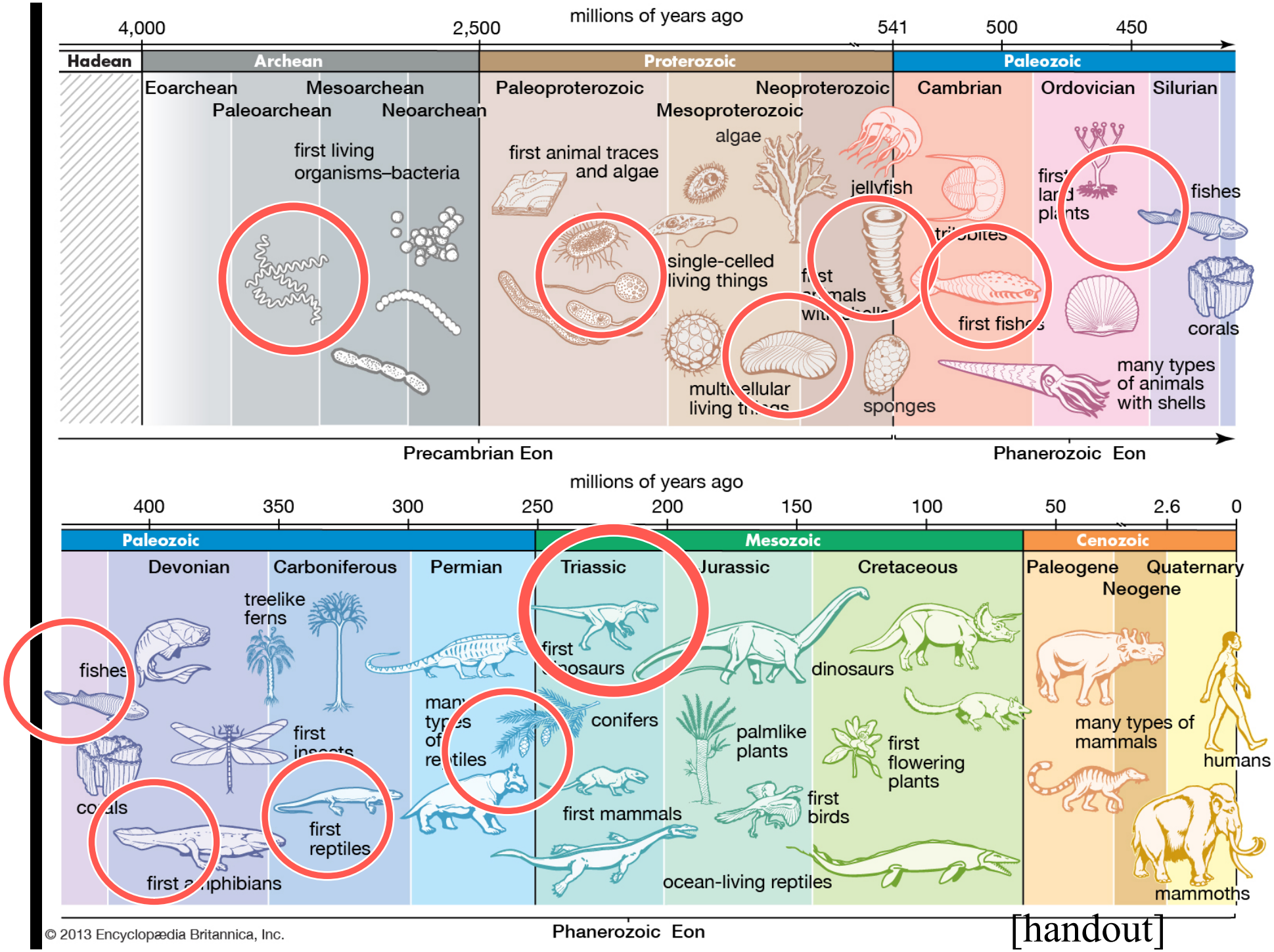
millions of years ago
4,000
2,500
541
500
450
Hadean
Archean
Proterozoic
Paleozoic
Eoarchean
Mesoarchean
Paleoarchean
Neoarchean
Paleoproterozoic
Neoproterozoic
Mesoproterozoic
Cambrian
Ordovician
Silurian
first living organisms–bacteria
first animal traces and algae
algae
jellyfish
single-celled living things
sponges
fishes
corals
many types of animals with shells
Precambrian Eon
Phanerozoic Eon
millions of years ago
400
350
300
250
200
150
100
50
2.6
0
Paleozoic
Mesozoic
Cenozoic
Devonian
Carboniferous
Permian
Triassic
Jurassic
Cretaceous
Paleogene
Neogene
Quaternary
treelike ferns
fishes
first insects
first reptiles
first amphibians
corals
conifers
first mammals
palmlike plants
first birds
ocean-living reptiles
dinosaurs
first flowering plants
many types of mammals
humans
mammoths
Phanerozoic Eon
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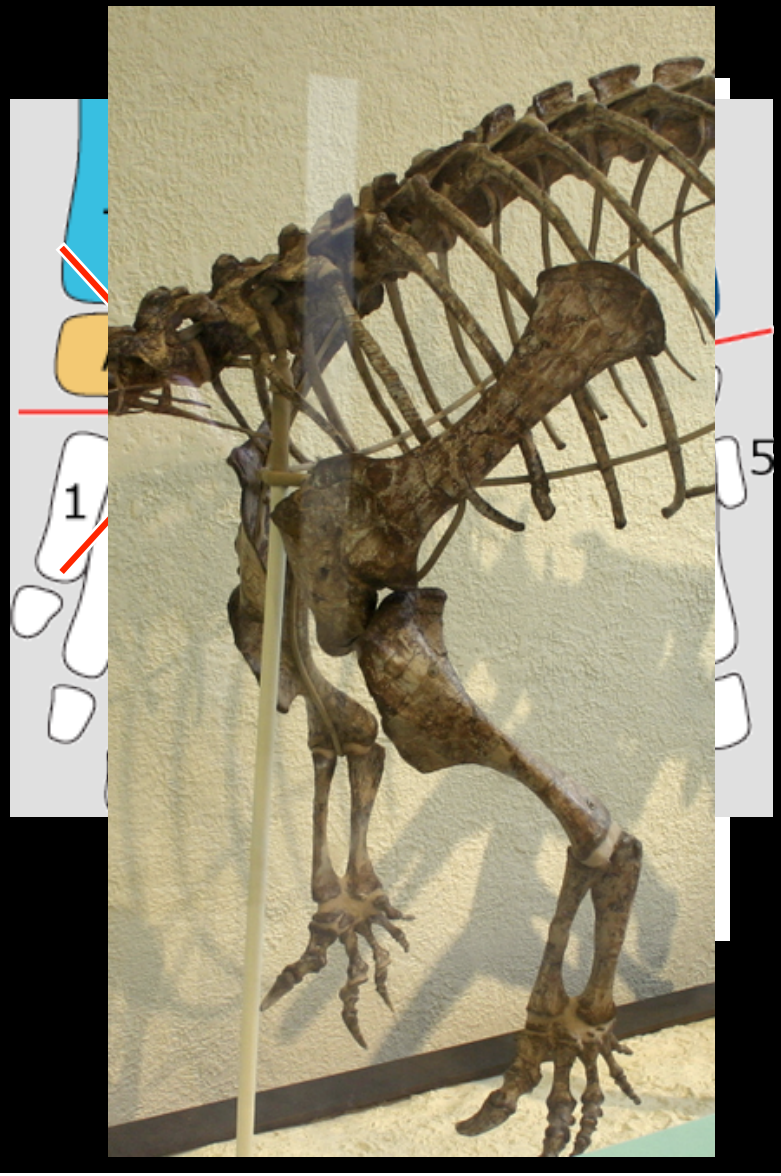
[handout]

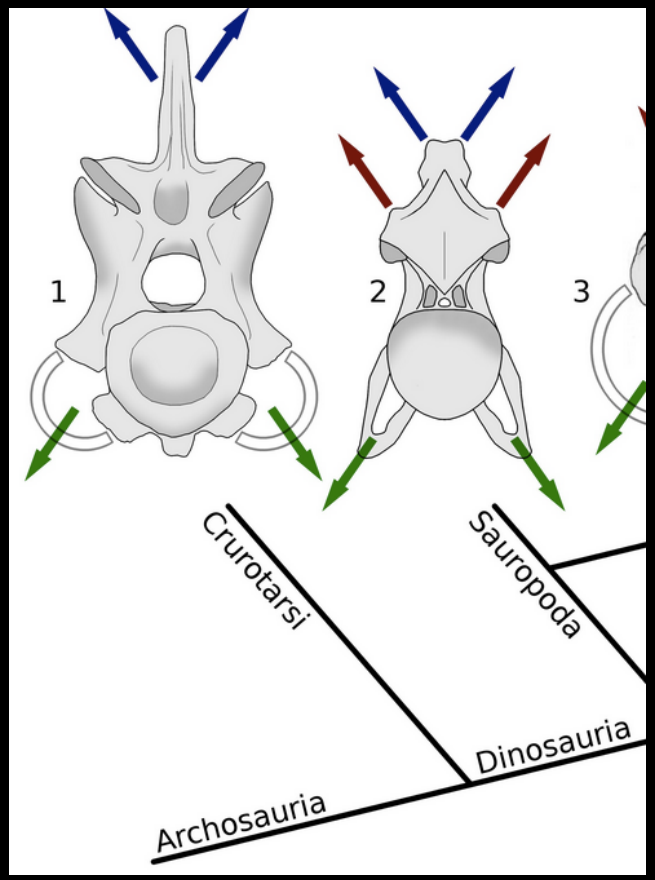
DINOSAURIA – distinguishing characters

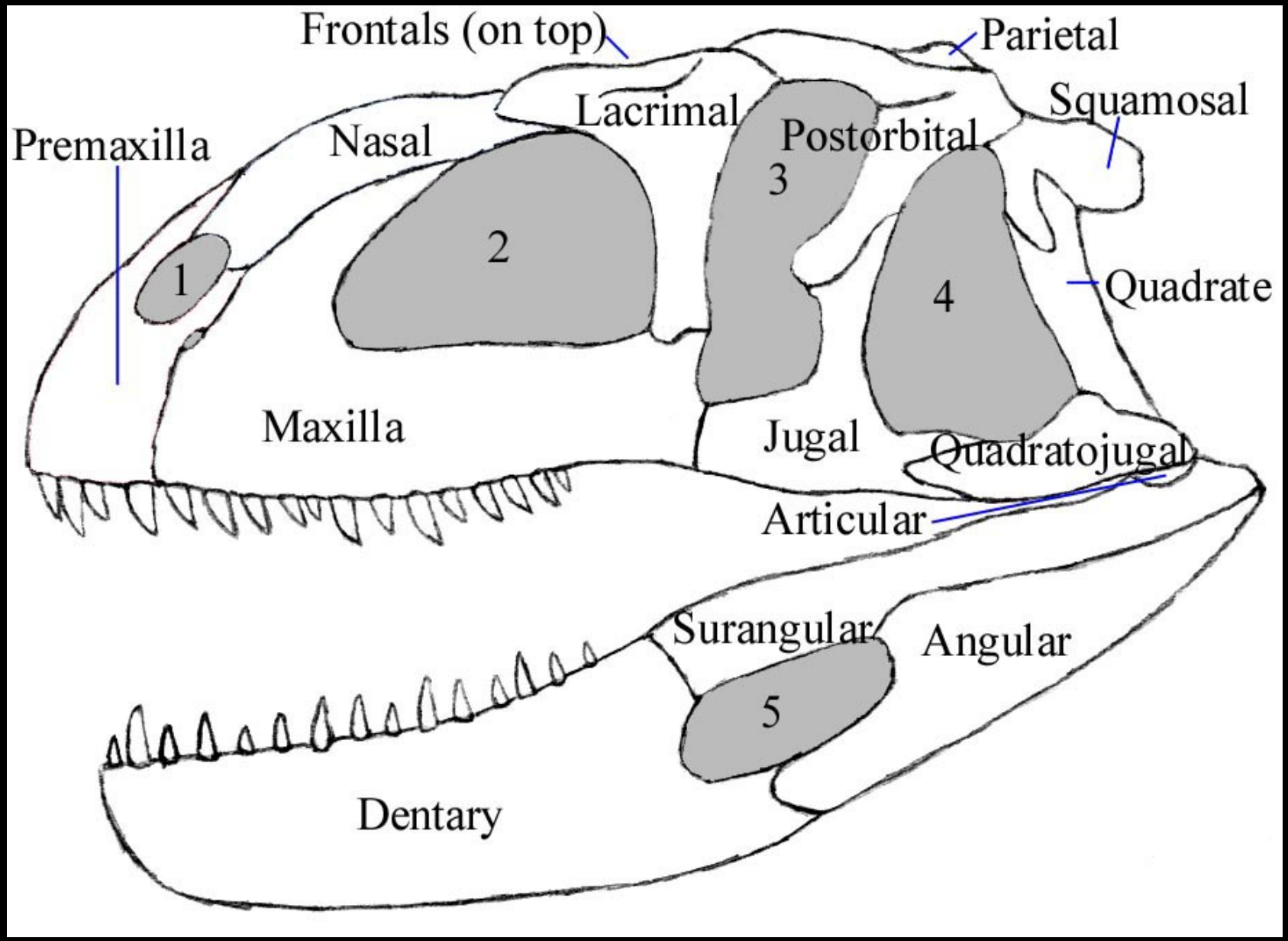
- advanced mesotarsal ankle
- limbs beneath the body, upright posture
- (a sacrum composed of three or more fused vertebrae)
- (open hip socket, the acetabulum)
- asymmetric hand with two smaller outer digits
- elongate deltopectoral crest on the upper arm bone

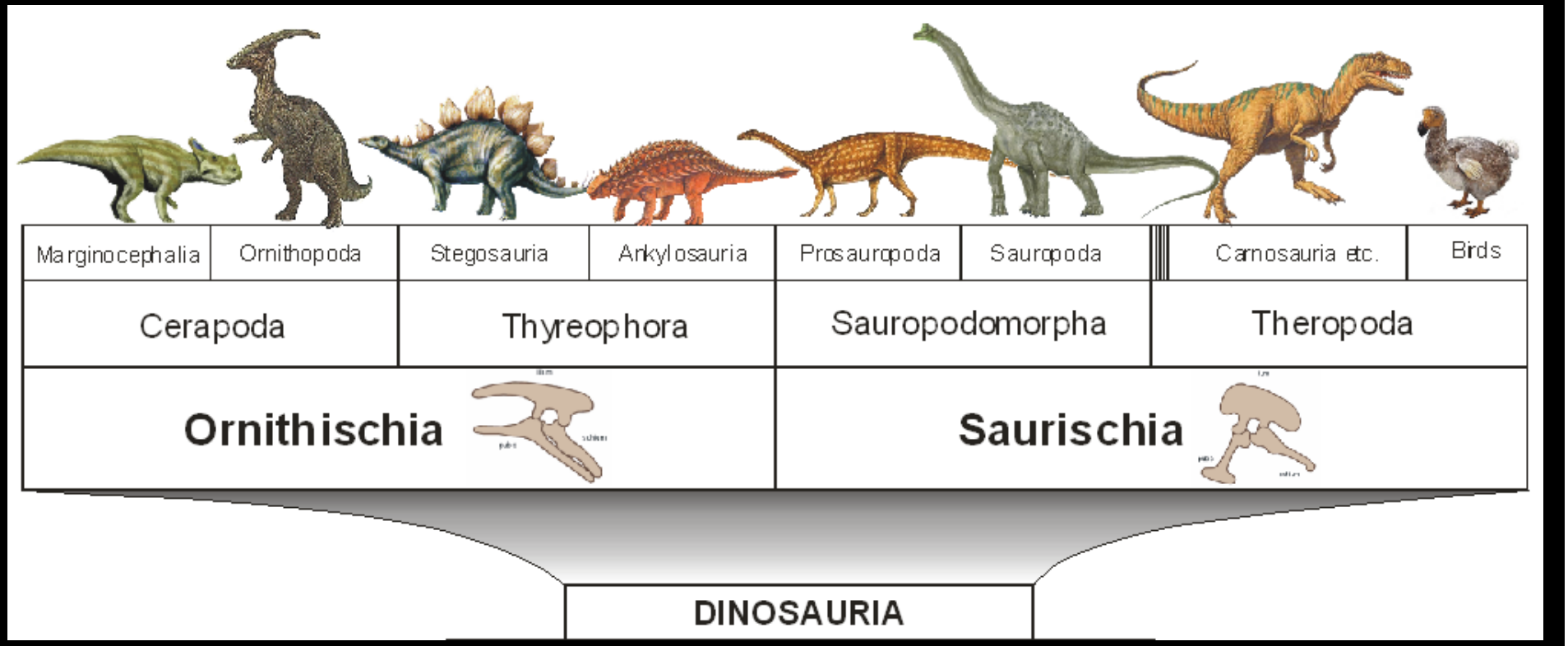


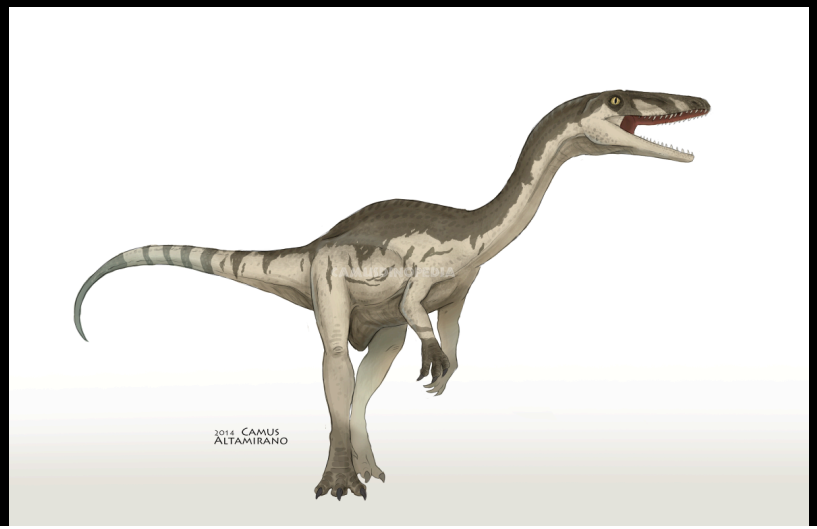
according to Brusatte (2011)

- temporal musculature (mandibular adductors enlarged)
- epipophyses on cervical vertebrae
- elongate deltopectoral crest on humerus
- open acetabulum
- asymmetrical fourth trochanter
- bifurcating posterior jugal process



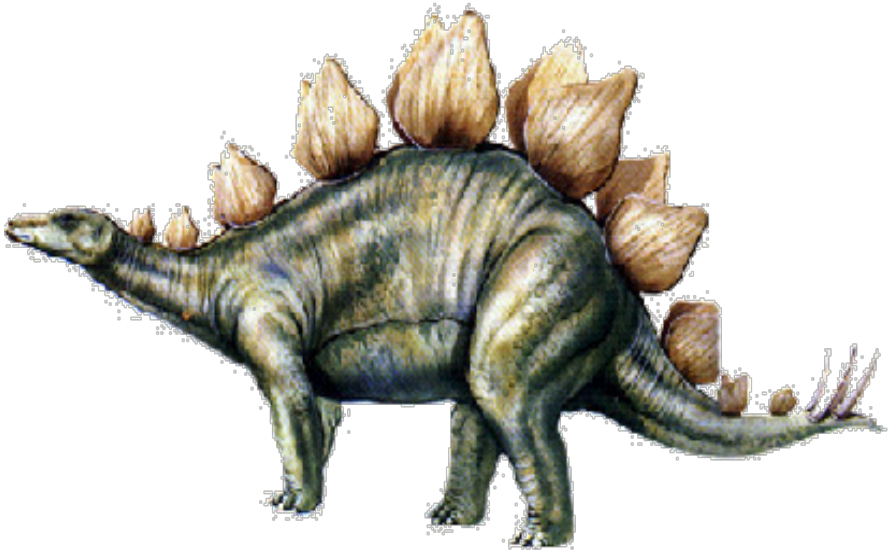

Frontals (on top)
Parietal
Lacrimal
Squamosal
Premaxilla
Nasal
Postorbital
3
2
1
4
Quadrate
Maxilla
Jugal
Quadratojugal
Articular
Surangular
Angular
5
Dentary

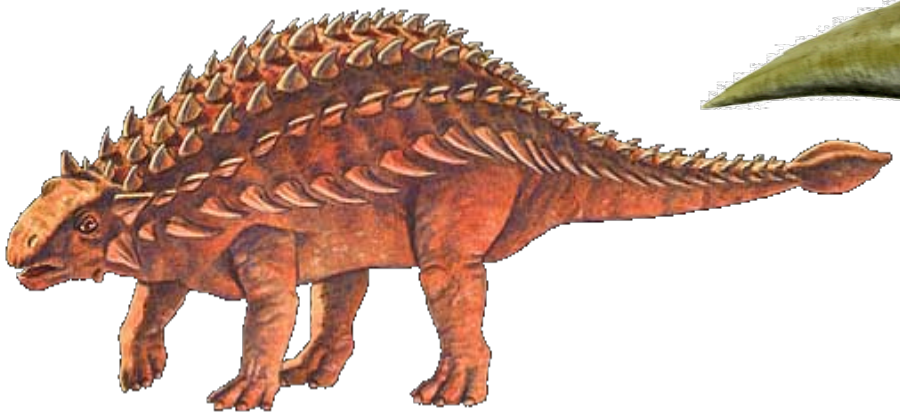




Coelophysis

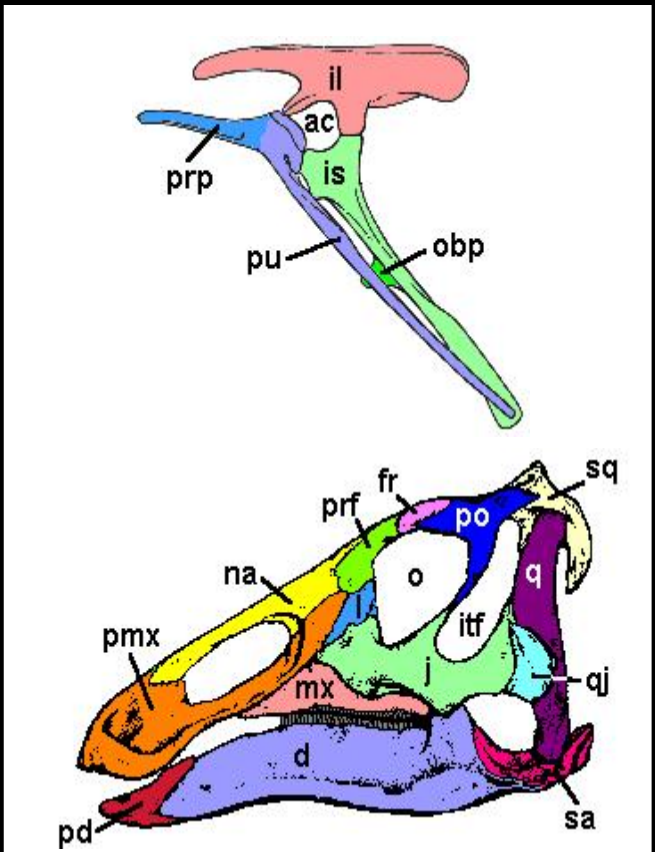
Ornithischia

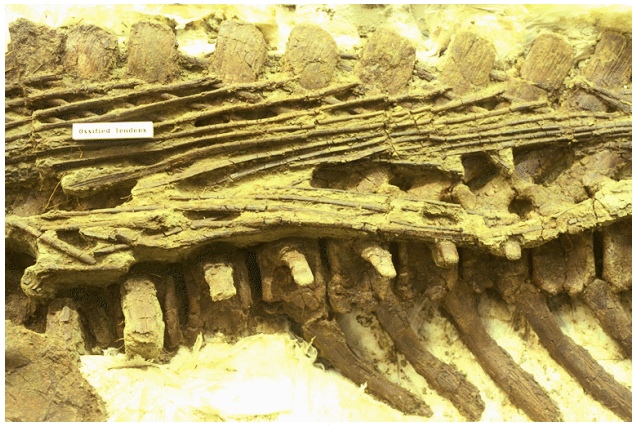




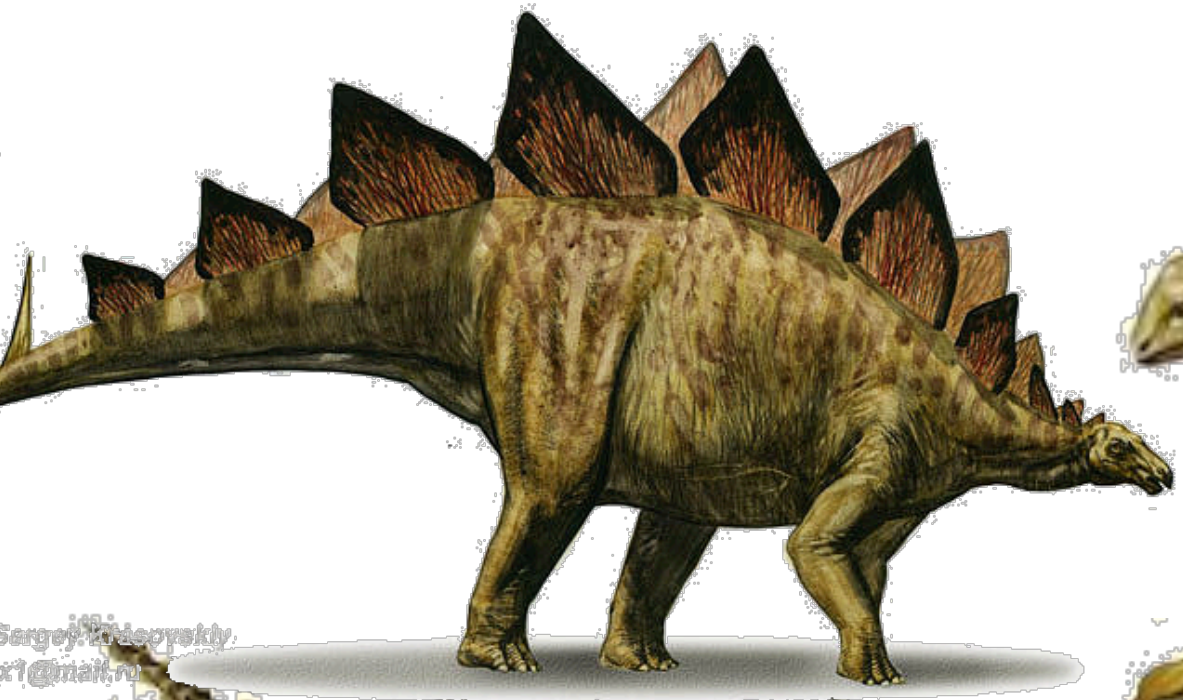
Ornitischian characters

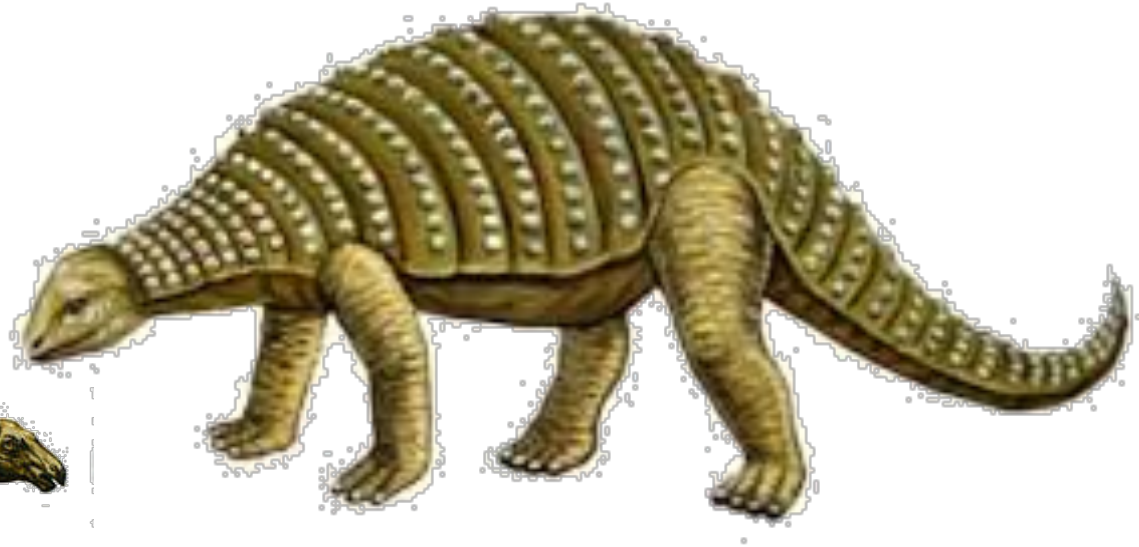
- ”bird hip” (pubis points backward)
- predentary bone; premaxillae expanded and toothless
- small antorbital fenestrae
- blunt or leaf shaped teeth
- ossified tendons along parts of spinal column
- five or more sacral vertebrae
- herbivorous (omnivorous)
- since the late Triassic





