Growth series of one

Case studies in time-transgressive morphology

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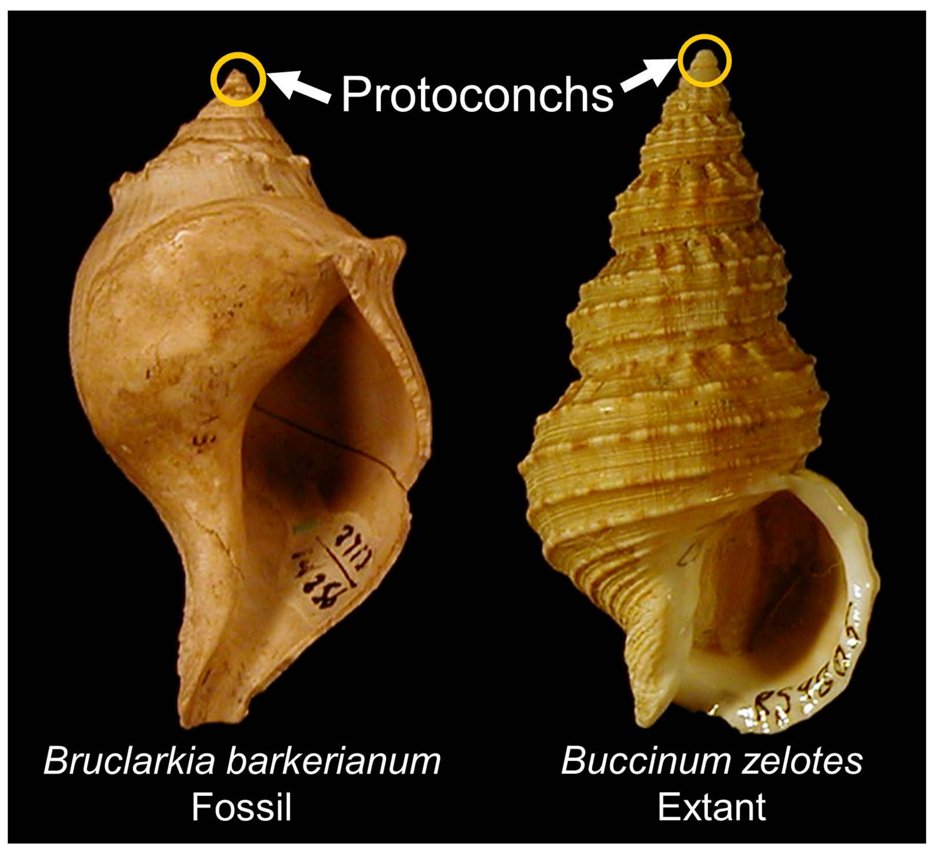
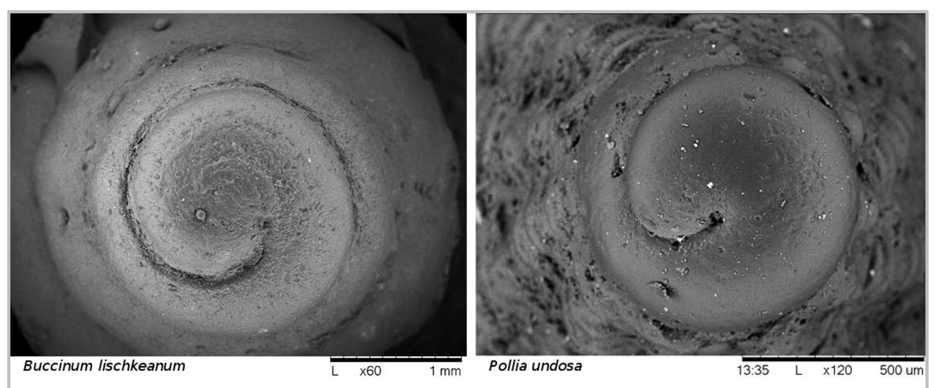
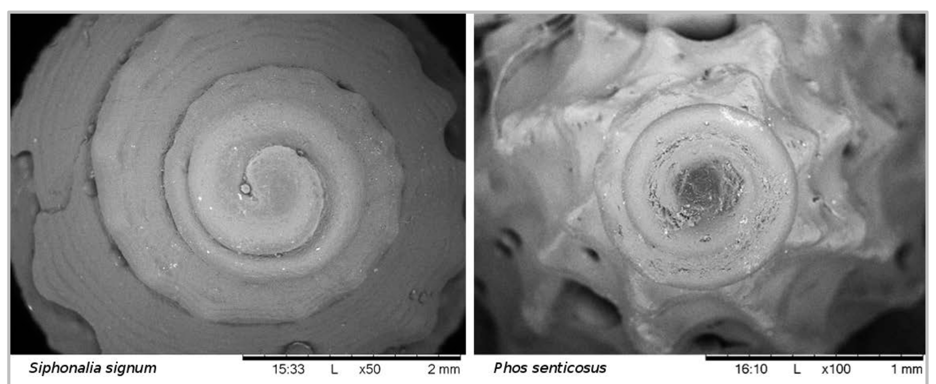
Snail shells grow by accretion from the apical larval shell outward, building a record of character change.




