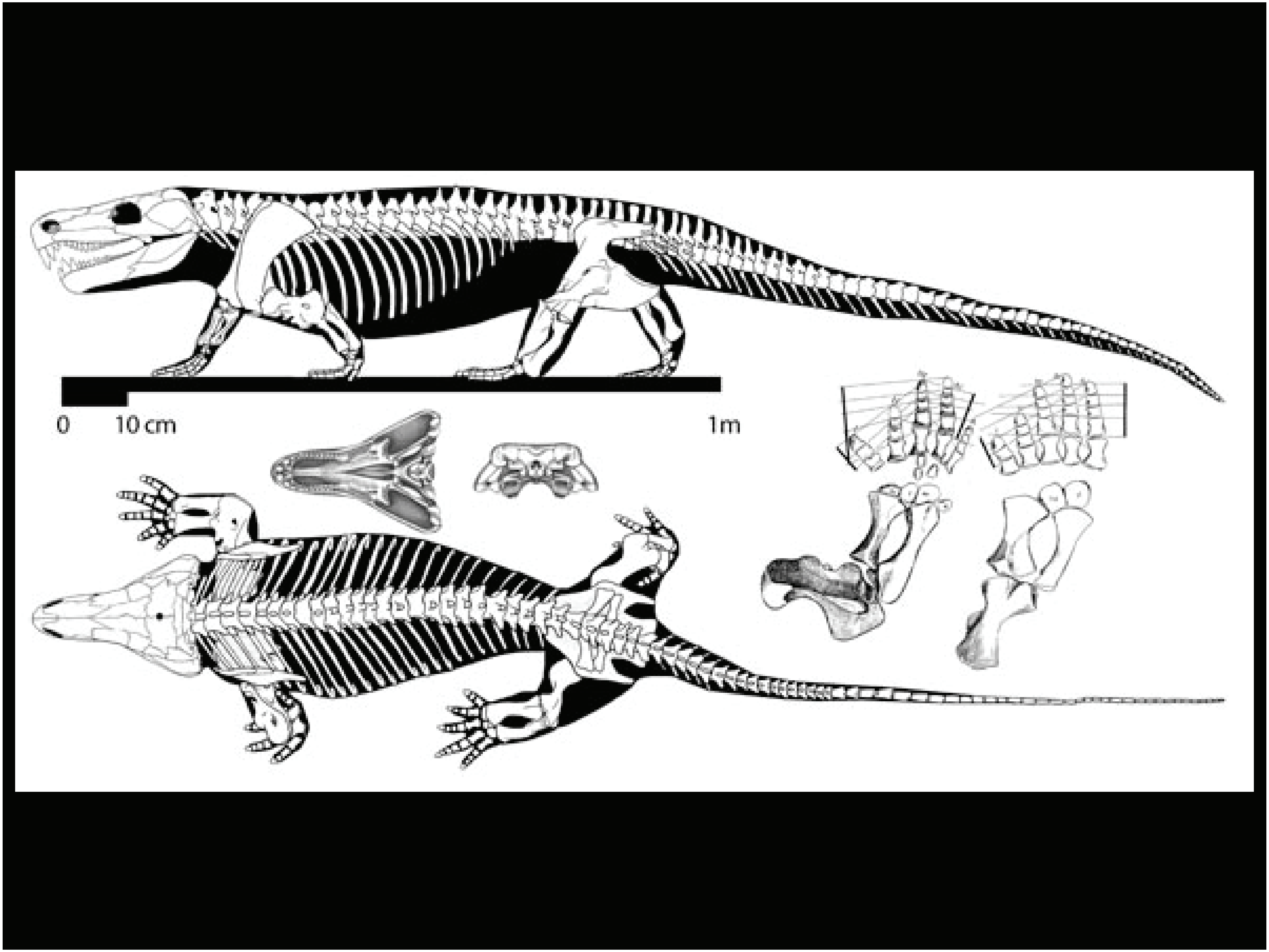


FIGURE 142. Cranial kinesis in reptiles. There are three types of cranial kinesis based largely on the position at which the hinge (X) lies across the top of the skull. The hinge may run across the back of the skull roof (metakinesis), behind the orbit (mesokinesis) or in front of the orbit where the snout or beak articulates (prokinesis.) The top series demonstrates all three kinetic types. Another cranial kinetic phenomenon is streptostyly (bottom). Streptostyly produces parallel movement of the skull in relation to the mandible as a result of the ability of the quadrate to rotate about its dorsal end. (*after Kent & Miller*)


0
10 cm
1m