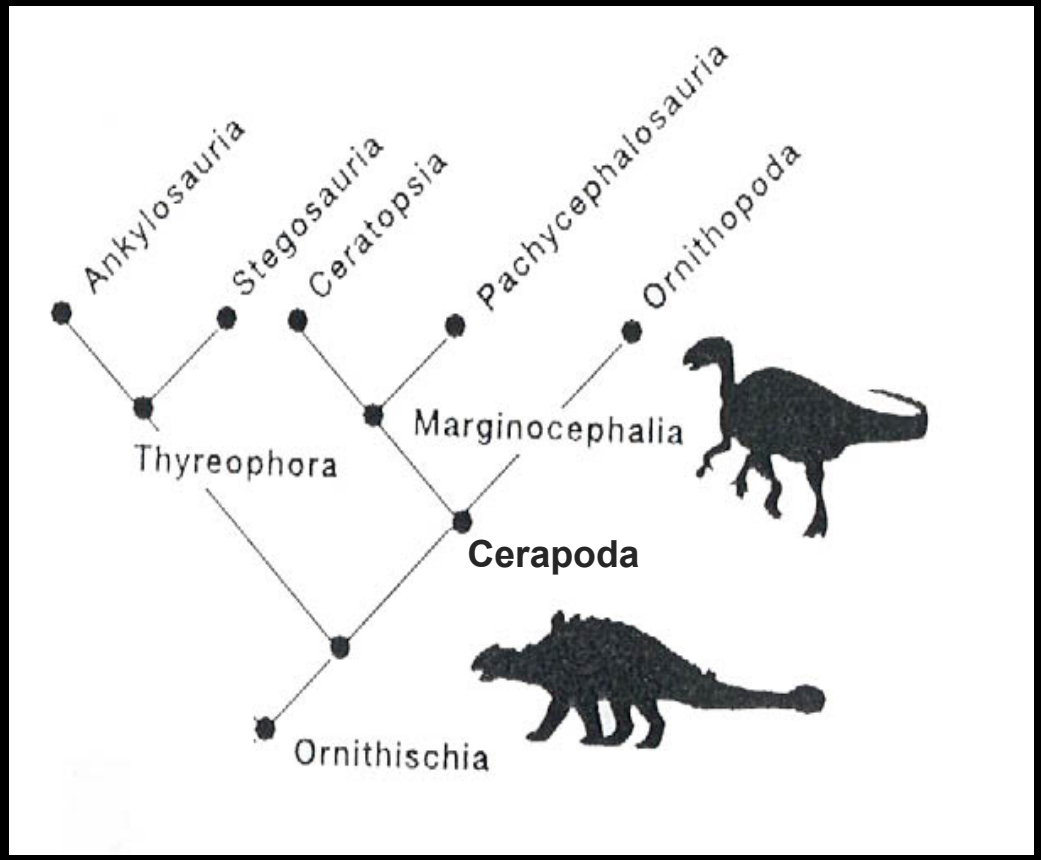
Ornitischia – group 1



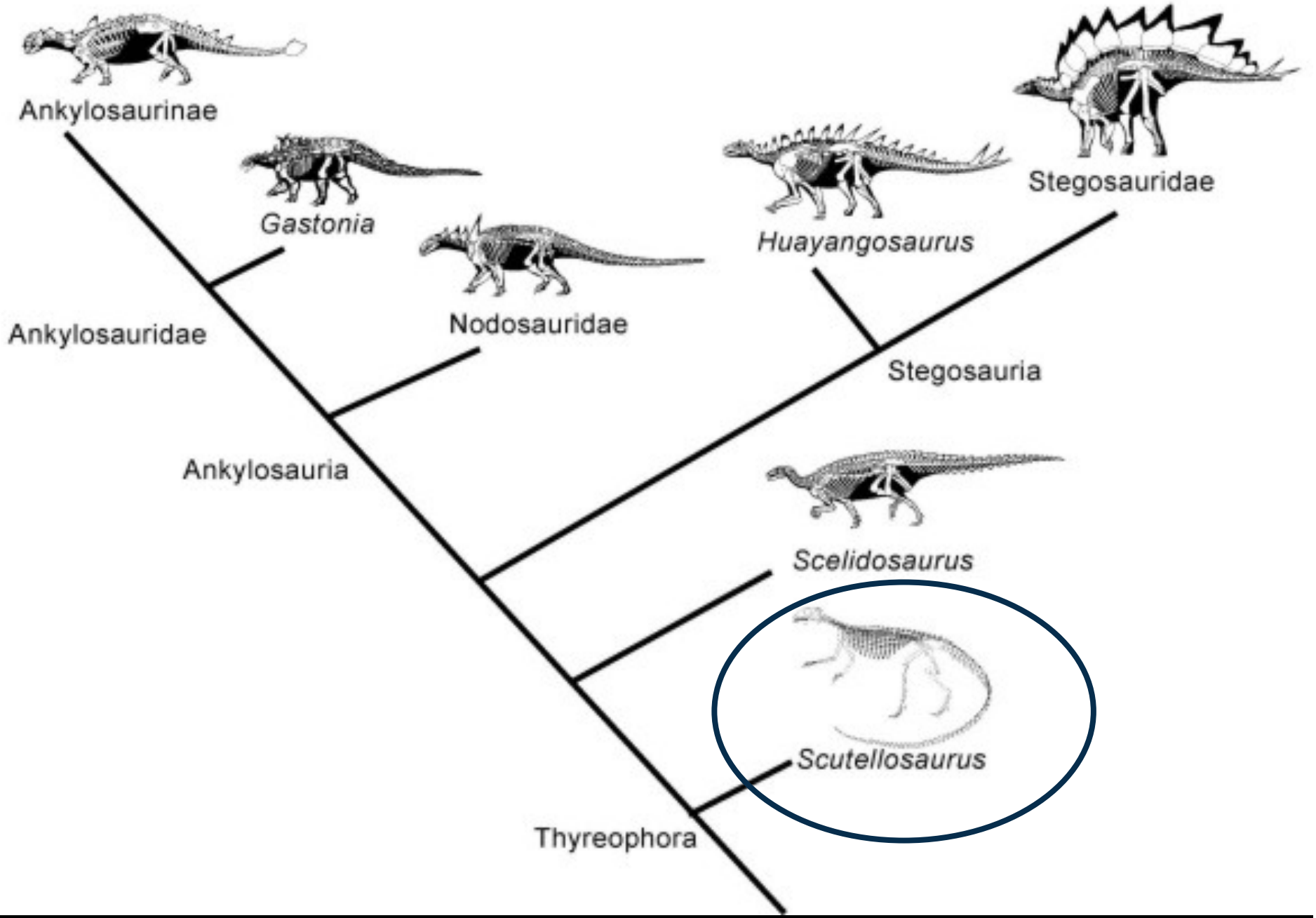


ORNITHISCHIA

Thyreophora (“shield-bearers - *sköldbärare*")



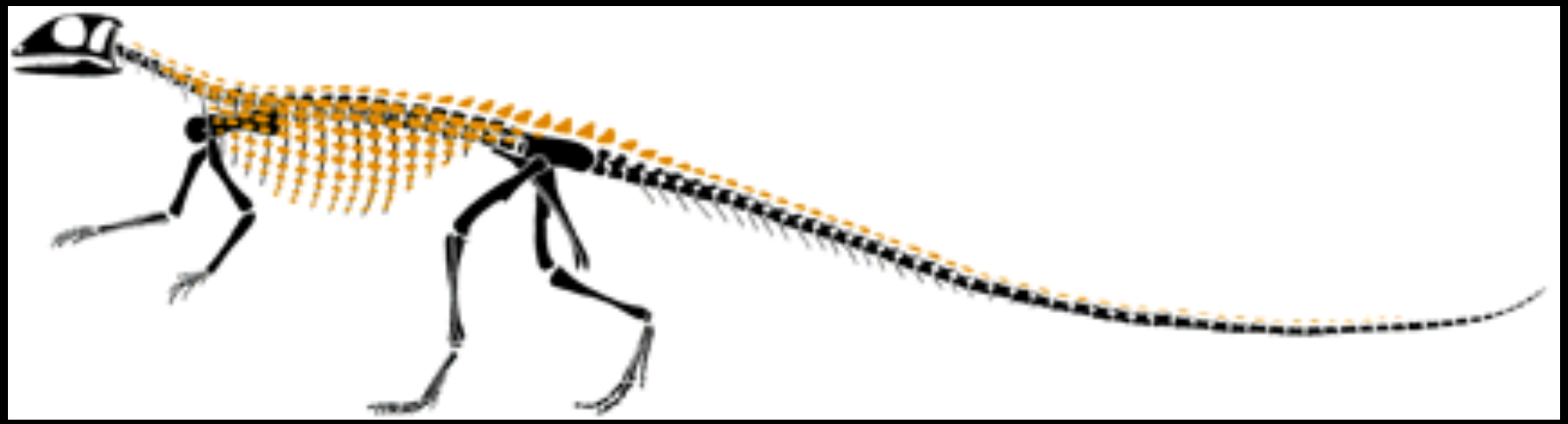
- Rows of dermal ossification (armored dinosaurs)

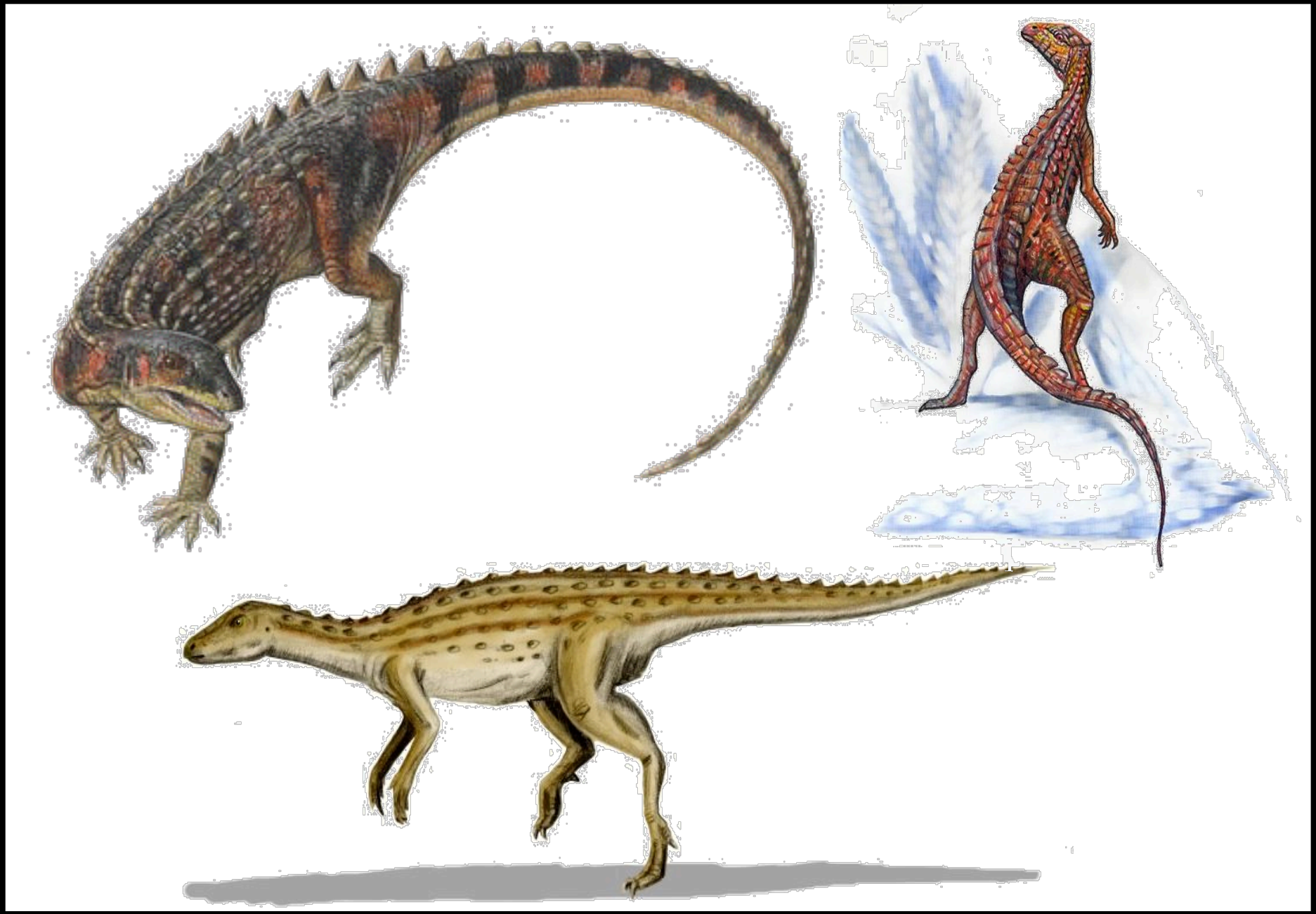


Thyreophora – **stem forms** – Stegosauria / Ankylosauria

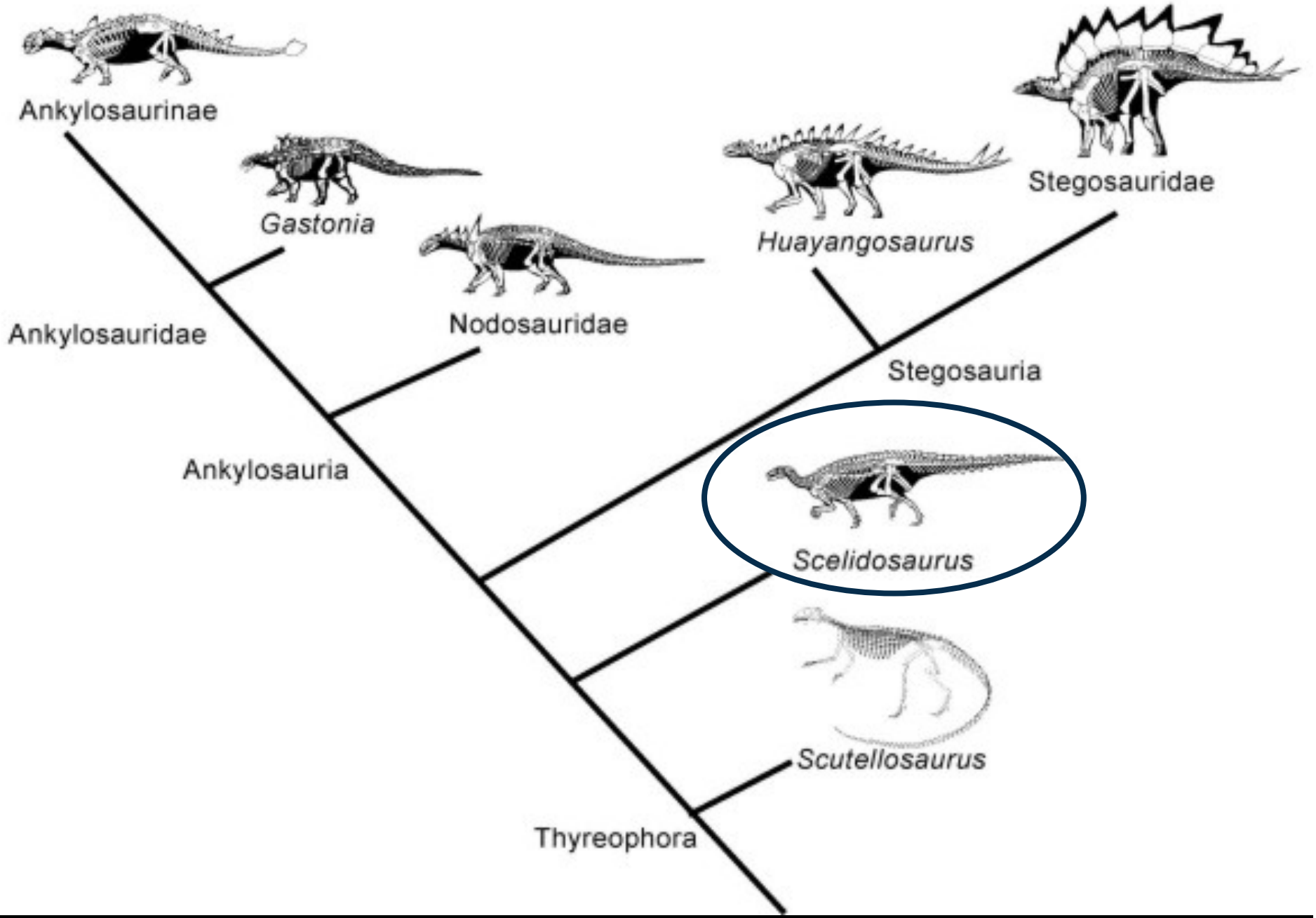
Scutellosaurus

- Relatively small (1 m long), biped
- armored with several hundreds scutes (or osteoderms)
- only two partial skeletons known
- Early Jurassic, North America





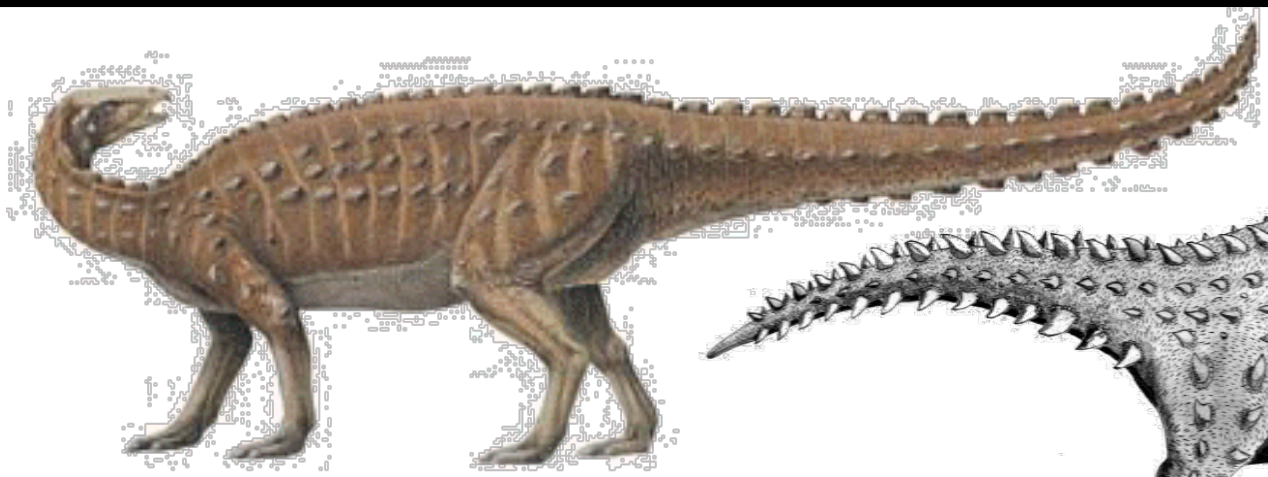
Thyreophora – stem forms – Stegosauria / Ankylosauria

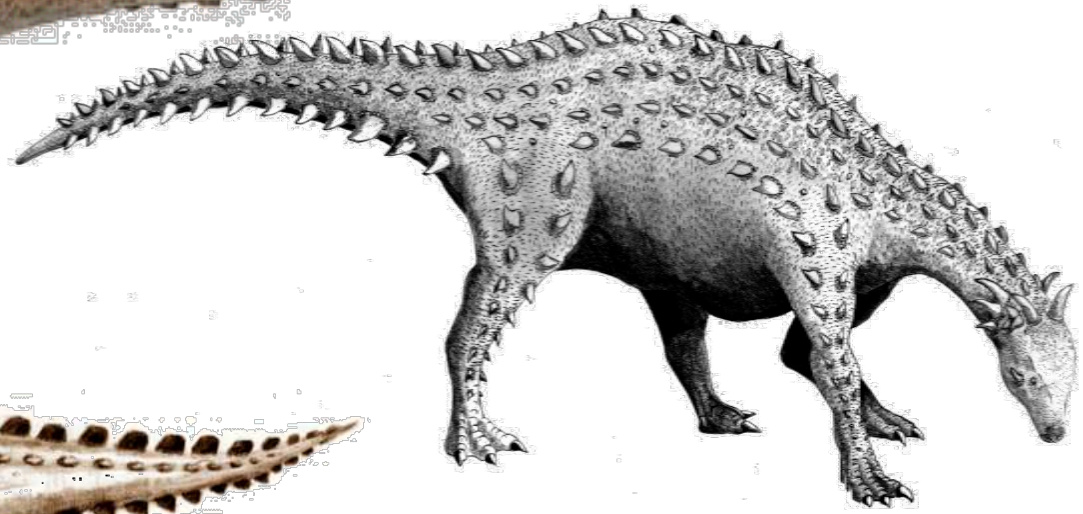


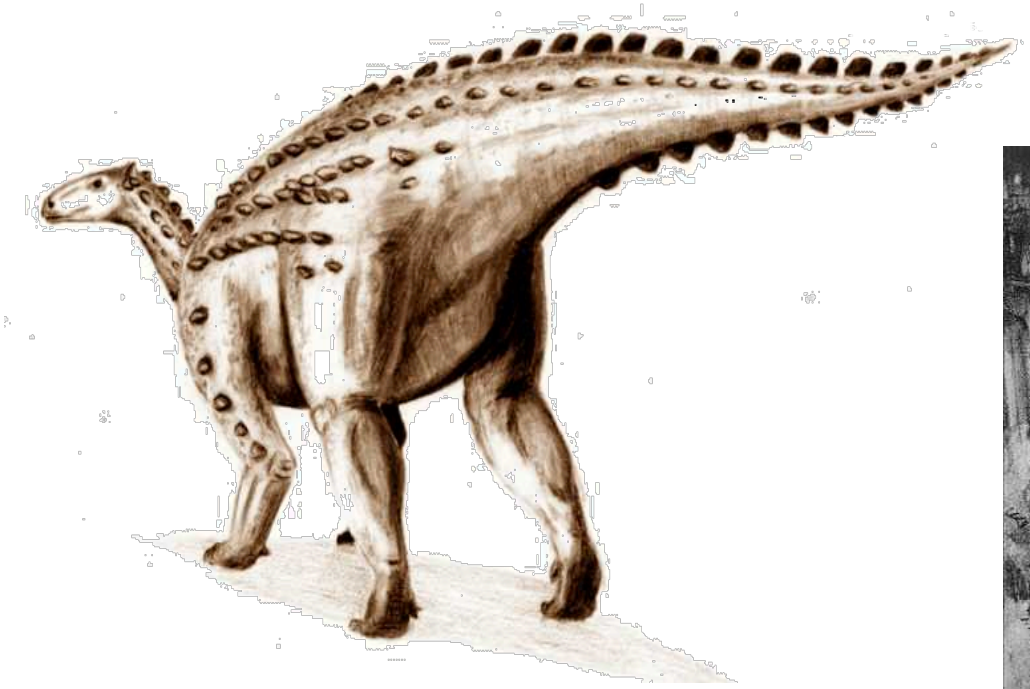
Thyreophora – **stem forms** – Stegosauria / Ankylosauria

Scelidosaurus

- quadruped (ca. 4 m long)
- heavily armored
- Early Jurassic, Europe and North America



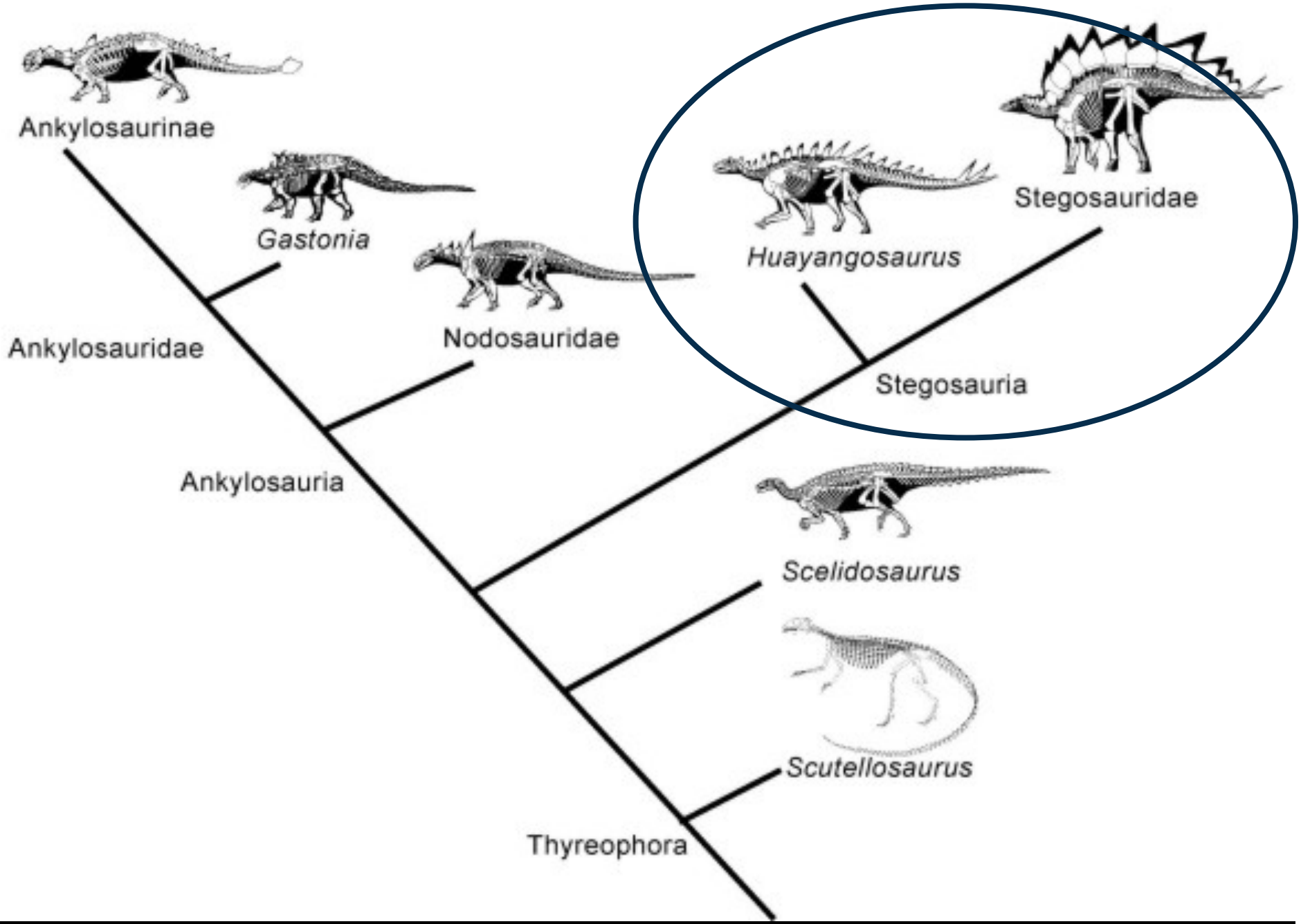




Thyreophora – **stem forms** – Stegosauria / Ankylosauria

Scelidosaurus

Thyreophora – **stem forms** – Stegosauria / Ankylosauria

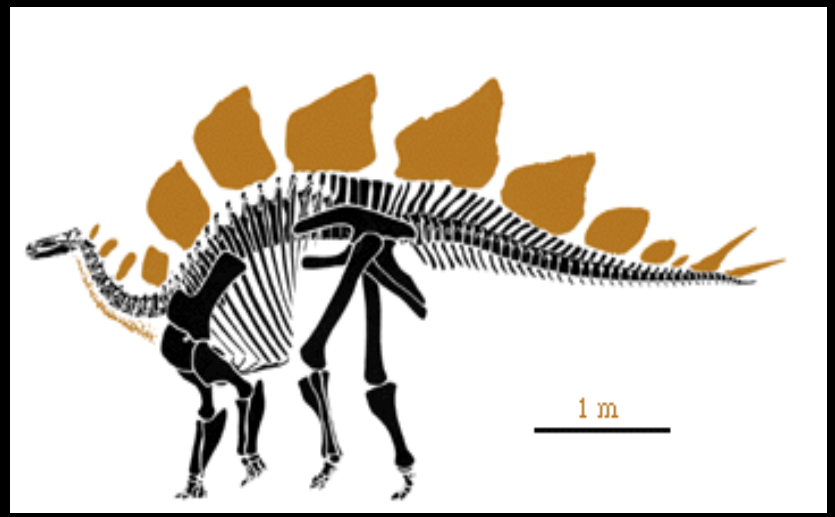


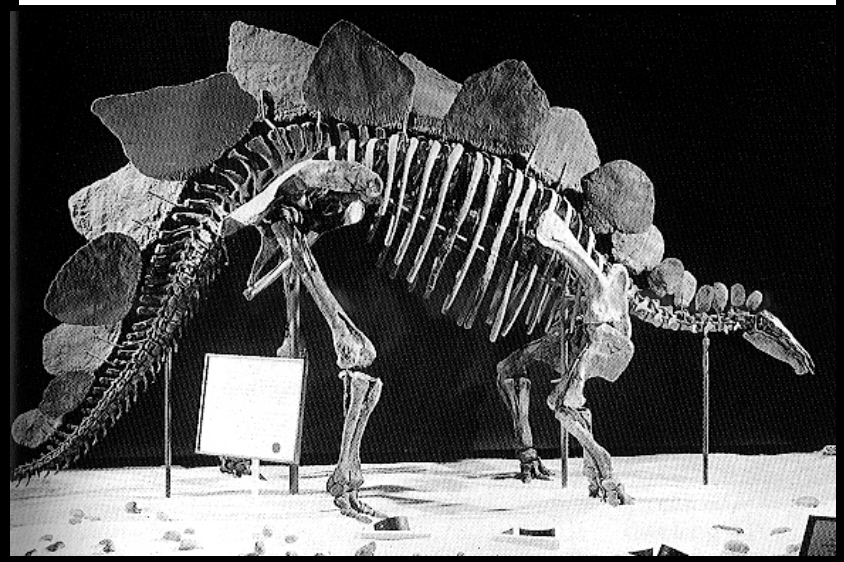
Thyreophora – stem forms – **Stegosauria** / Ankylosauria

Stegosauria (Jurassic to Cretaceous)

(“roof-lizards, plated lizards - taködlor")

- quadrupedal; legs with hoof-like toes
- long, narrow heads and a horn-covered toothless beak
- head relatively small to body size
- weak teeth
- row(s) of osteoderms, which develop into plates and spines along the back and tail
- long neck and tail

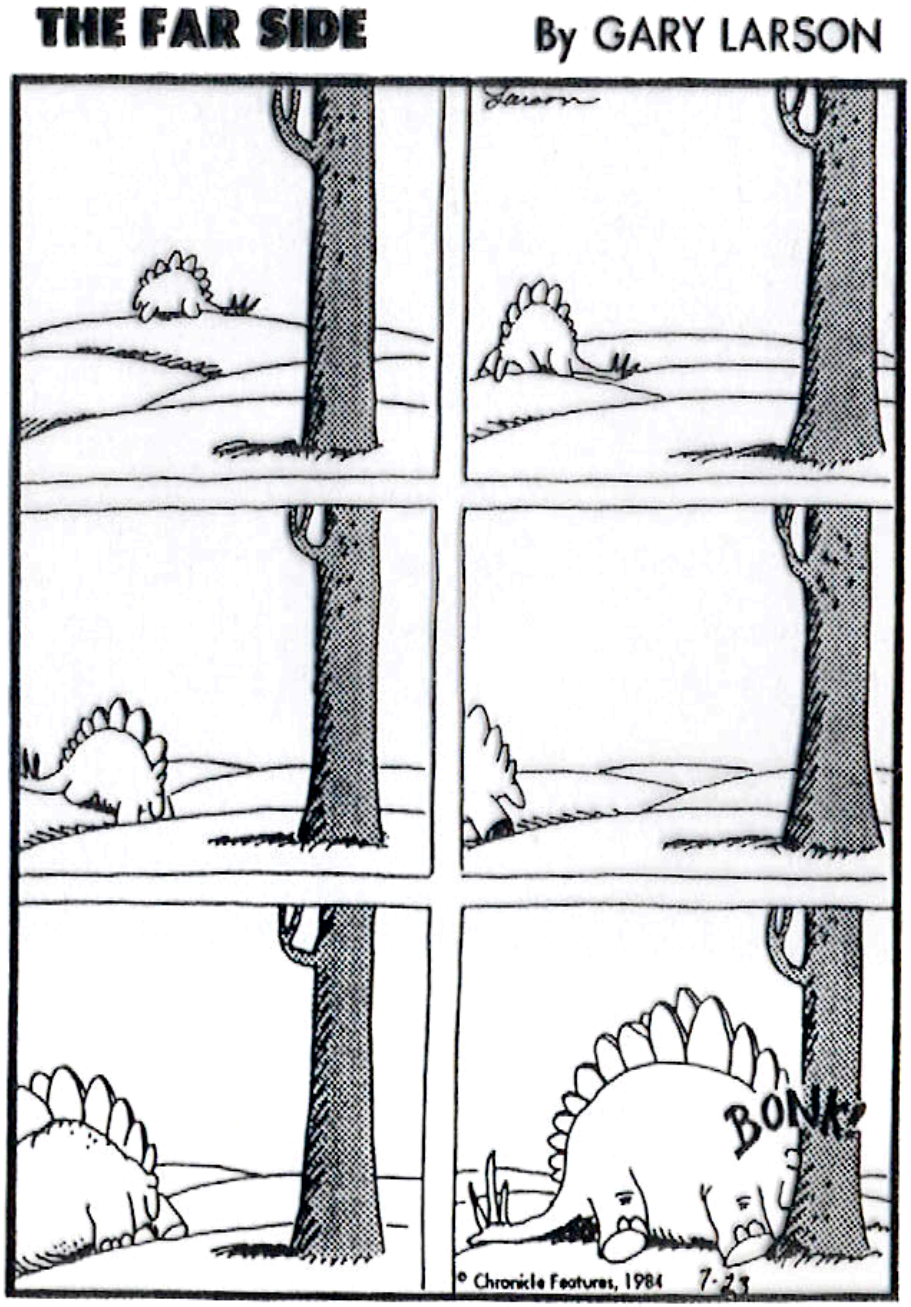




small antorbital fenestrae, toothless predentary bone

Stegosauria

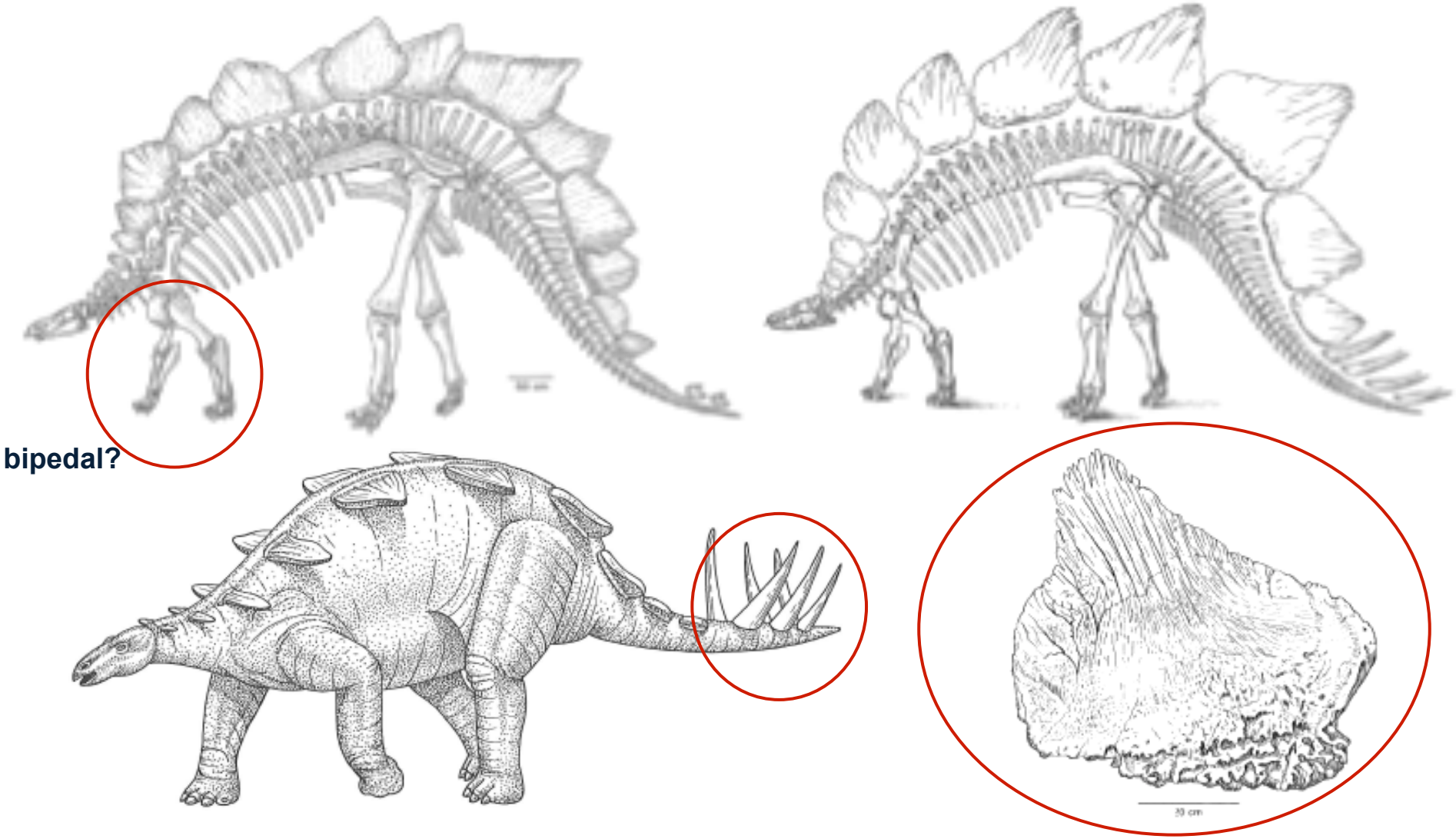
- Appear during the Middle Jurassic
- Diversify during the Middle and Late Jurassic
- Decline during the Cretaceous and go extinct at the end of the Cretaceous (not because of their small brain)



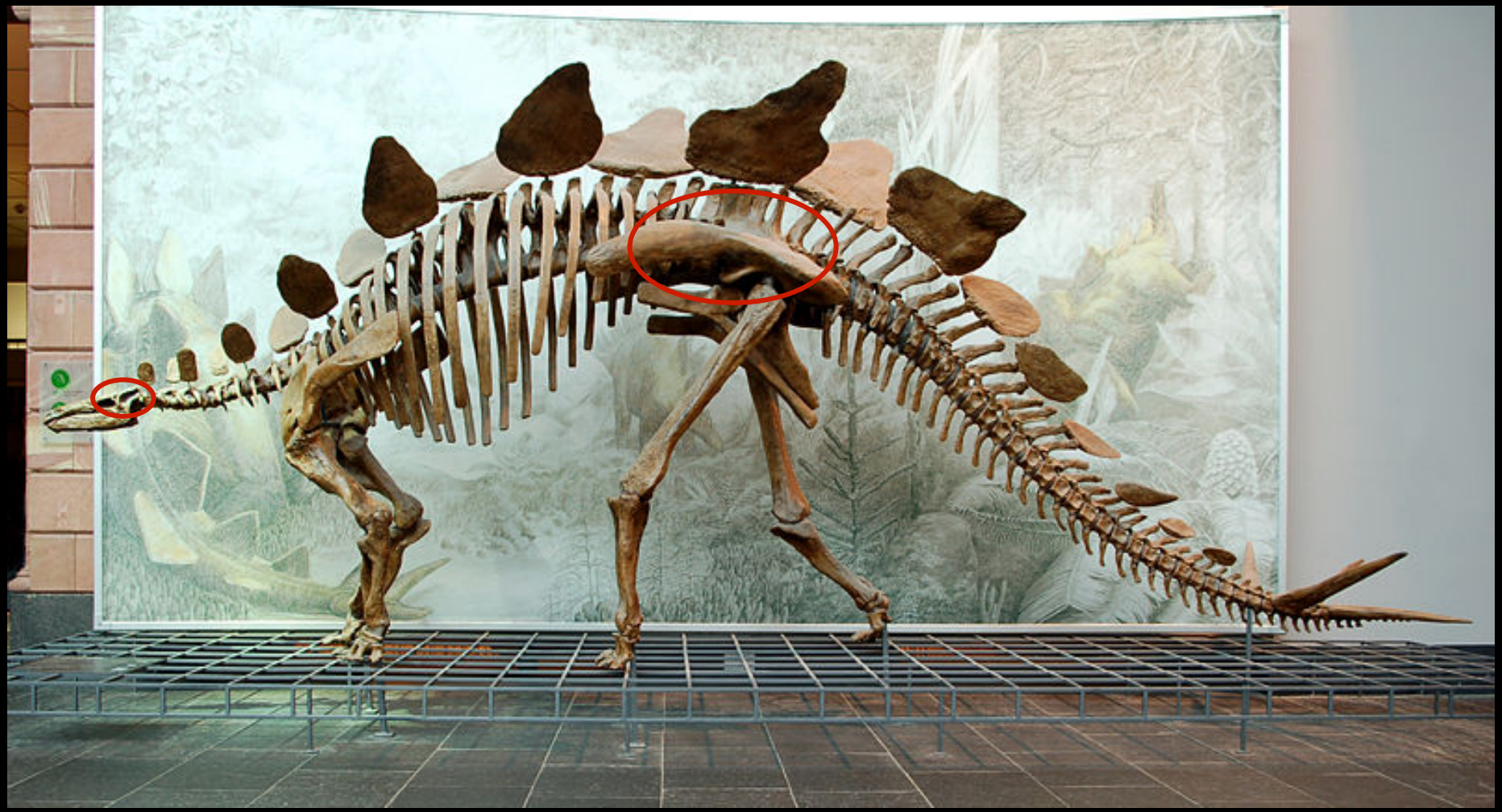
Stegosaurus Marsh, 1879

the best know, and also most famous stegosaur

... and the trouble with the plates (osteoderms)



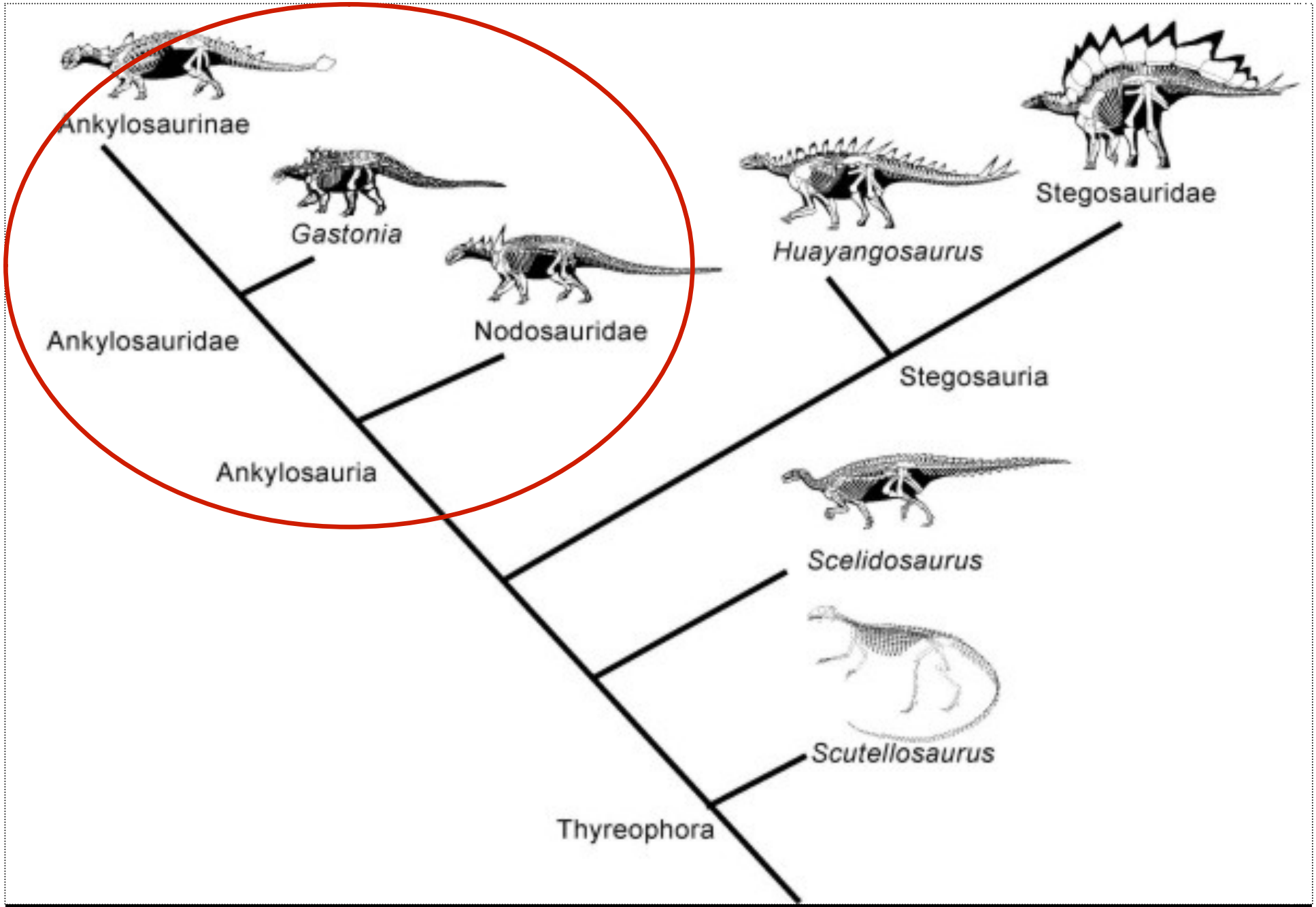
Stegosaurus *and the second brain*



large canal in the spinal cord (20 times larger than the brain)
→ glycogen body ??

Ode to *Stegosaurus* by B. L. Taylor (1912)

"[…]
If one brain found the pressure strong
It passed a few ideas along.
If something slipped his forward mind
'Twas rescued by the one behind.
And if in error he was caught
He had a saving afterthought.
[…]"

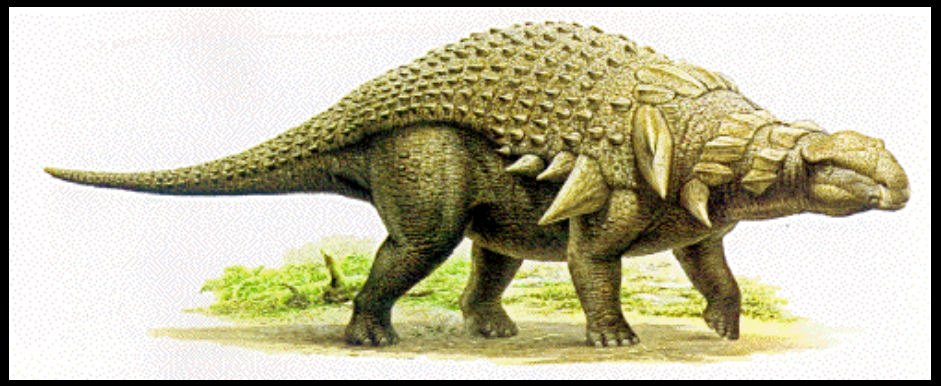


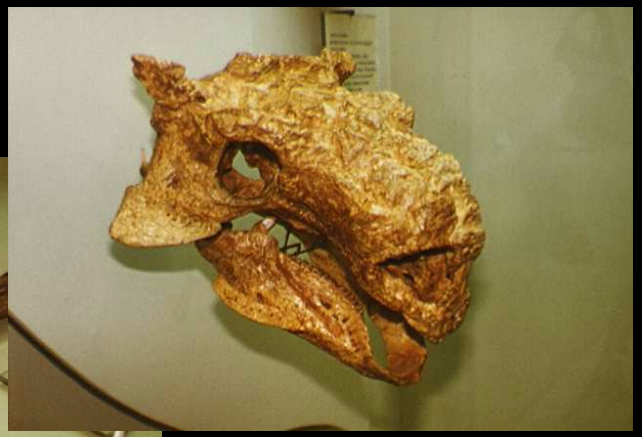
Thyreophora – stem forms – Stegosauria / **Ankylosauria**

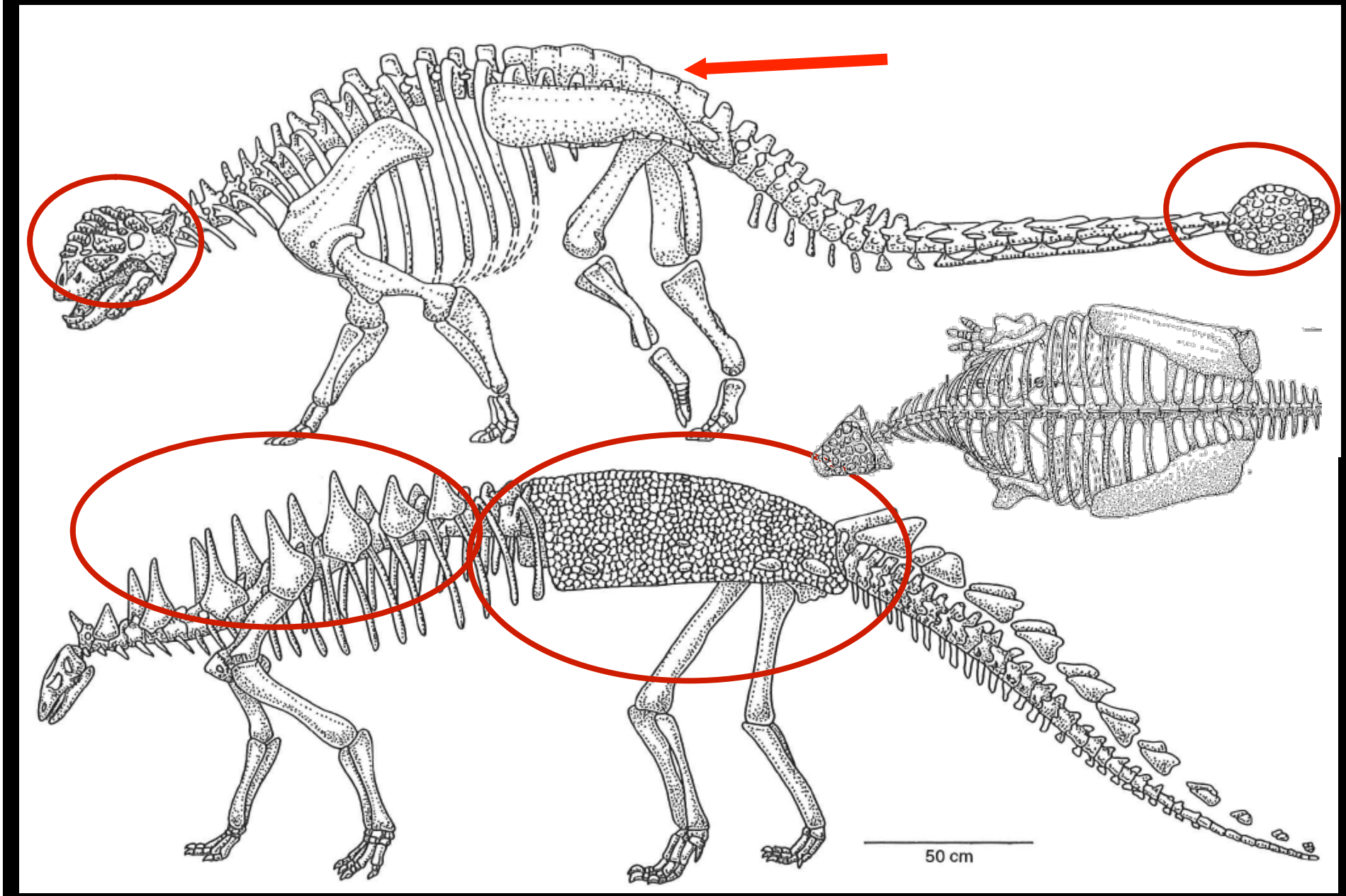
Ankylosauria

("fused lizards" – "*pansardinosaurier*")

- herbivorous
- quadruped – up to 9 m
- long body with relatively short legs
- heavily armored with osteoderms
- cranial ornamentation, reduction of cranial fenestrae
- wide body
- weak jaws with small teeth
- Often with club at the end of tail
- typical for the Cretaceous (since Late Jurassic)

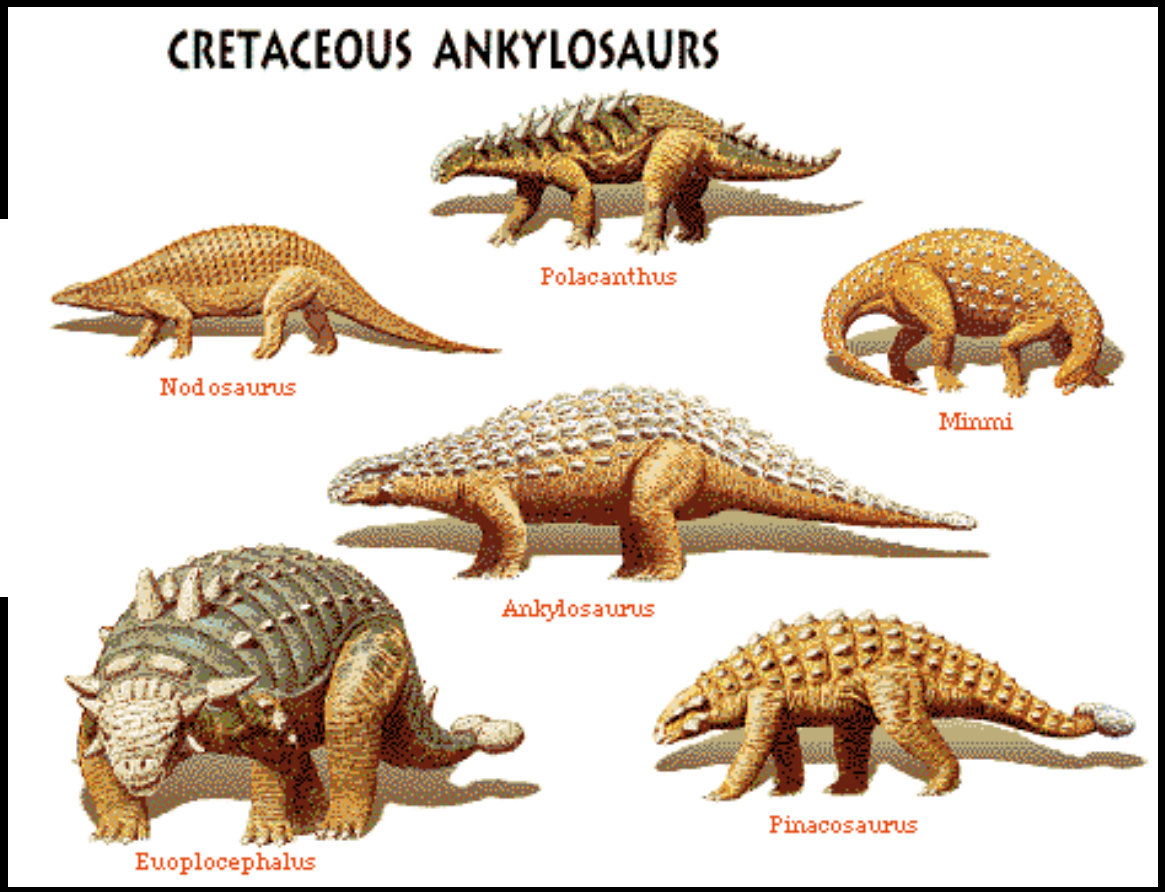






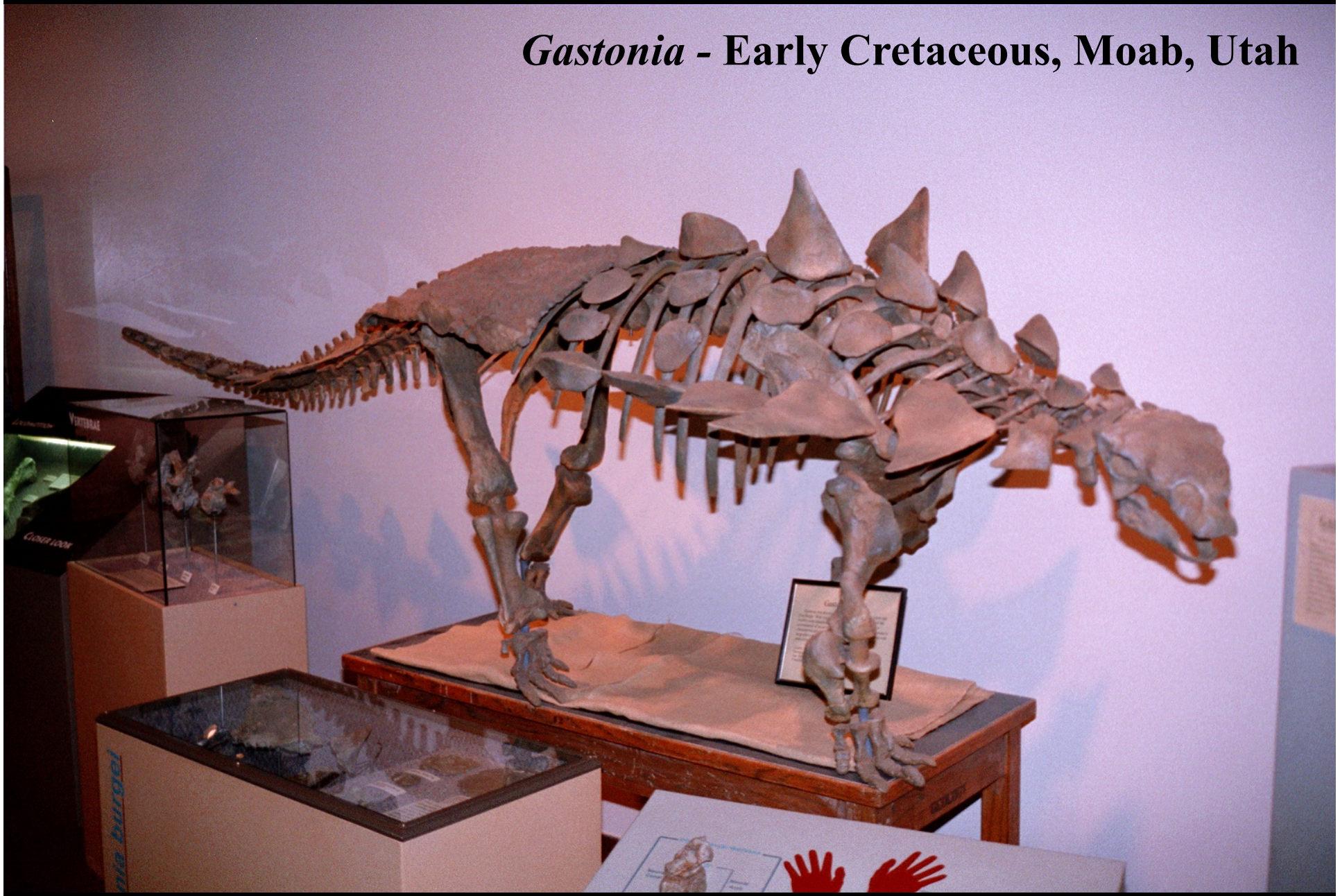
Thyreophora – stem forms – Stegosauria / **Ankylosauria**

Ankylosauria and their armor



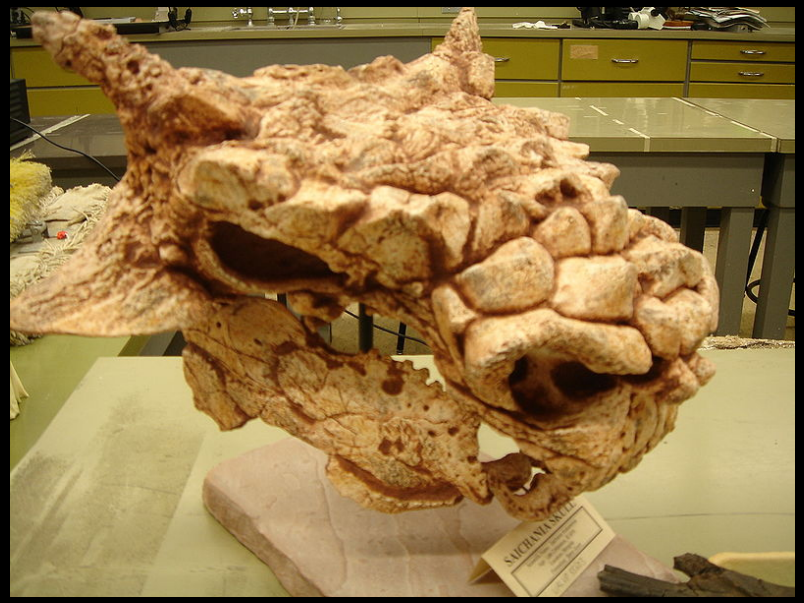
- armor is rarely preserved *in situ*
- dermal plates most likely arranged in rows (longitudinally and/or transversely)

Thyreophora – stem forms – Stegosauria / **Ankylosauria**



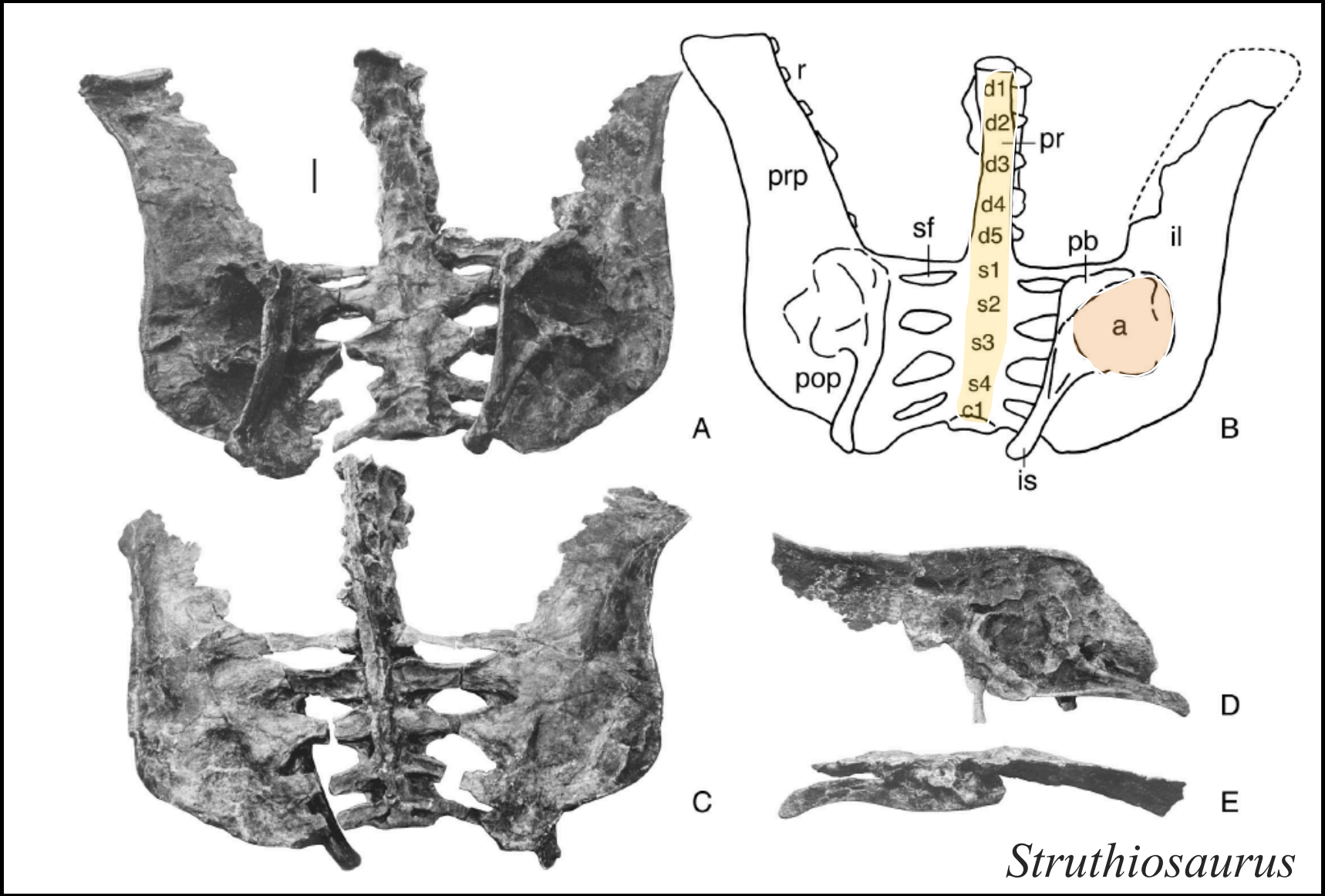
Thyreophora – stem forms – Stegosauria / **Ankylosauria**

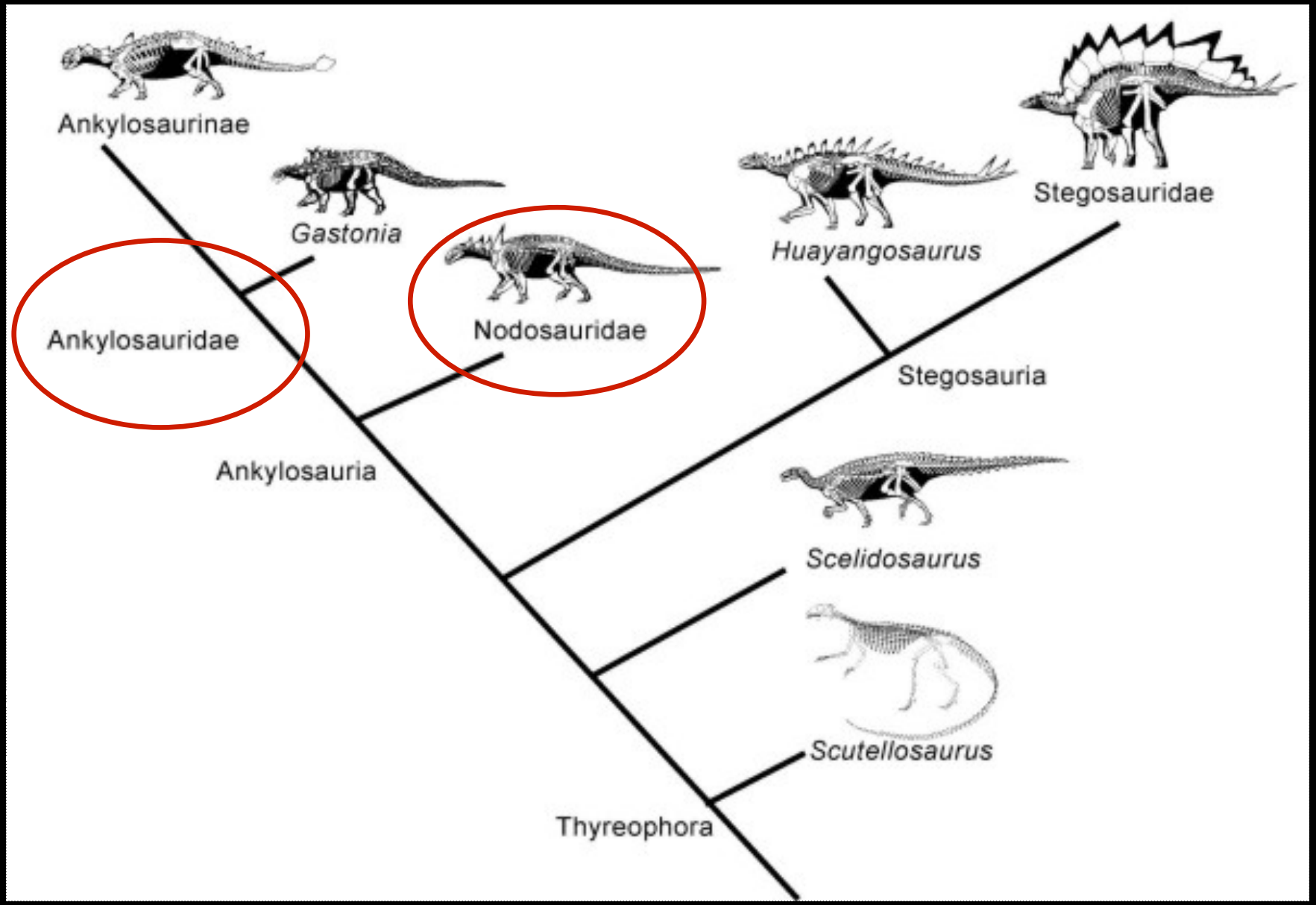
Reduction of cranial fenestrae



Thyreophora – stem forms – Stegosauria / **Ankylosauria**

Ankylosaur synsacrum





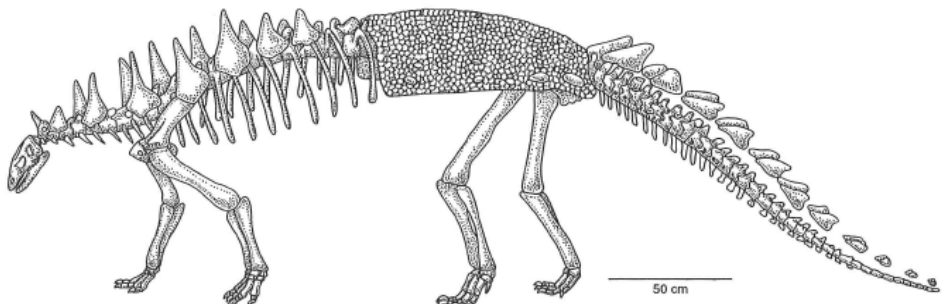
Thyreophora – stem forms – Stegosauria / **Ankylosauria**

Nodosauridae

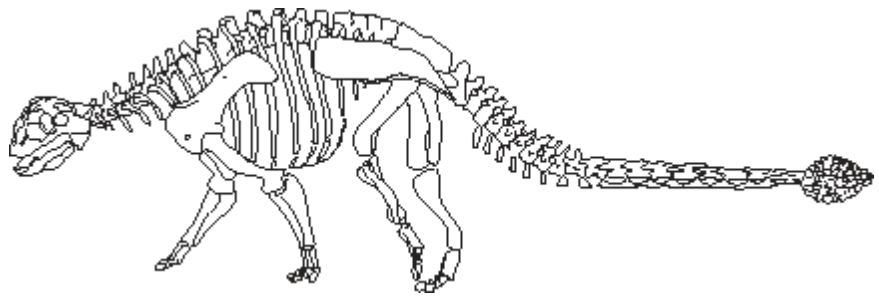
- narrow skull without excessive armor or horns
- presence of spines as armor
- lack of tail cub
- open lateral temporal fenestrae

Ankylosauridae

- wide armored head with horns
- few or no spines as armor
- presence of tail cub
- closed fenestrae (i.e., covered with bony armor)



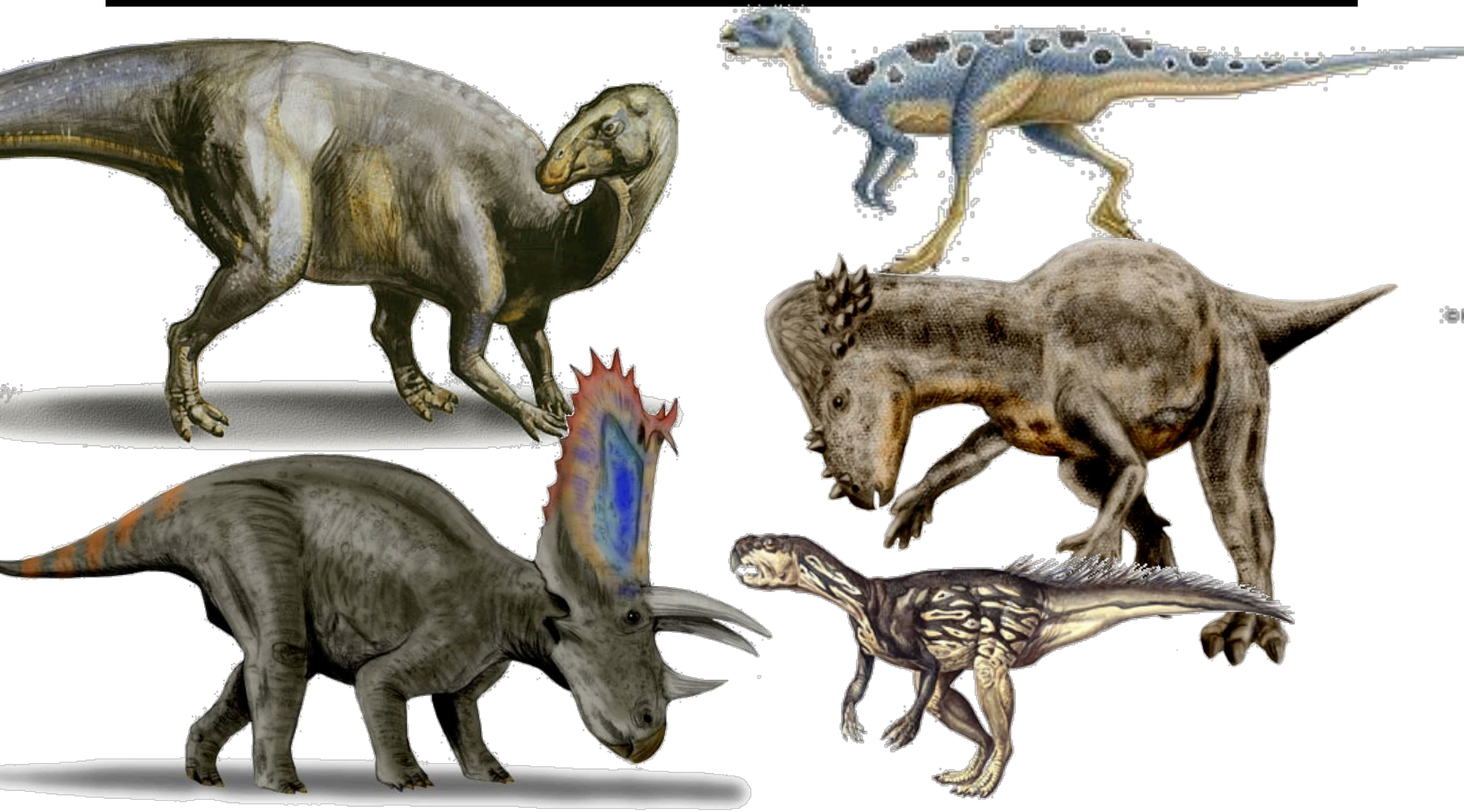
Polacanthus



Euoplocephalus

Euoplocephalus

Ornitischia – group 2

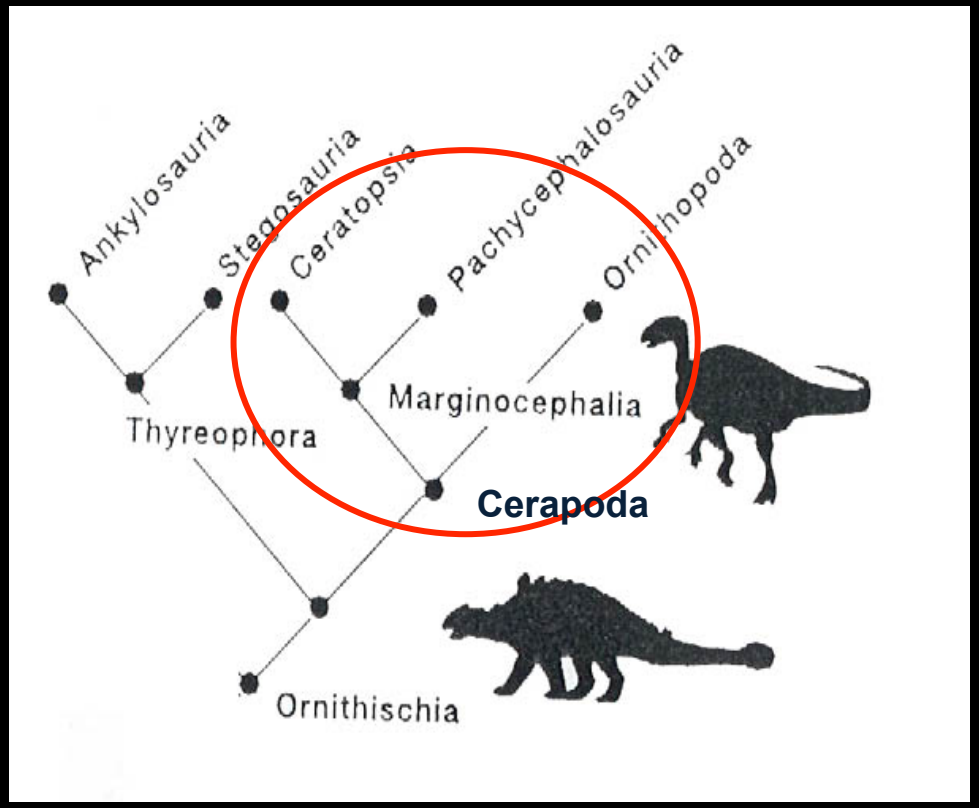


ORNITHISCHIA

Cerapoda (“horned feet")

shared character:

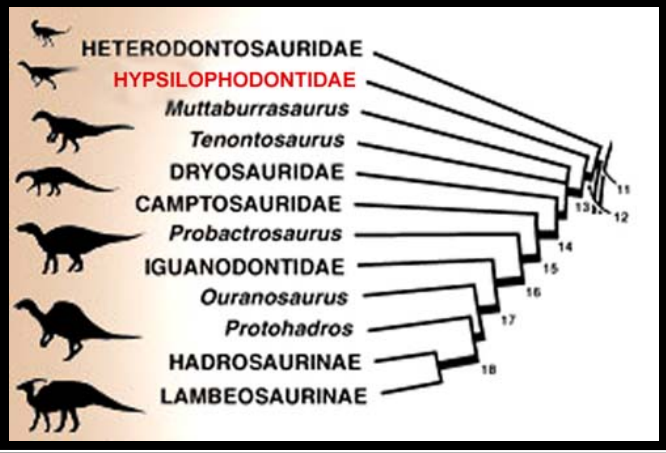
→ thicker layer of enamel on the inside of their lower teeth

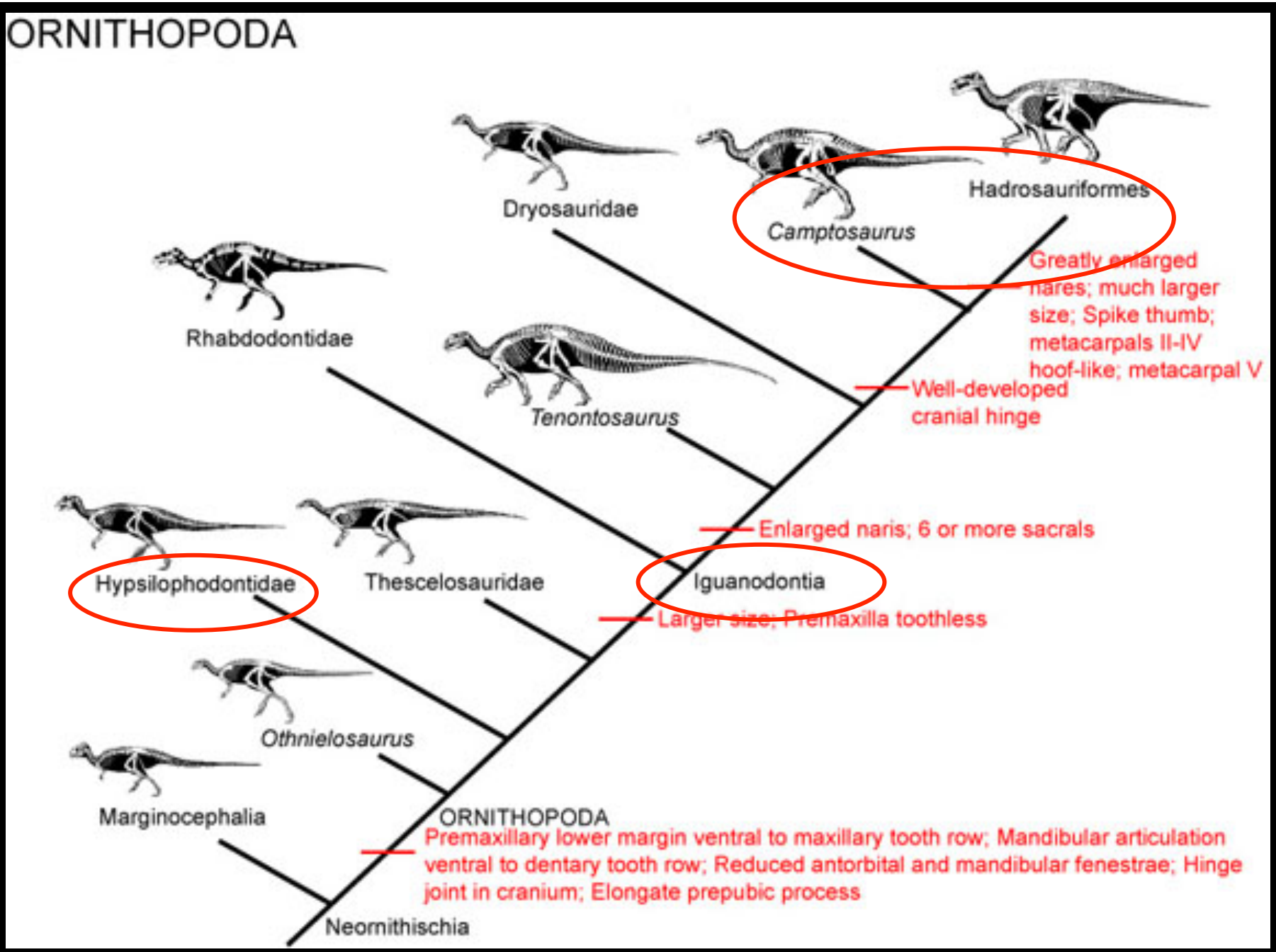


Cerapoda – Marginocephalia + Ornithopoda

Ornithopoda - (“bird feet”)

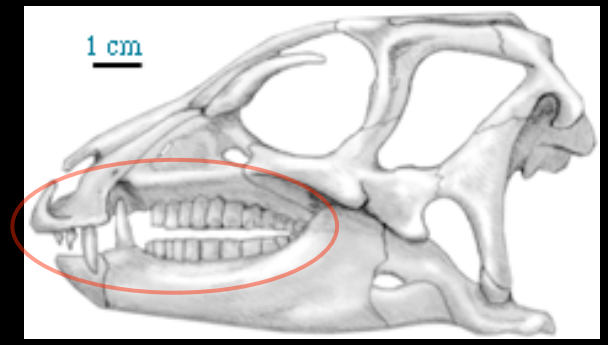
- bipedal or quadrupedial
- no body armor
- since early Jurassic
- diverse group
  - heterodontosaurids
  - iguanodontids
  - duck-billed dinosaurs
- ventrally offset tooth rows
- low located lower jaw joint



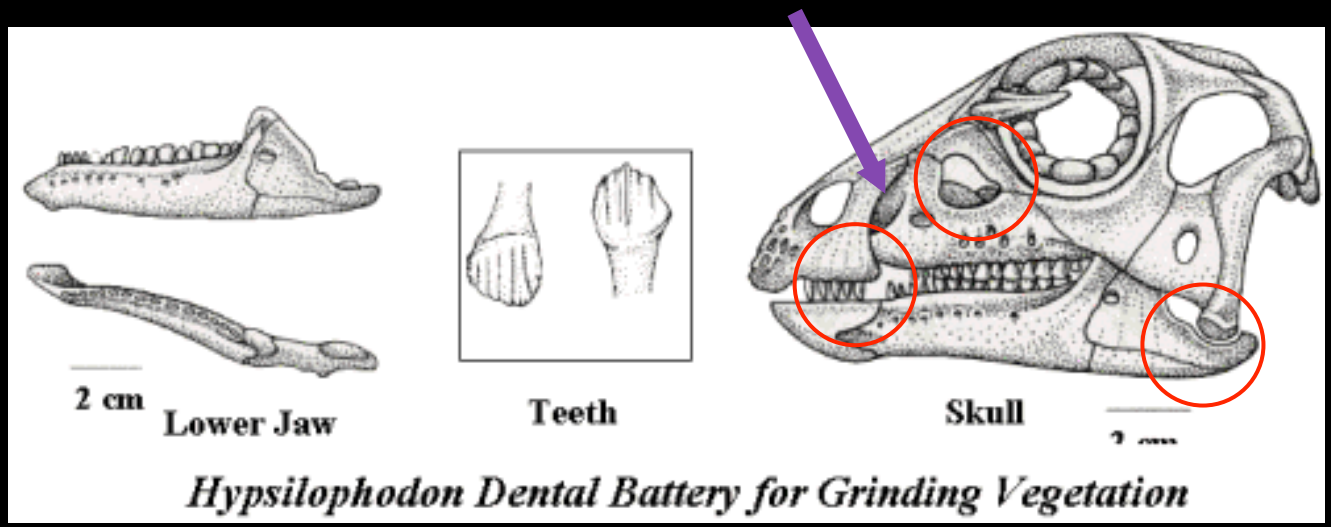


Cerapoda – Ornithopoda – Heterodontosauridae - Iguanodontidae - Hadrosauridae

Hypsilophodonts



- Mostly small (1-3 m long), obligate bipeds
- Probably fast runners
- Earliest forms in Middle Jurassic, persist until end of Cretaceous
- Most famous representative is the hypsilophodontid ***Hypsilophodon***

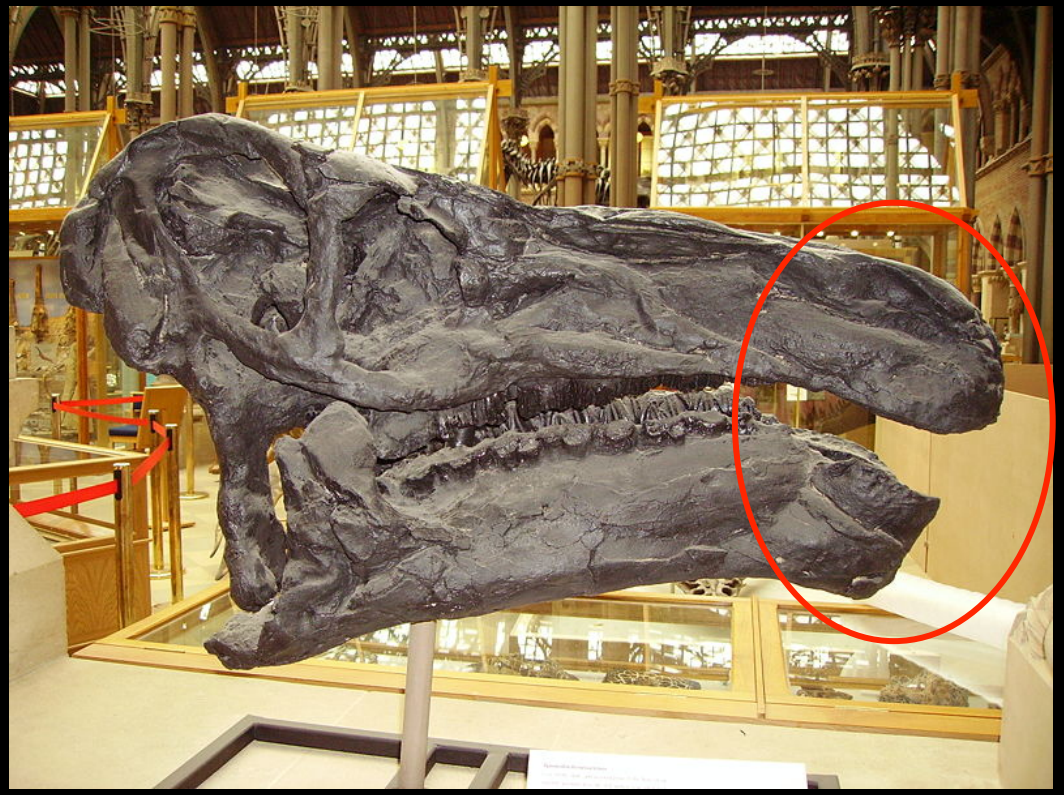


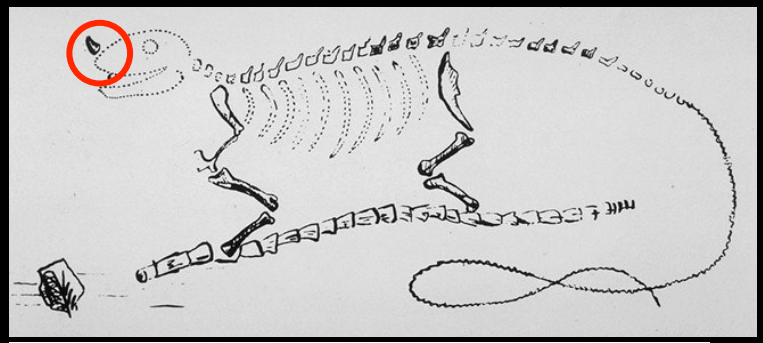
Hypsilophodon Dental Battery for Grinding Vegetation

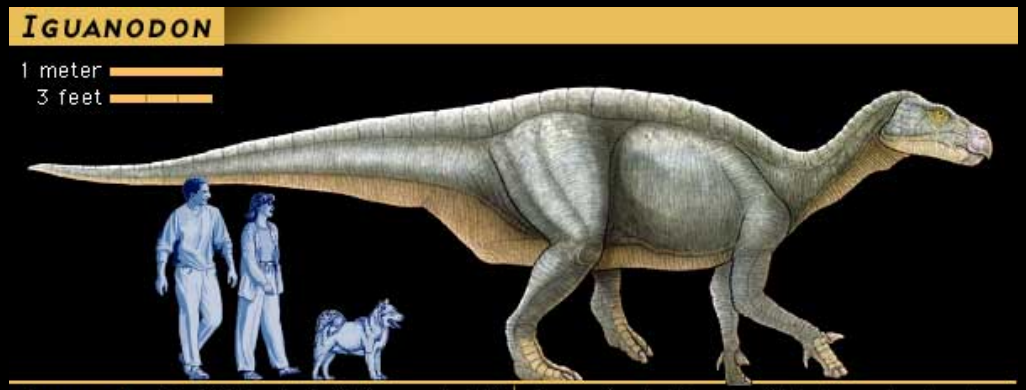
special way of grinding food → probably a key to their success

Iguanodontidae

- Almost all are **larger** than "hypsilophodonts"
- strong forelimbs, and were probably **facultative bipeds**
    - bipedal when running and feeding on trees
    - quadrupedal while walking and browsing on low vegetation
- Characterized by **loss of premaxillary teeth**
- **spike-like thumb** present in many iguanodontids
- Since Middle Jurassic, but become more common in Late Jurassic and Early Cretaceous
- ***Camptosaurus*** (Late Jurassic, North America)
  Tenontosaurus (Early Cretaceous, North America)
  and ***Iguanodon*** (Early Cretaceous, Europe)

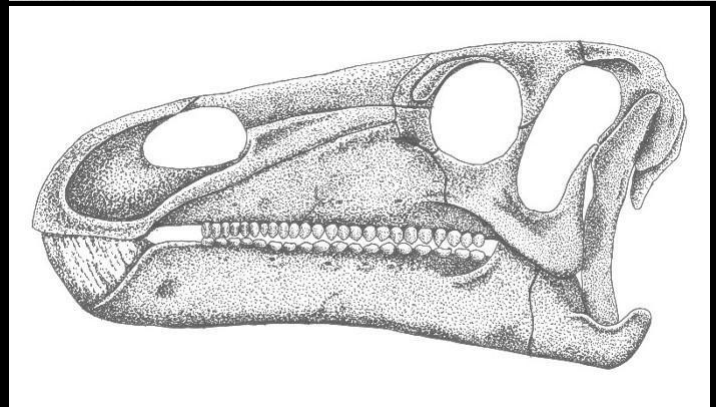






Iguanodon (ig-WHA-noh-don) "iguana tooth"
Period: Late Jurassic and Early Cretaceous
Length: 30 feet (9 meters)
Location: Africa, Asia, Australia, Europe, and North America

A massive herbivore with a horny beak and cheek teeth for grinding vegetation. Its hands had distinctive hoofed fingers and spiked thumbs.



Hadrosauridae - ”duck-billed dinosaurs”

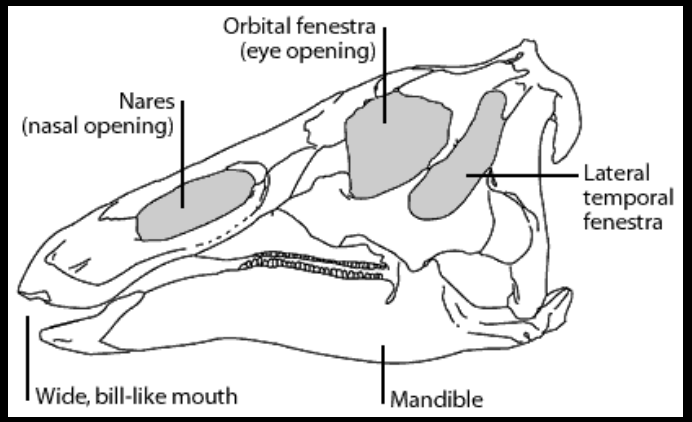
- Extremely common in Late Cretaceous of North America, also known from Asia, Europe, South America
- one of the best known dinosaur group (from eggs through adults)
- lived in herds and had nesting colonies

- **End of snout flares outward** to form "duck bill"
  - increase in number of teeth
    → Teeth organized into **dental battery**
    a continuous grinding surface
    → most complex and sophisticated chewing of any reptile
  - **Manual digit I lost**
  - **Metacarpals II-IV very long and slender**:
  - probably quadruped most of the time

Cerapoda – Ornithopoda – Hypsilophodonts - Iguanodontidae - **Hadrosauridae**

Cerapoda – Ornithopoda – Hypsilophodonts - Iguanodontidae - **Hadrosauridae**

Hadrosauridae - ”duck-billed dinosaurs”



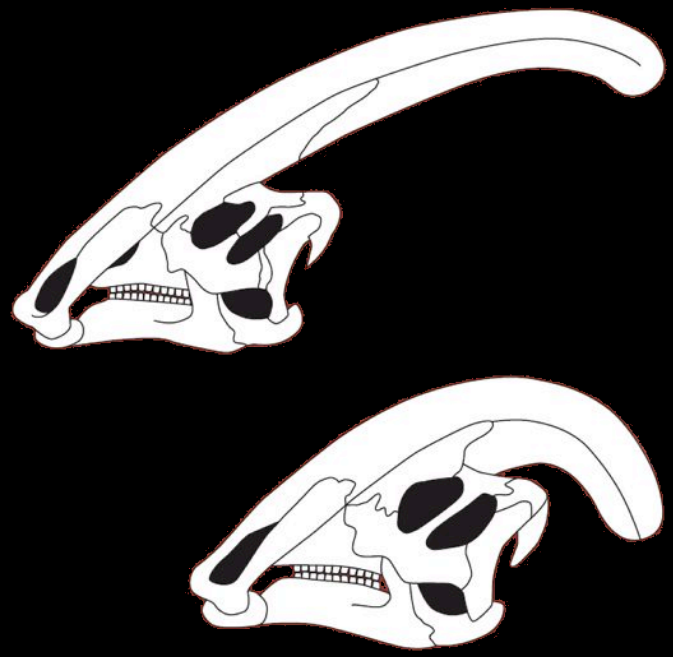
Two major clades:

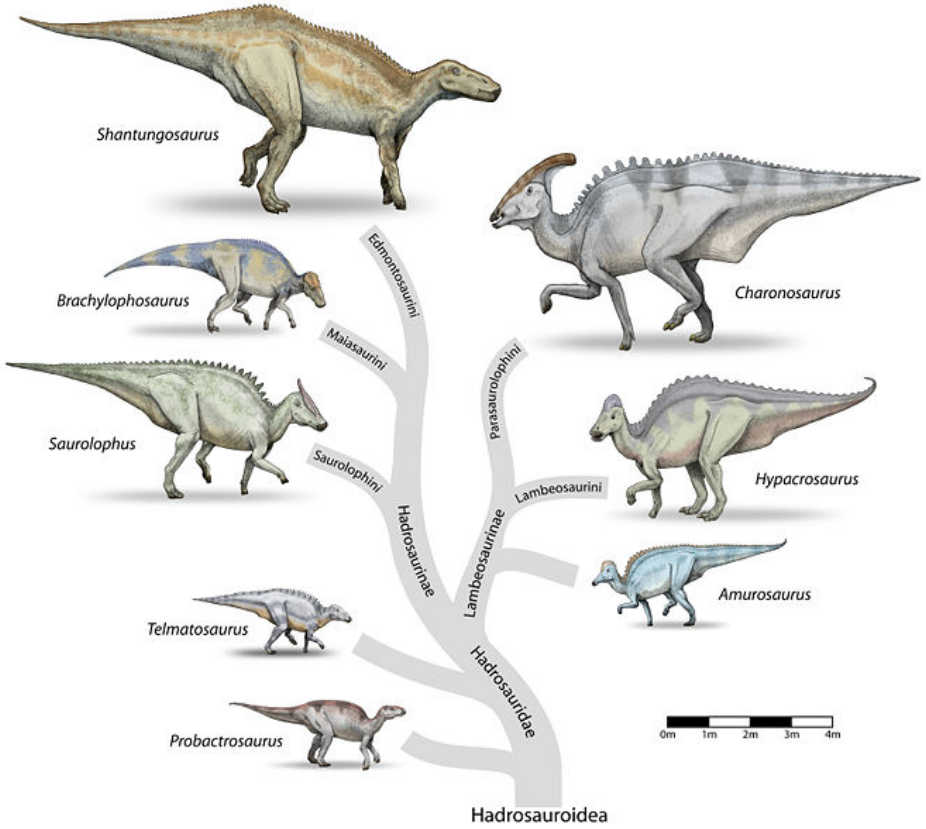
Hadrosaurinae

→ **enlarged external nares**
and **broader snouts**

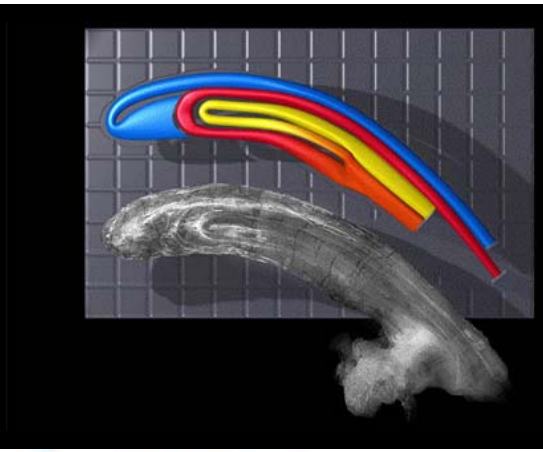
Lambeosaurinae

→ **hollow crests on top of head**

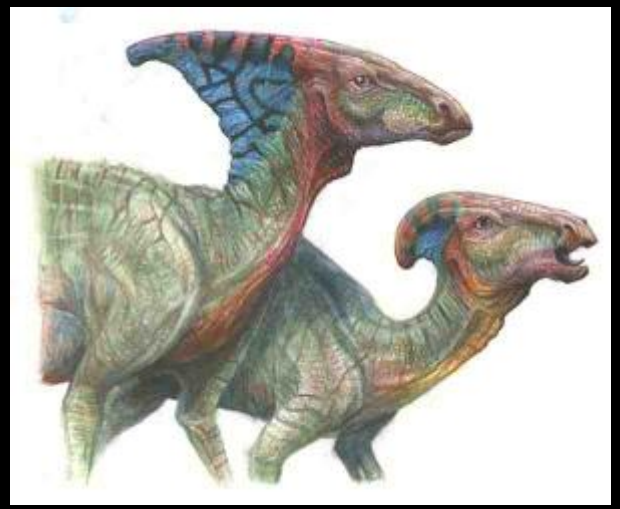




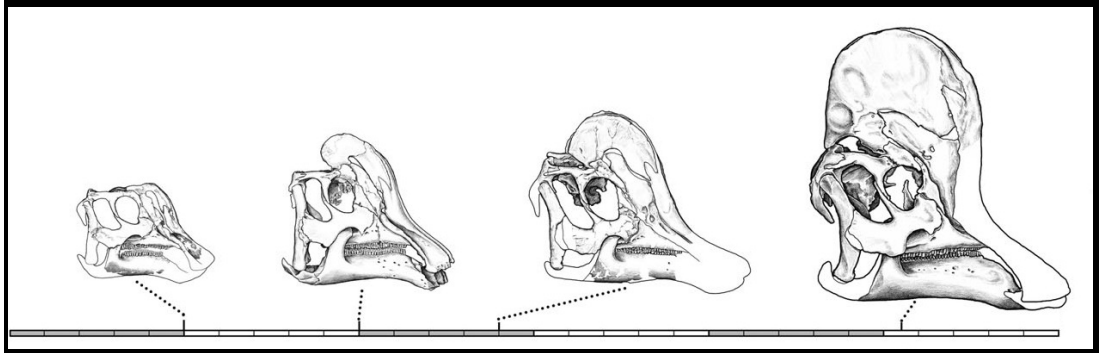
Possible uses of lambeosaurine crests?

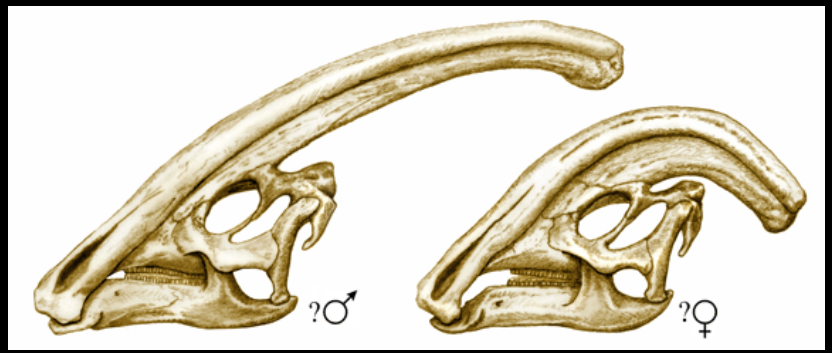


- Increase surface area for smelling sensors
- Sound generation
- Visual display
- Trapping moisture in exhaling breath to keep lungs from drying out
- Or a combination



- are different in every species
- probably display also sexual dimorphism





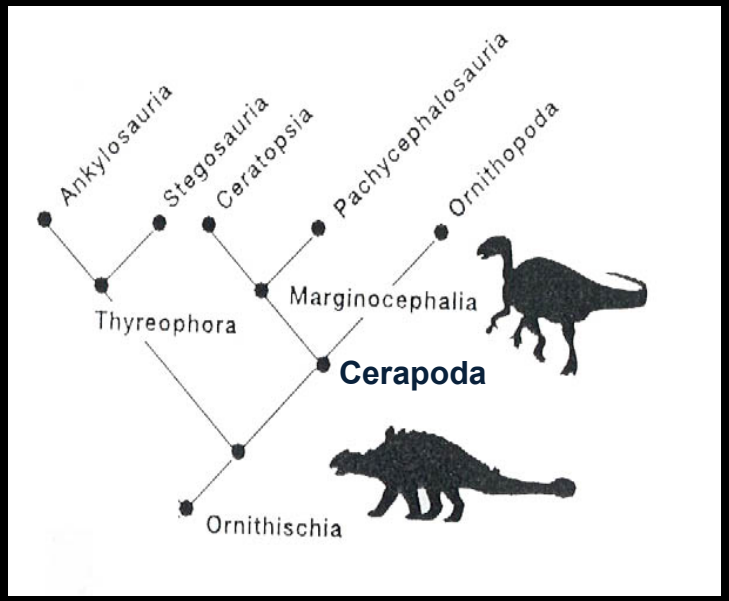
How to speak dinosaur

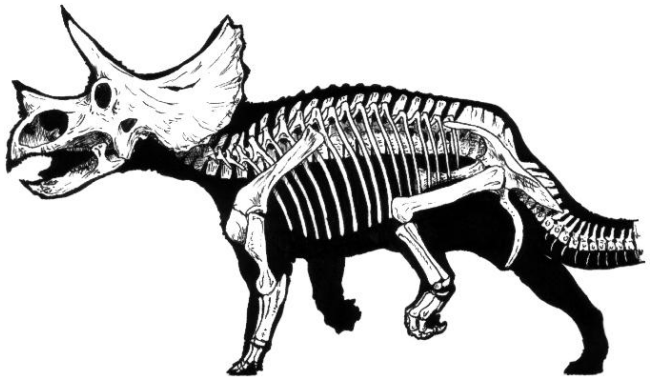
- (http://www.courtney-brown.net/)
- http://prix2015.aec.at/prixwinner/15549/

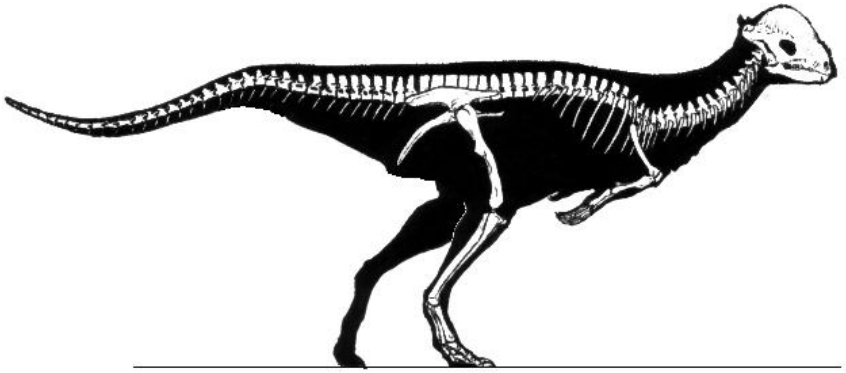
ORNITHISCHIA

Marginocephalia (“fringed heads” - “*kragförsedda*”)

- all herbivores
- bi- or quadrupedal
- characterized by a bony ridge or frill on the back of the skull
- evolved during the Jurassic
- especially Upper Cretaceous
- Ceratopsia + Pachycephalosauria



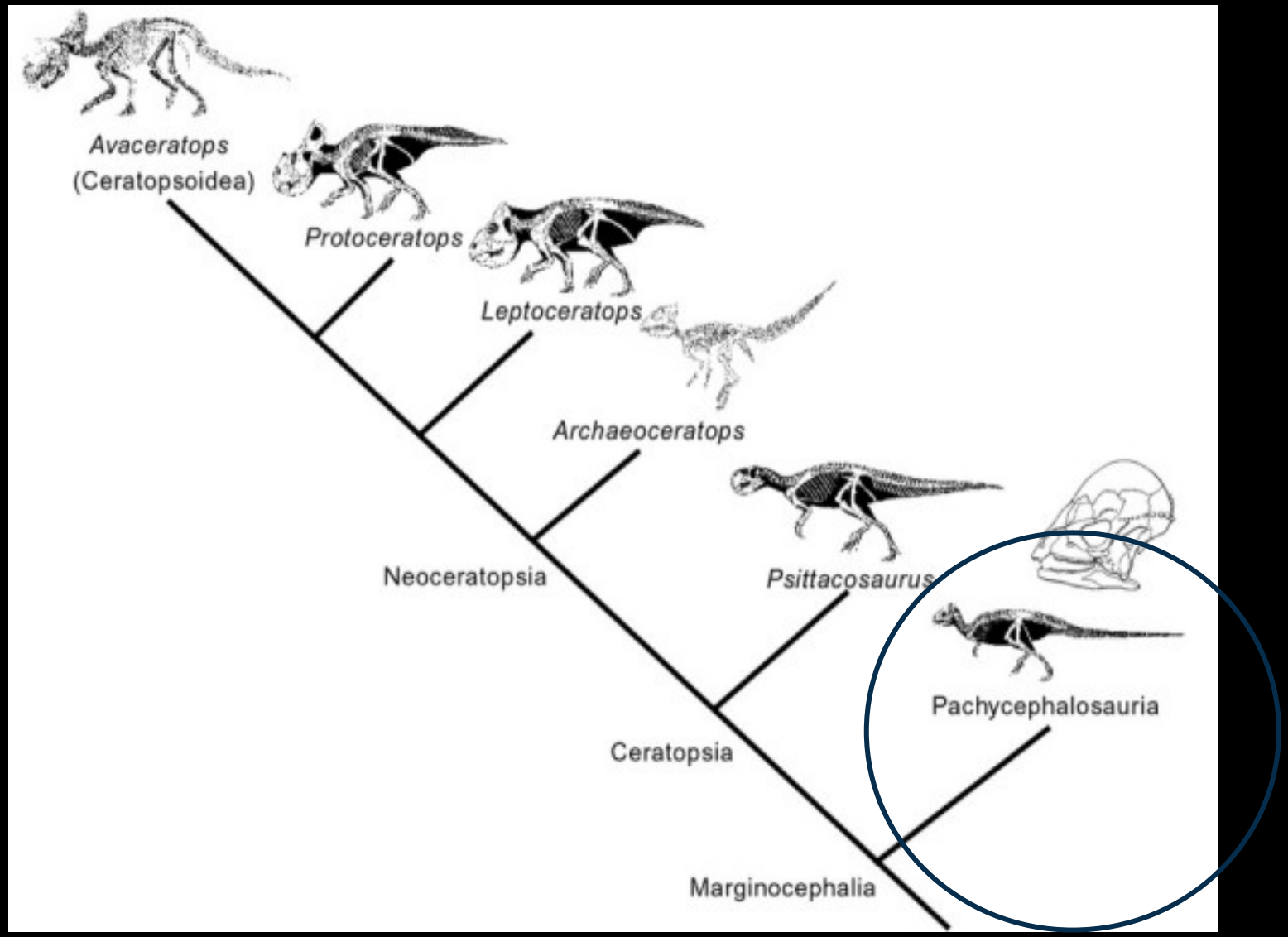




The five dinosaur faunas

		Fauna	Theropoda	Sauropodomorpha	Ornithopoda	Thyreophora	Marginocephalia
Cretaceous	Late	5	Carnosauria: (Tyrannosauridae) Coelurosauria: (Ornithomimosauridae) (Dromaeosauridae) (Oviraptorosauridae)		Hadrosauridae	Ankylosauria: Ankylosauridae	Neoceratopsians: Protoceratopsidae Ceratopsidae Pachycephalosauria
Cretaceous	Early	4		Sauropoda: Small Sauropods (Titanosaurids)	Large Ornithopods: Iguanodontidae	Ankylosauria: Nodosauridae Stegosauria: A few Stegosaurids	Psittacosaurs
Jurassic	Late	3	Carnosauria: (Allosauridae)	Sauropoda: Large Sauropods	Medium Ornithopods: Hypsolophodontidae Iguanodontidae	Stegosauria: Large Stegosaurids	
Jurassic	Middle / Early	2		Sauropoda: Small Sauropods (Cetiosaurids)	Small Ornithopods: Hypsilophodontidae	Stegosauria: Small Stegosaurids Primitive Thyreophorans	
Triassic	Late	1	Ceratosauria Also Primitive Saurischians	Prosauropods	Primitive Ornithischians		

Marginocephalia: evolve during the Middle Jurassic, but become common during the Cretaceous



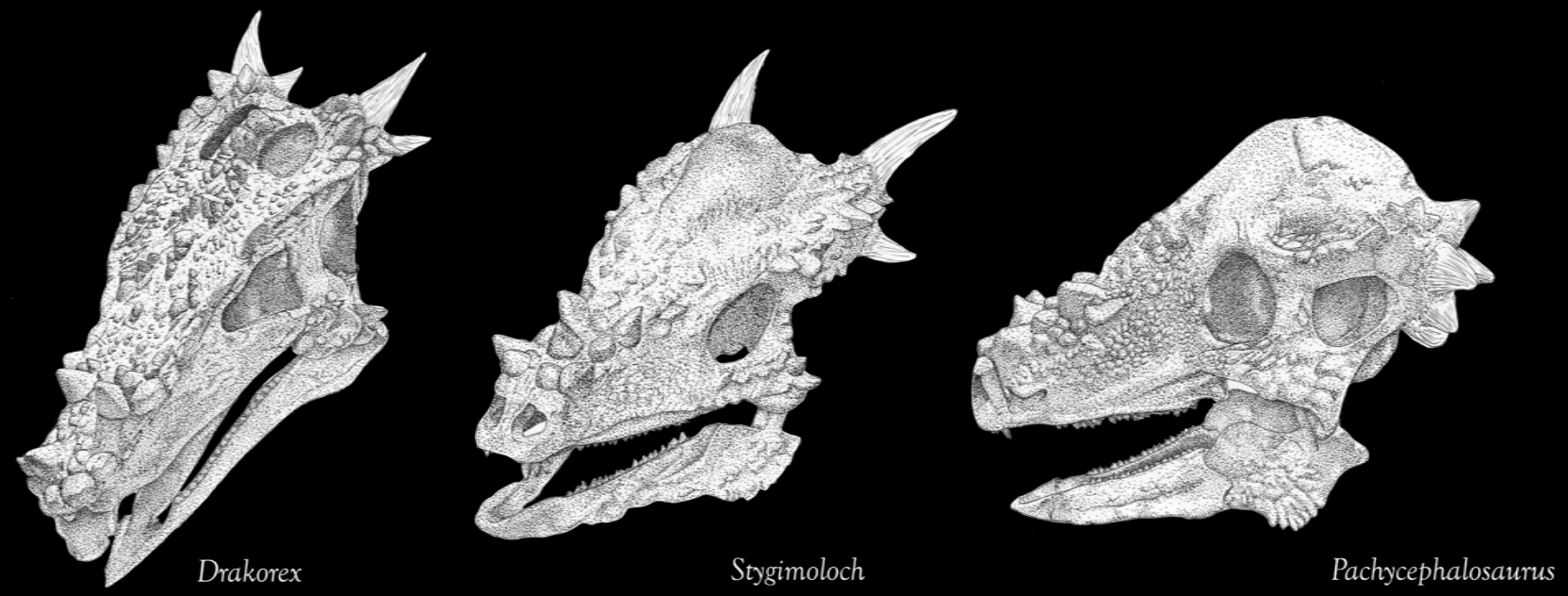
Cerapoda – Marginocephalia – **Pachycephalosauria** – Ceratopsia

Pachycephalosauria

("thick headed lizards"- "*benskallar*")

- Since Cretaceous (esp. North America & Asia)
- massive, thick skull roof (fusing and thickening of frontal & parietal bones)

→ typically no supratemporal openings

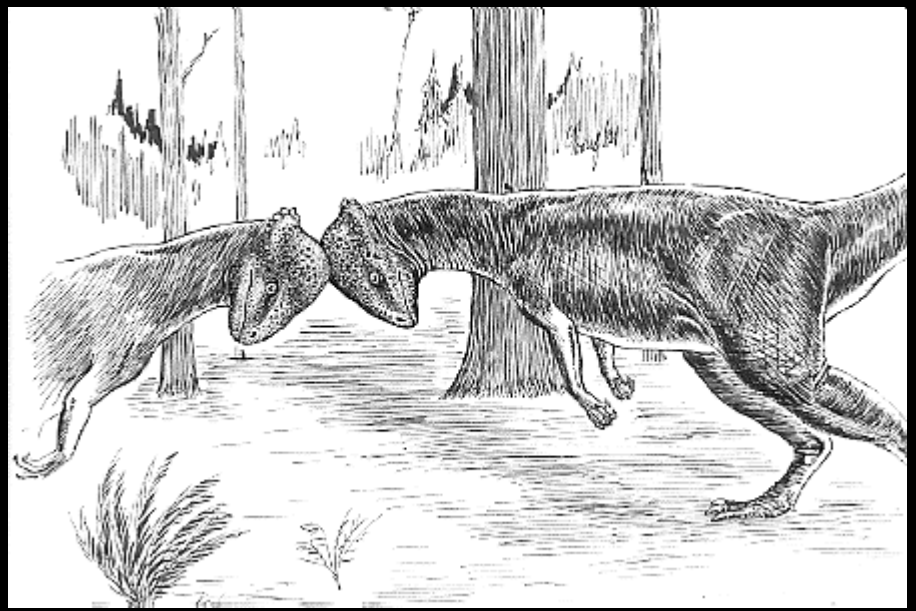


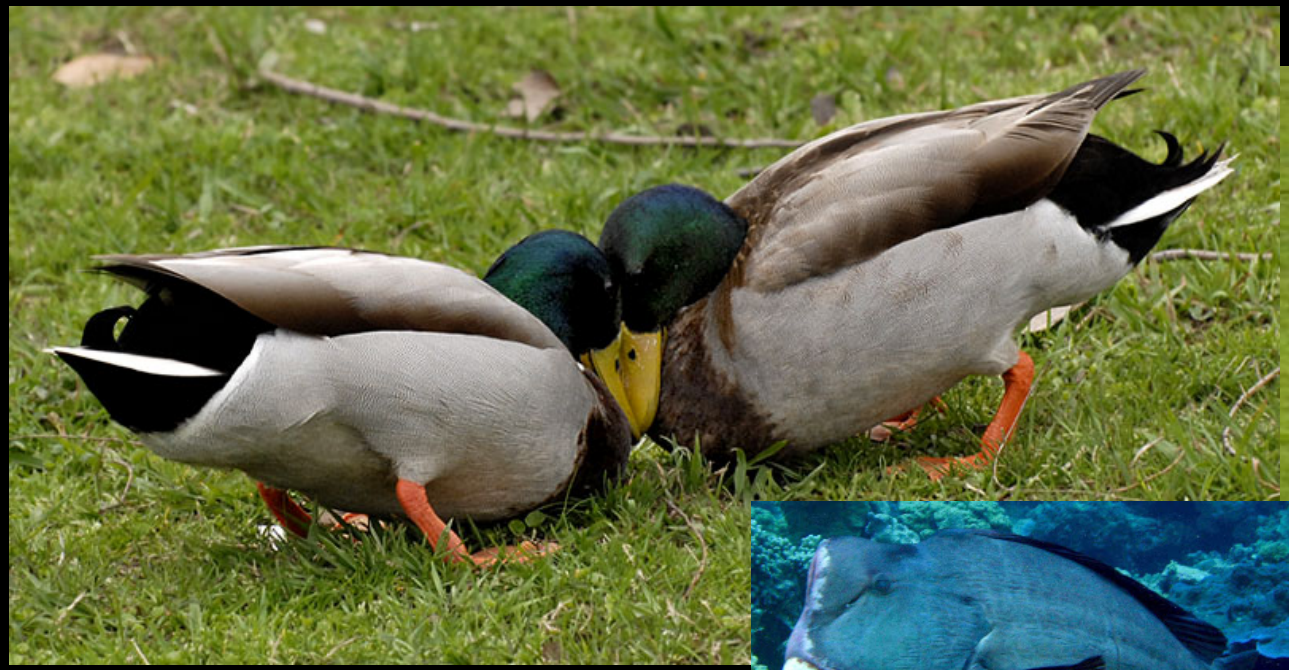
Pachycephalosauria

- long hindlimbs, short forelimbs
- long tail with vertebrae tightly joined by ossified tendons
  → much like ornithopods
- long illium bone
- six to eight sacral vertebrae
- head placed at an angle to the vertebral column
- bipedal
- Sexual dimorphism
- similar to the ornithopods

Head butting?

- thick skull to protect brain
- shortened neck
- strengthened vertebral coulmn
- inclination of the skull



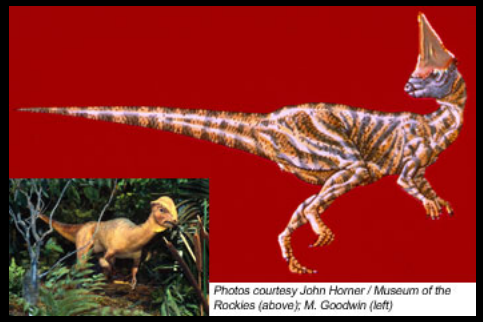


but ...

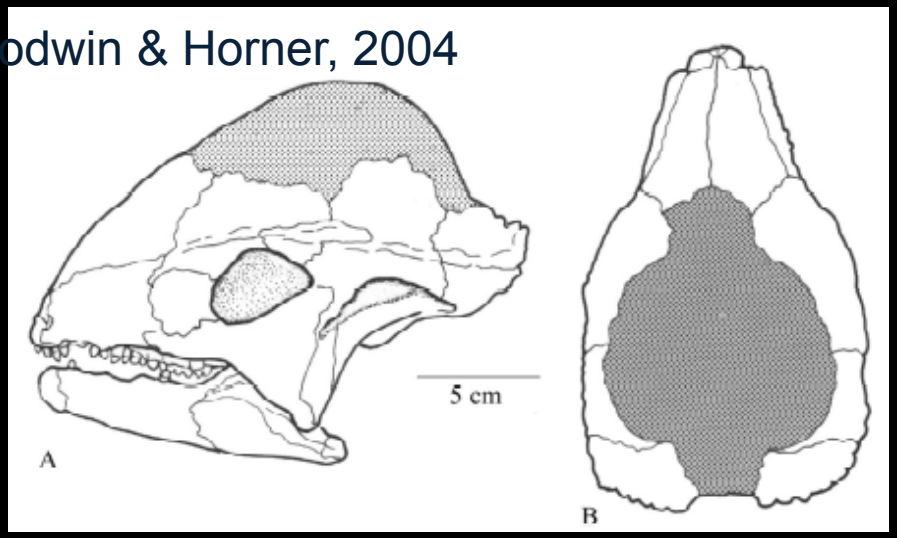
Microstructure showed:

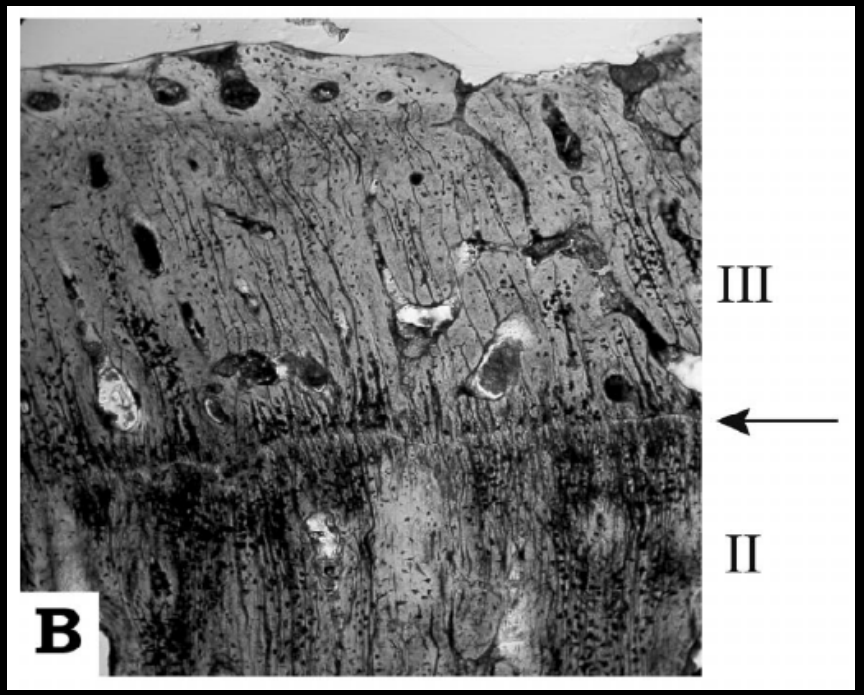
• internal structure of the pachycephalosaur dome is a dynamic tissue, fast growing bone (ontogenetic stage of dome growth)

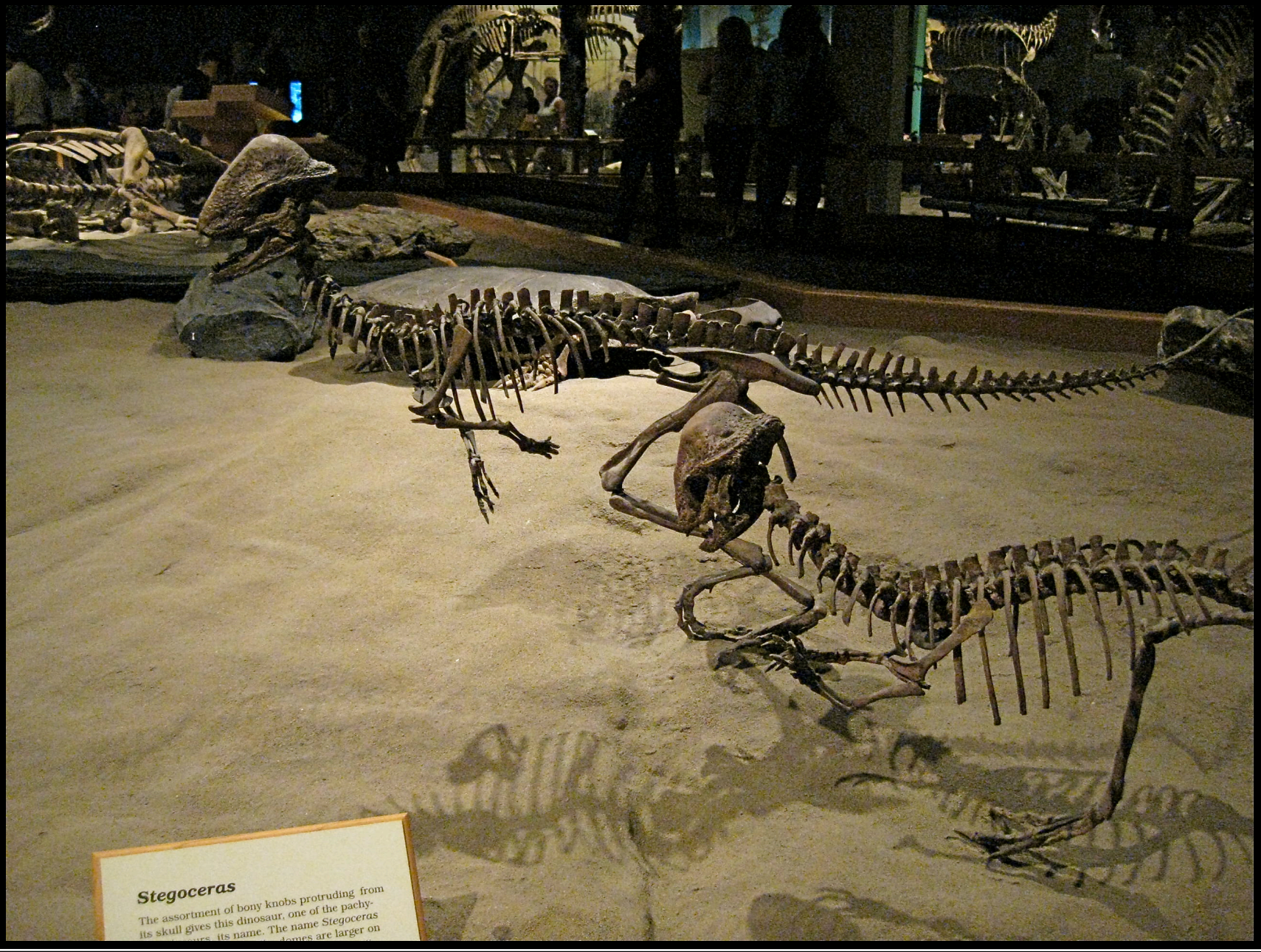
• dense layer of Sharpey's fibers indicates external covering



Goodwin & Horner, 2004

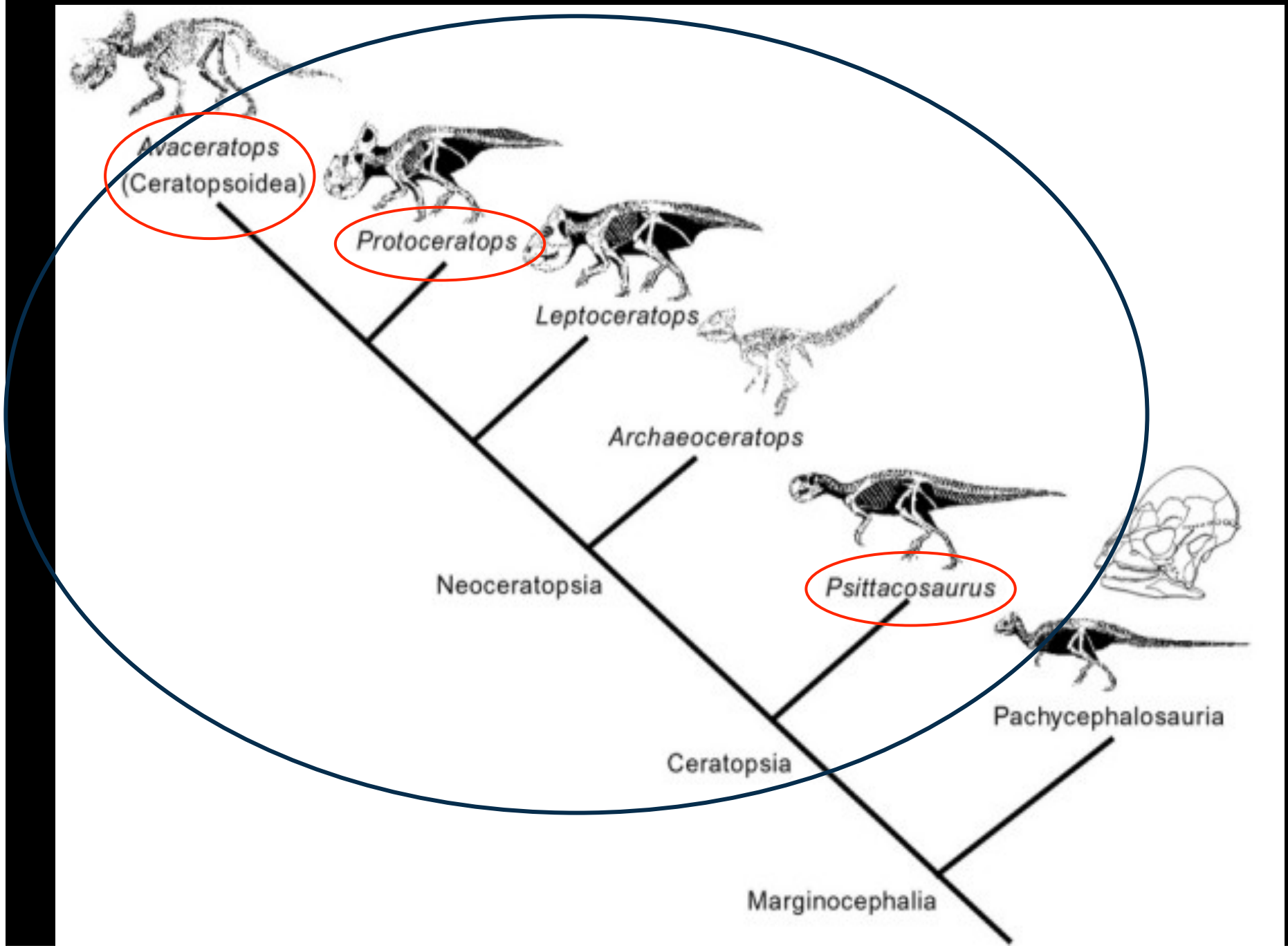






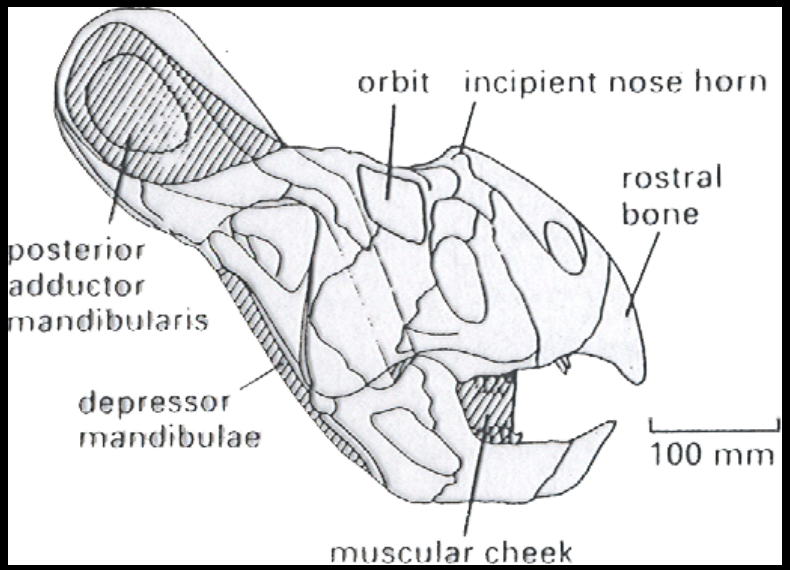
Cerapoda — Marginocephalia — **Pachycephalosauria** — Ceratopsia

Cerapoda — Marginocephalia — **Pachycephalosauria** — Ceratopsia


Avaceratops
(Ceratopsoidea)
Protoceratops
Leptoceratops
Archaeoceratops
Neoceratopsia
Psittacosaurus
Pachycephalosauria
Ceratopsia
Marginocephalia

Ceratopsia ("horned faces" - "*hornansikte*")

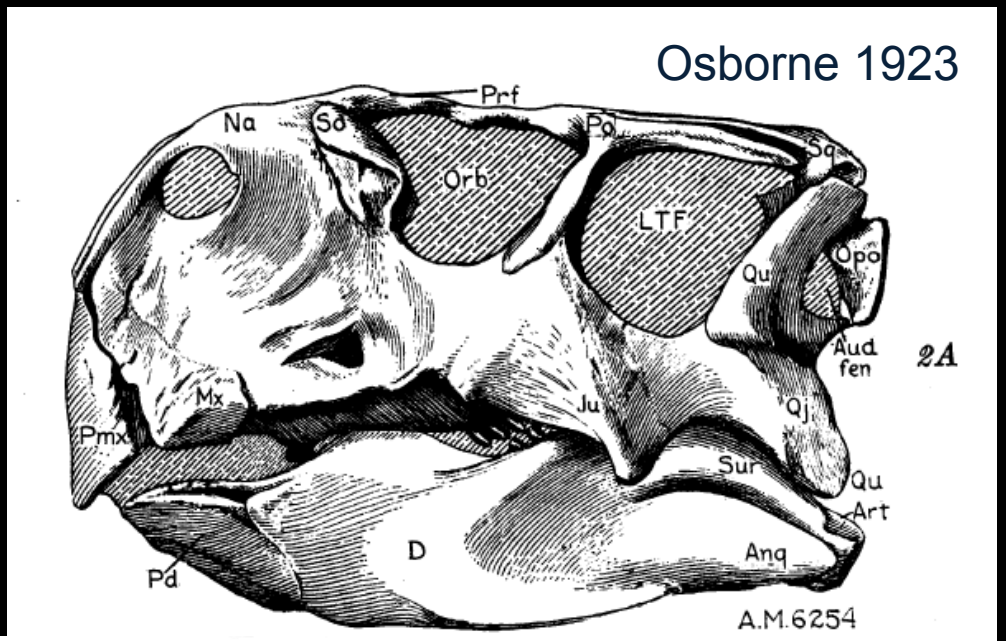
- generally quadrupedal
- triangular head
- **rostral bone**
- skull with narrow beak
- advanced forms with shelf of bone (and horn)
- Cretaceous of Asia and North America

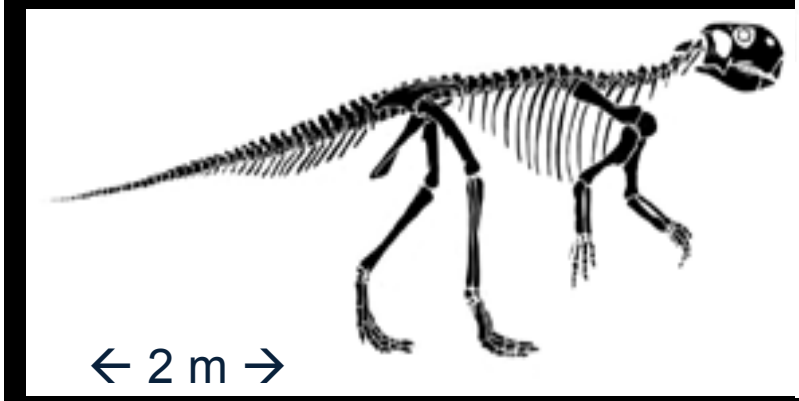


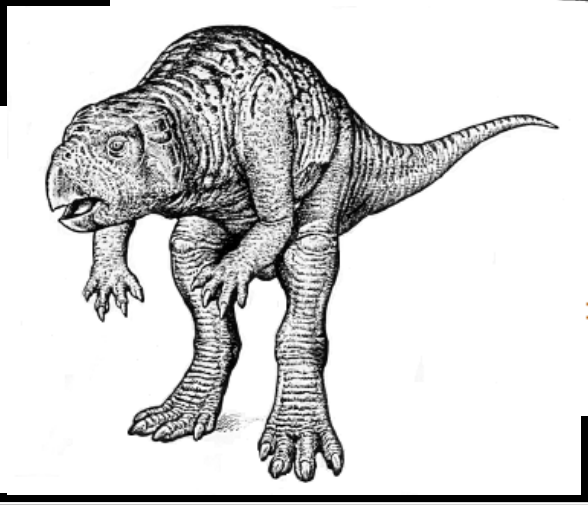
Psittacosaurus ”the parrot dinosaur”

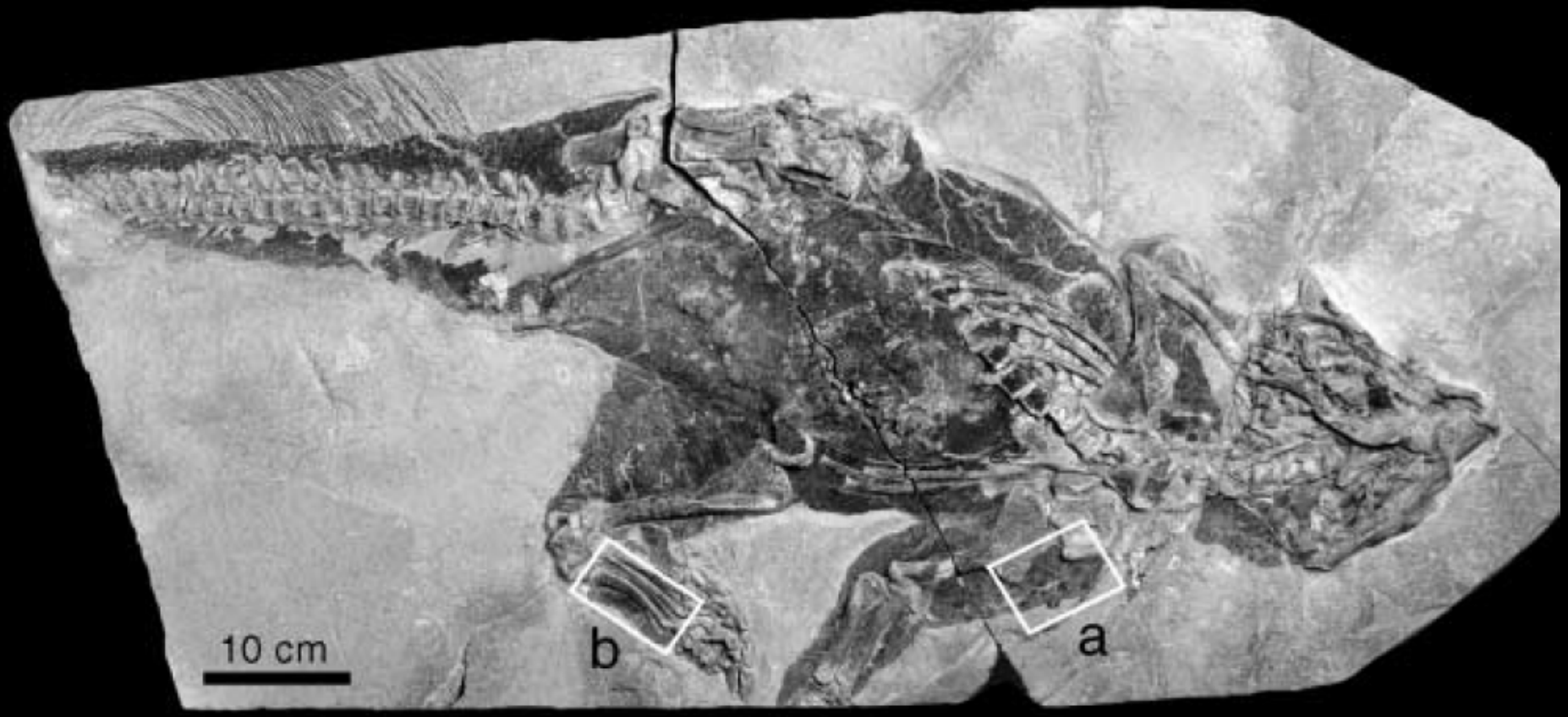
- ancestral to the Ceratopsia
- similar to ornithopods
- most rudimentary frill
- rostrum, beak, short snout, high position of the nostrils

→ primitive ceratopsian

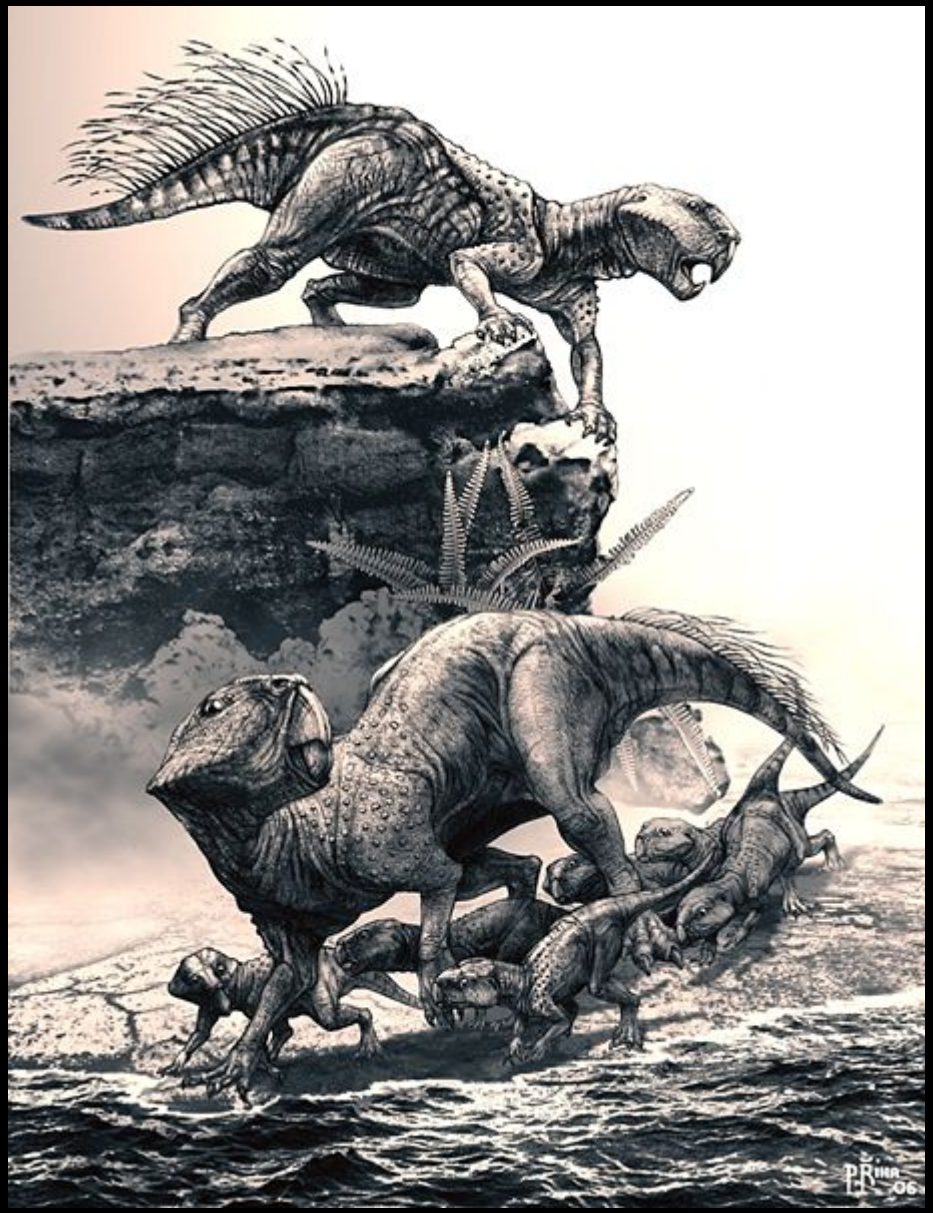


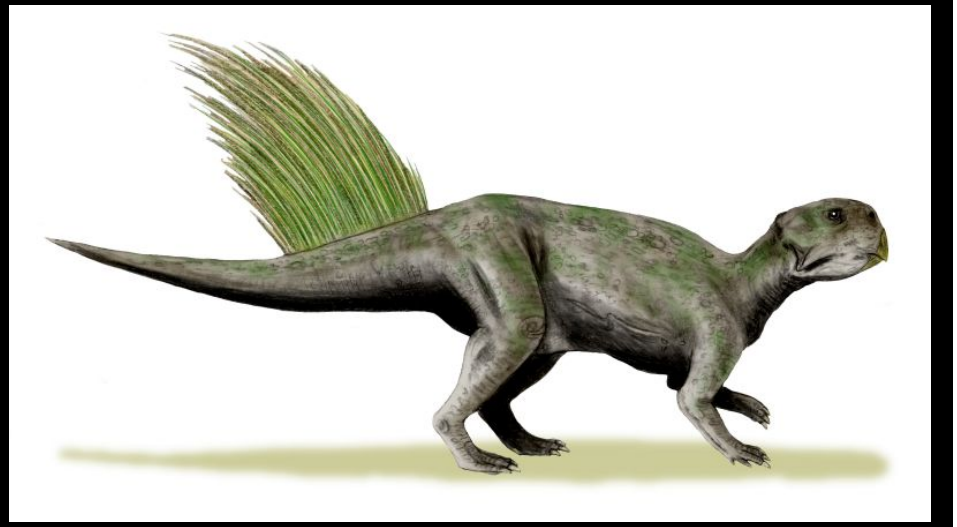






- *Psittacosaurus* (early Cretaceous of China)
- bristle-like structures on the proximal part of tail





Cerapoda – Marginocephalia – Pachycephalosauria – **Ceratopsia - psittacosaurids**

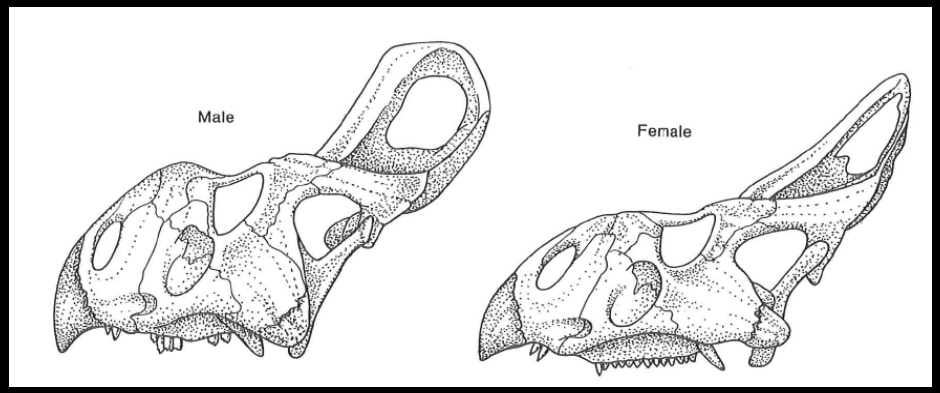
Protoceratops *and the protoceratopsids*

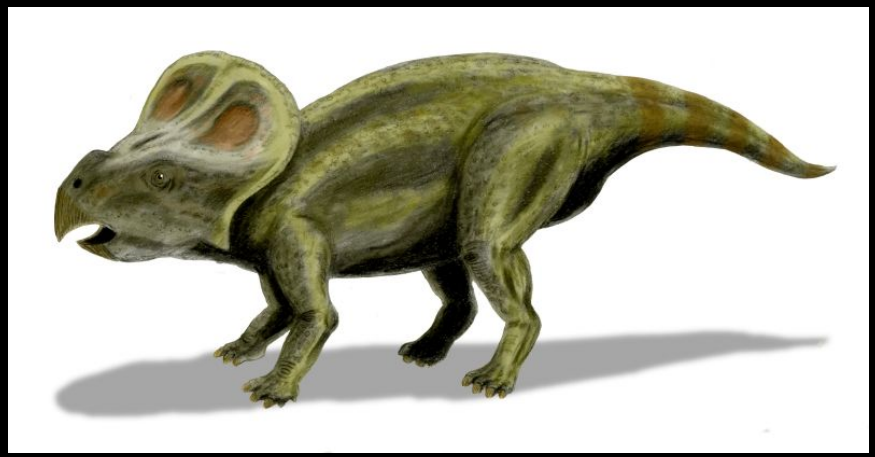
- still relatively small (1-2.5 m)
- intermediate between psittacosaurs and true ceratopsids
- forelimbs become equal in length with the hind limbs

→ quadrupedal

- Late Cretaceous of North America and Asia (esp. Mongolia and China)
- no horns, rather small frill
- small nostrils

→ more primitive





The Griffin Myth

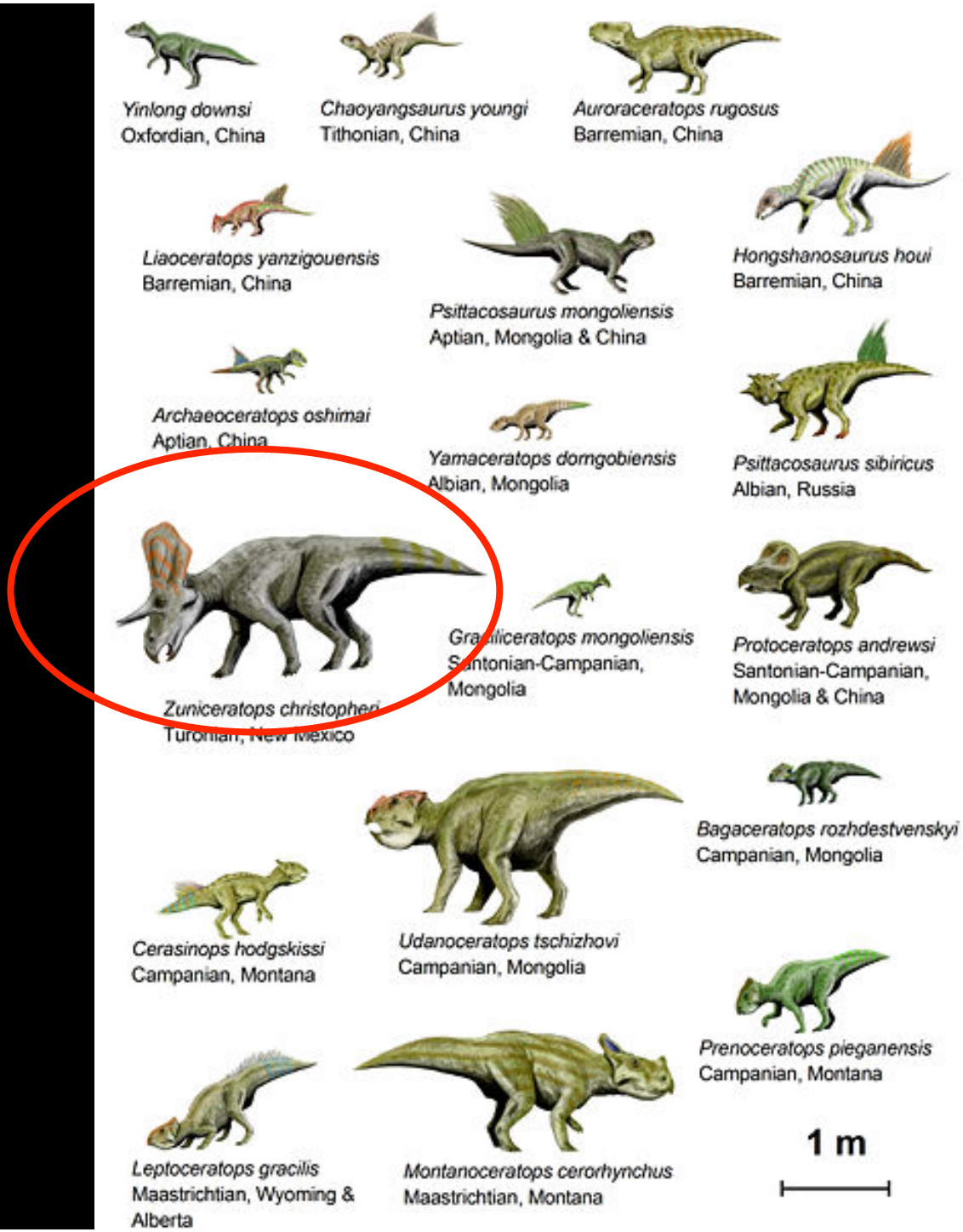
ca. 1260, France

ca. 375-350 BC, Eritrea

Griffin: a lion with an eagle head that lies eggs

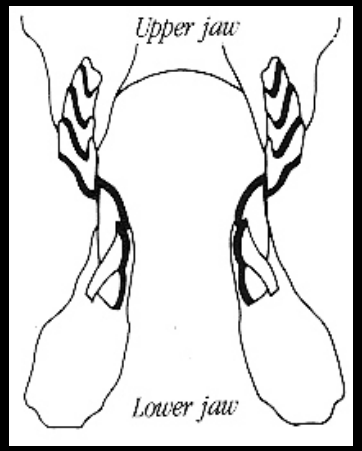
first described by Greek writers 675 BC

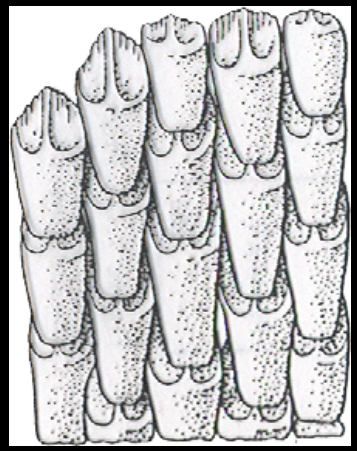
→ finds of protoceratopsids in Mongolia by Scythian nomads

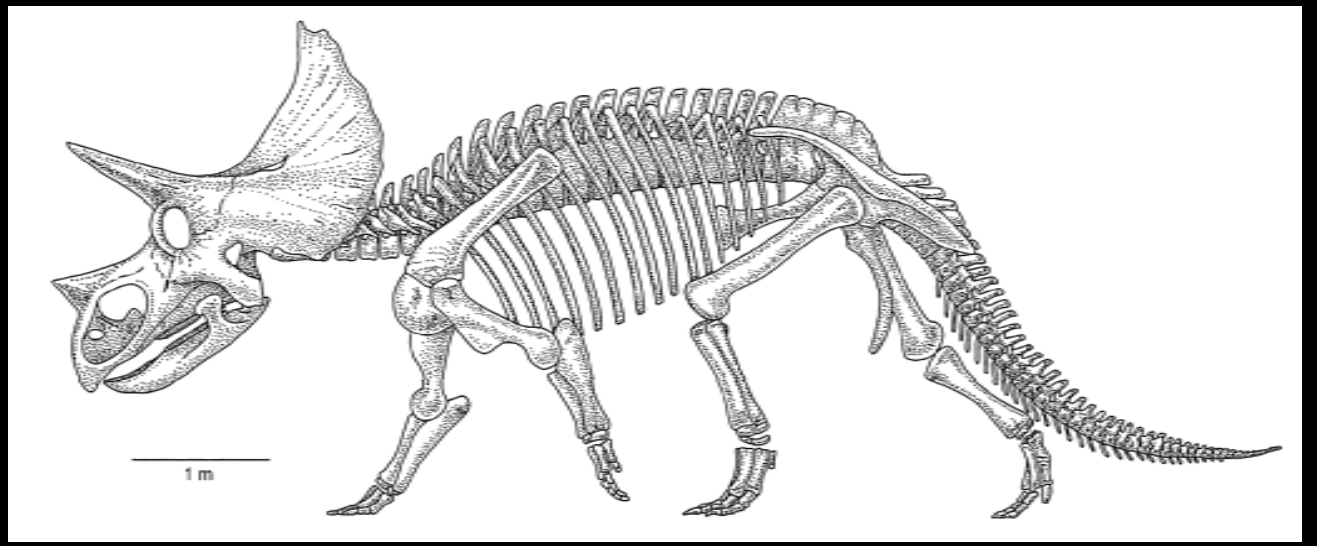

Yinlong downsi
Oxfordian, China
Chaoyangsaurus youngi
Tithonian, China
Auroraceratops rugosus
Barremian, China
Liaoceratops yanzigouensis
Barremian, China
Psittacosaurus mongoliensis
Aptian, Mongolia & China
Hongshanosaurus houi
Barremian, China
Archaeoceratops oshimai
Aptian, China
Yamaceratops dorngobiensis
Albian, Mongolia
Psittacosaurus sibiricus
Albian, Russia
Zuniceratops christopheri
Turonian, New Mexico
Graciliceratops mongoliensis
Santonian-Campanian,
Mongolia
Protoceratops andrewsi
Santonian-Campanian,
Mongolia & China
Bagaceratops rozhdestvenskyi
Campanian, Mongolia
Cerasinops hodgskissi
Campanian, Montana
Udanoceratops tschizhovi
Campanian, Mongolia
Prenoceratops pieganensis
Campanian, Montana
Leptoceratops gracilis
Maastrichtian, Wyoming &
Alberta
Montanoceratops cerorhynchus
Maastrichtian, Montana
1 m

Ceratopsidae

- all quadrupedal
- enlarged frill
  → skull up to 2.4 m long
  (parietal and squamosal bones)
- variety of horns
- **enlarged nares**
- 4 to 8 m long
- only Late Cretaceous of North America

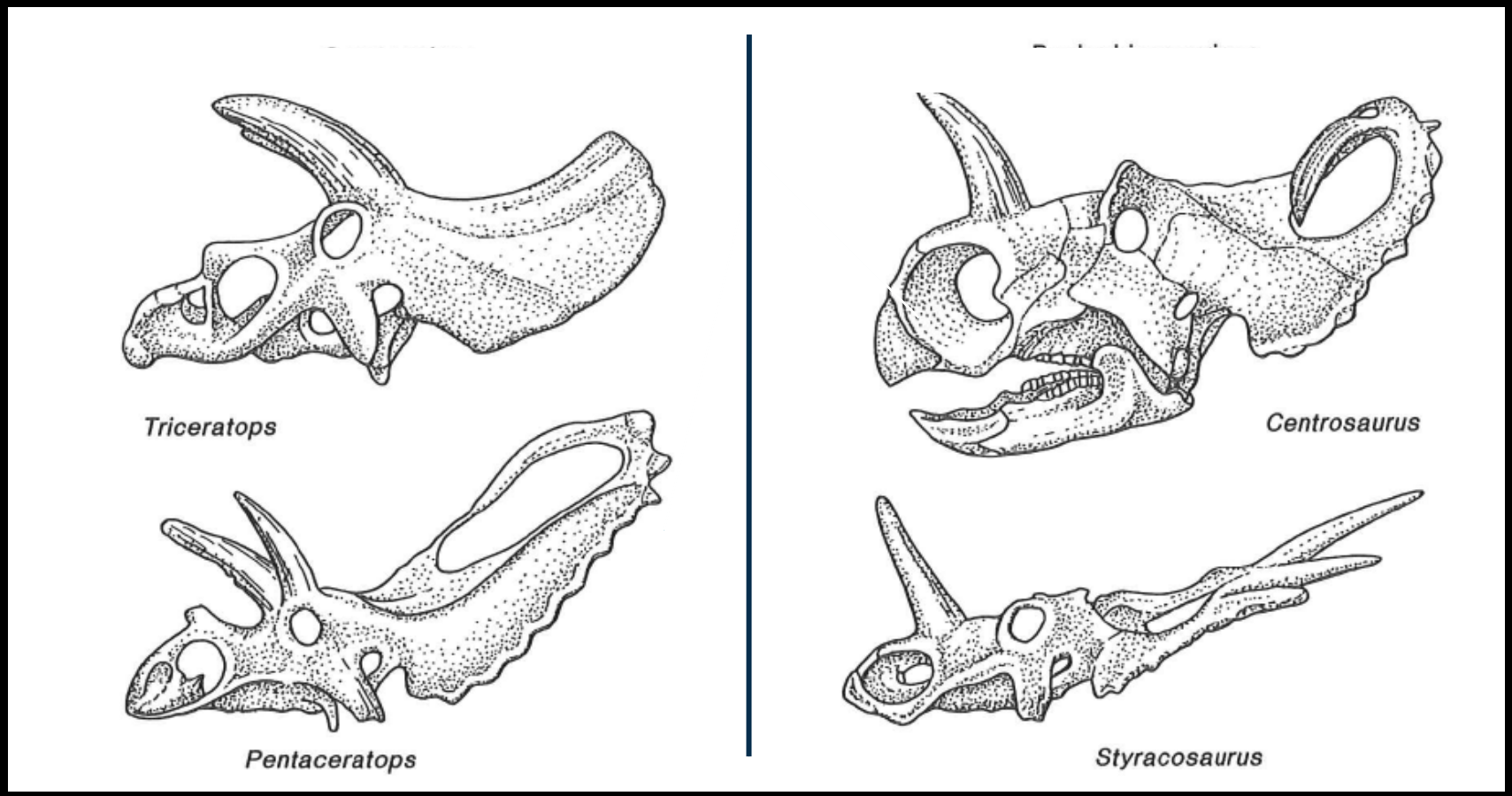






Two groups: Chasmosaurinae and Centrosaurinae

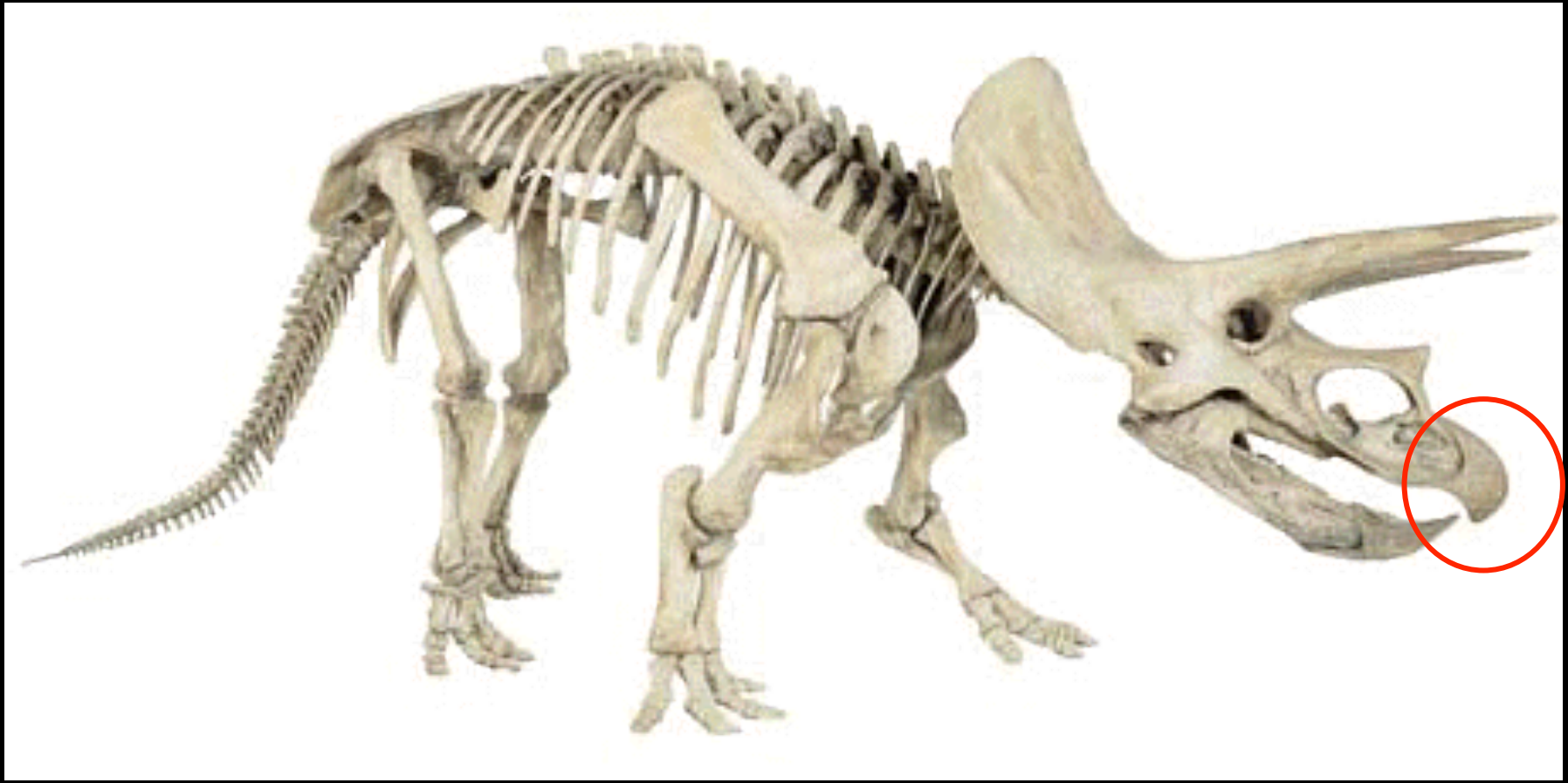
long-frilled, long-faced *vs*. short-frilled, short faced forms



→ large brow horns
→ enlarged and long frill
→ enlarged rostral bone and thickening of the snout bones

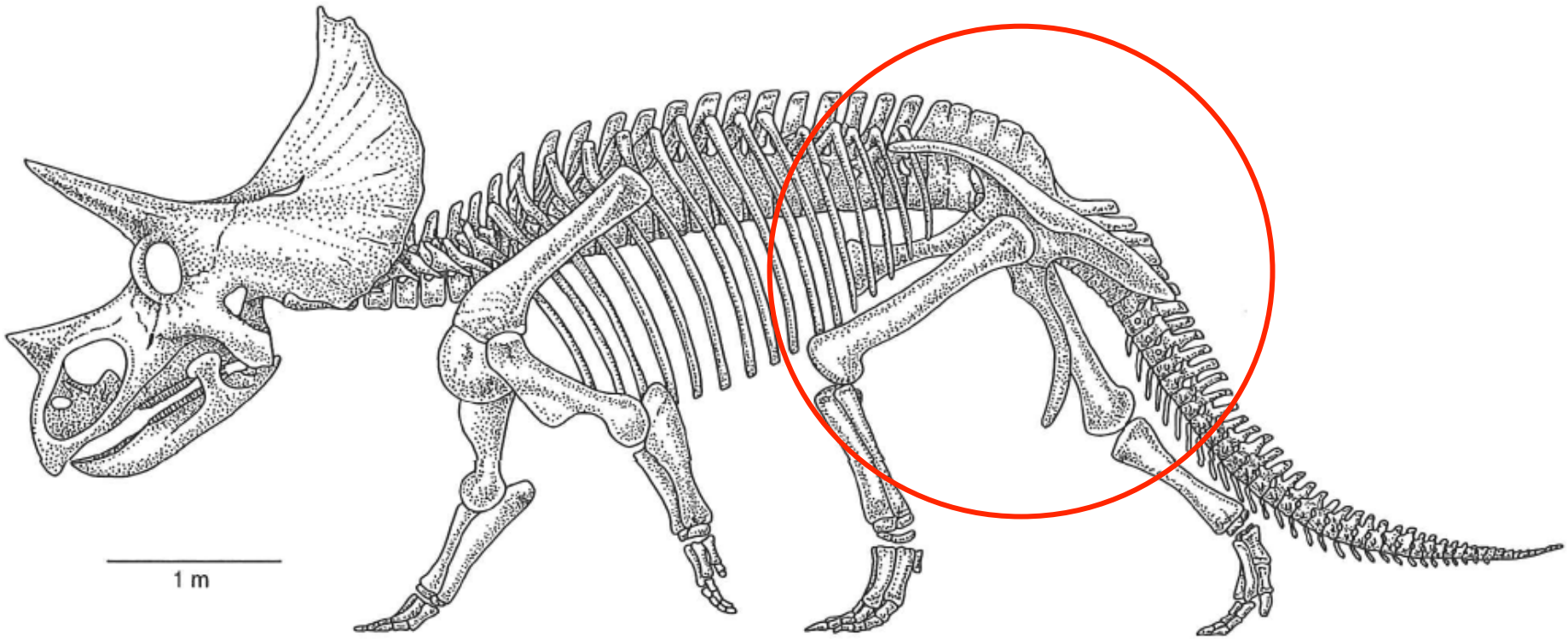
→ large nasal horn
→ short brow horns
→ hooks and spines on frill margin

Cerapoda – Marginocephalia – Pachycephalosauria – **Ceratopsia - ceratopsids**

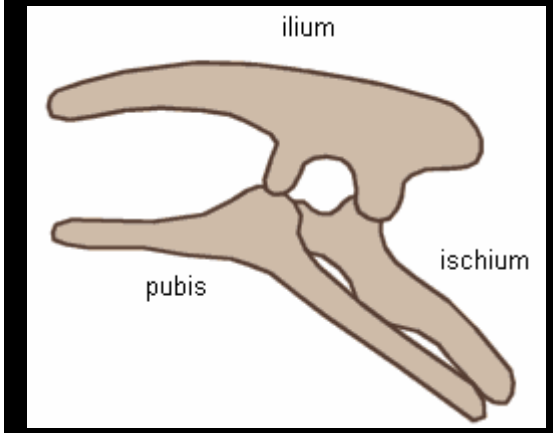


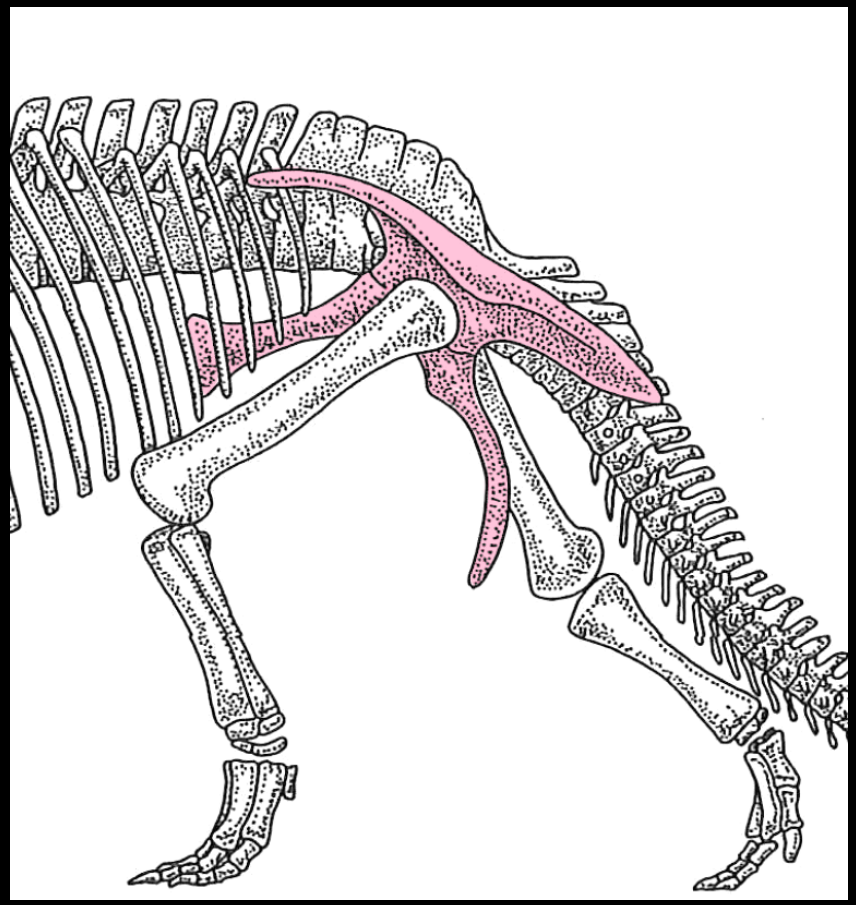
Cerapoda – Marginocephalia – Pachycephalosauria – **Ceratopsia - ceratopsids**

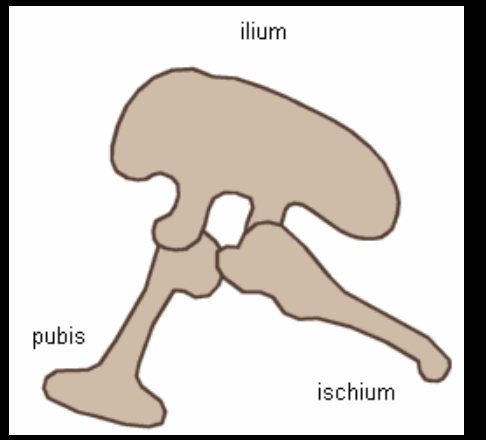
Cerapoda — Marginocephalia — Pachycephalosauria — **Ceratopsia - ceratopsids**



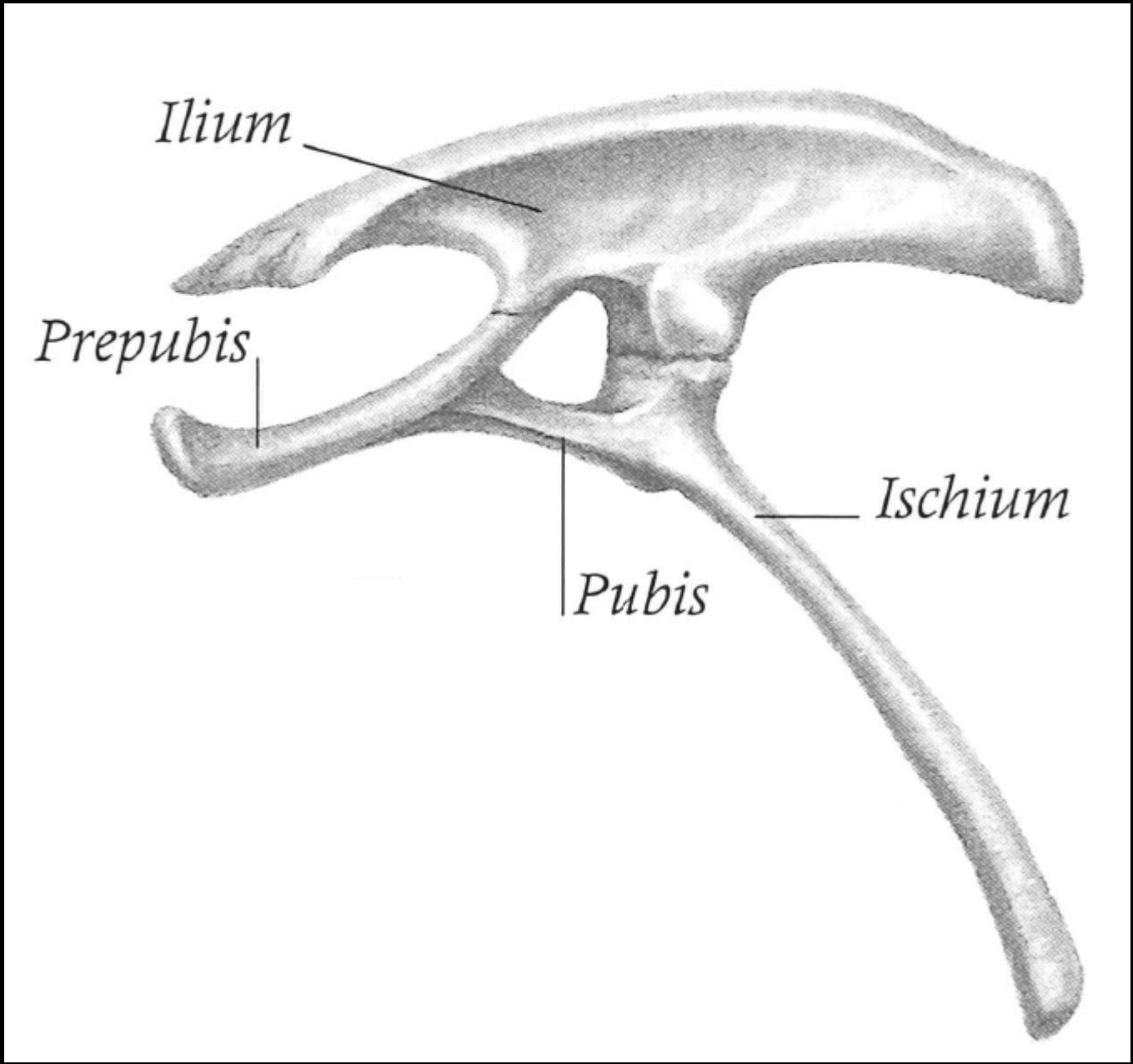
Cerapoda — Marginocephalia — Pachycephalosauria — **Ceratopsia - ceratopsids**



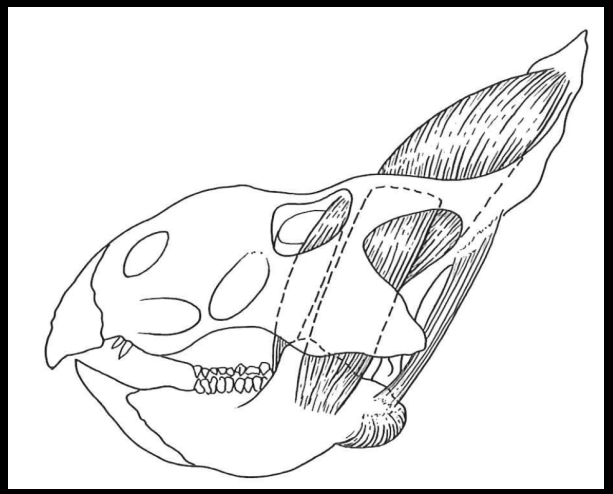




Cerapoda – Marginocephalia – Pachycephalosauria – **Ceratopsia - ceratopsids**

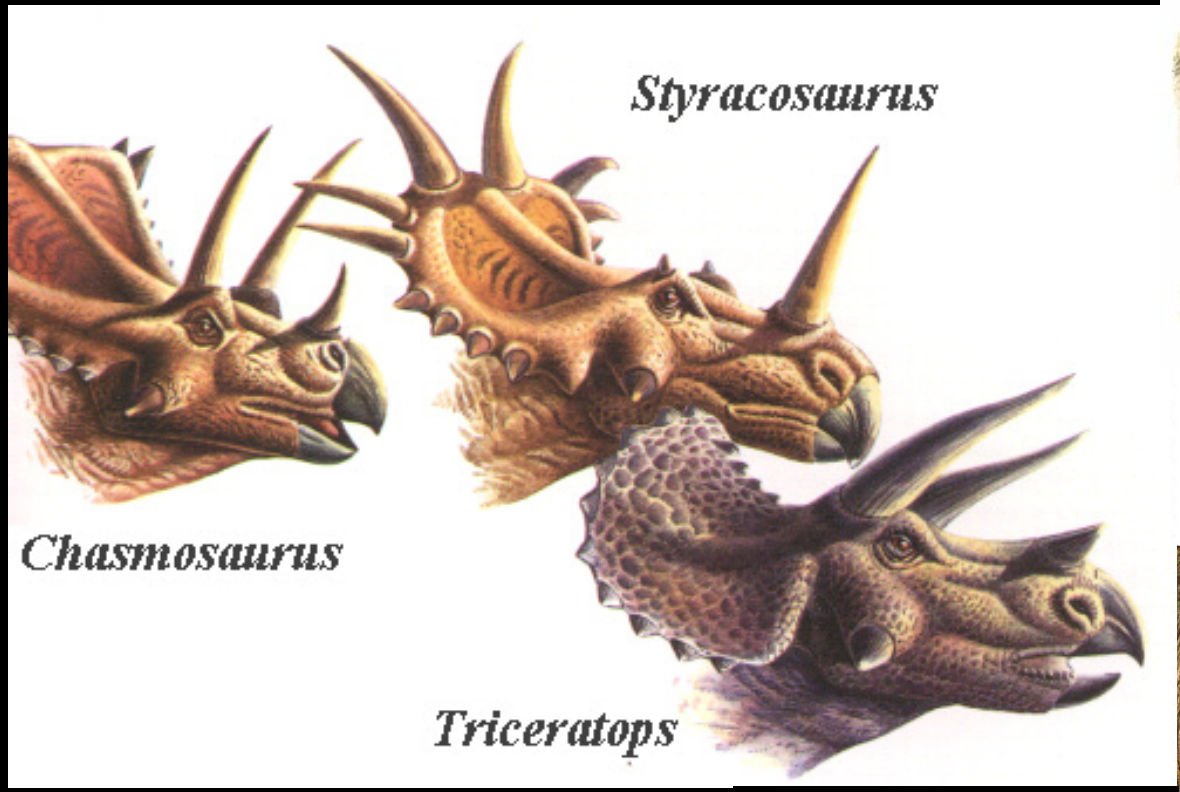

Ilium
Prepubis
Ischium
Pubis

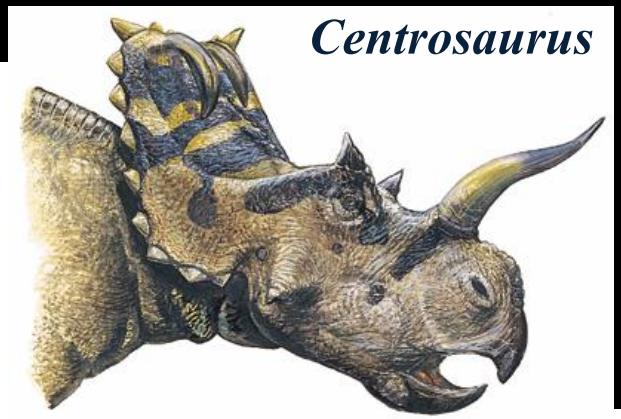
Function of the frill ??

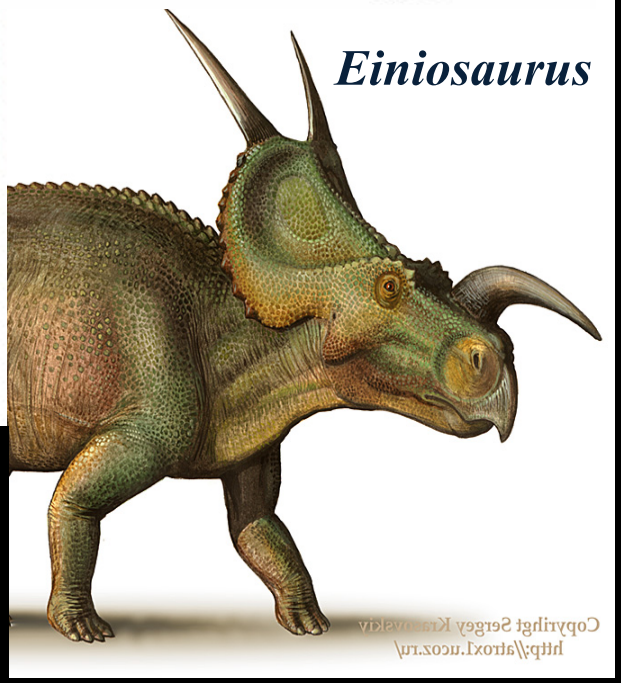


→ muscle attachment
→ reflects gender
→ ritualized combat and display
→ establishment of hierarchies
→ protection of the neck
→ thermoregulation

Function of the horns ??

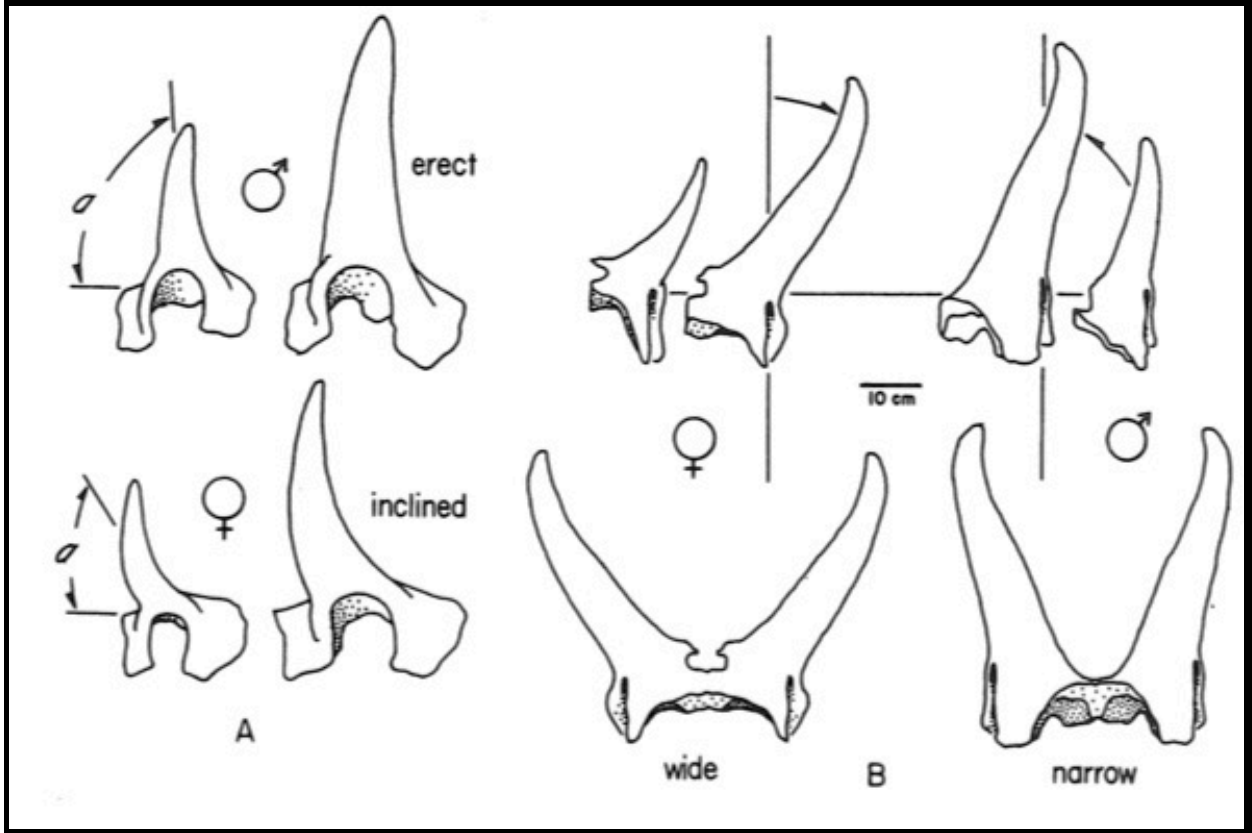


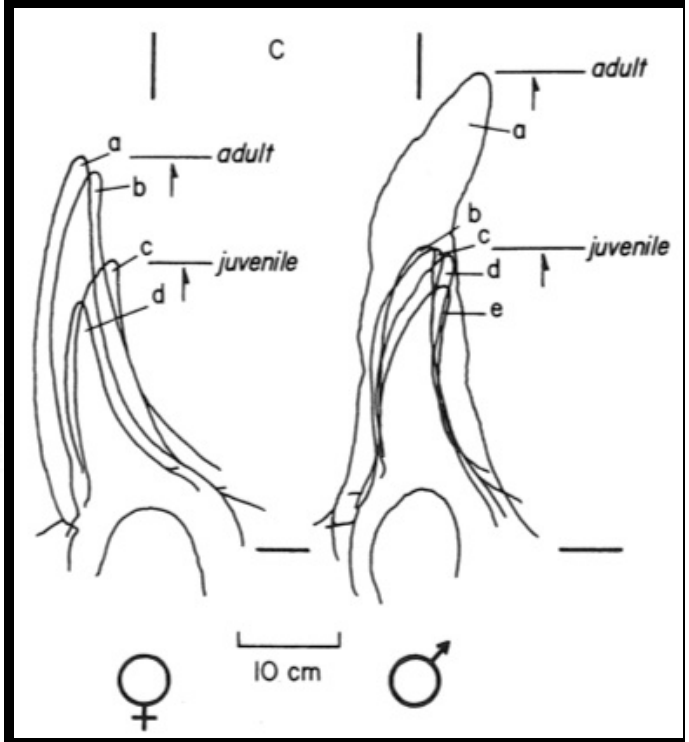




- predator defense
- intimidate predator
- mate recognition
- intraspecific competition

Sexual dimorphism





Chasmosaurus