Direct-developing: bulbous, few whorls


Planktonic: small, tightly coiled

The larval shell, or protoconch, is retained at the apex of the shell's spiral, providing a record of the snail's early development. Protoconch morphology varies predictably with larval ecology.

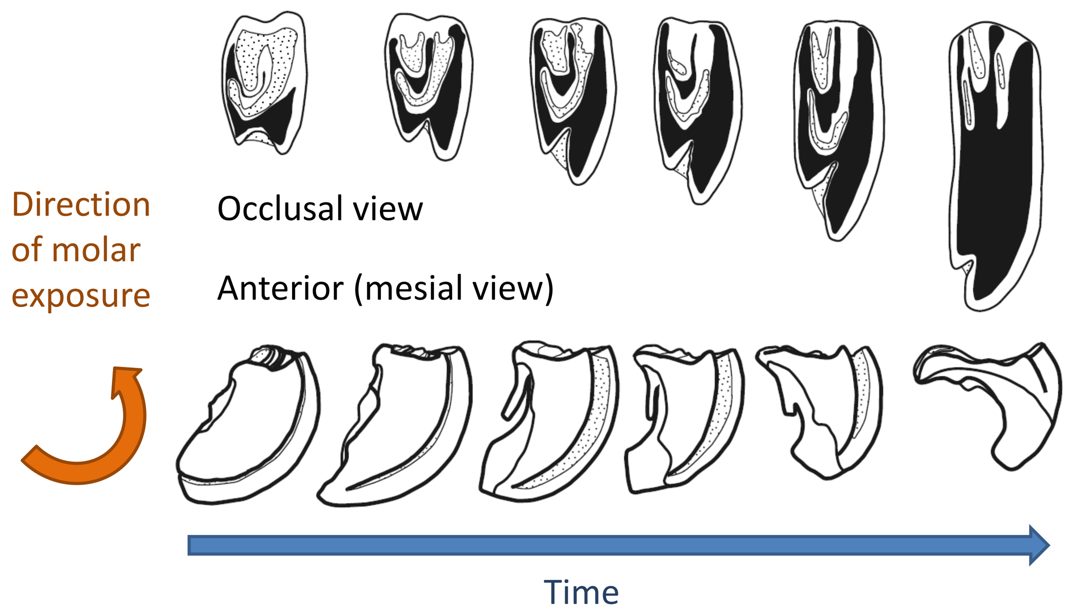
Direct-developing (non-planktonic) gastropods crawl out of their egg capsules as juveniles that have already been through metamorphosis. Their protoconchs tend to be bulbous, with few volutions (whorls).

In contrast, **planktonic** larvae swim out of their egg capsules and live in the water column for a time, before metamorphosing into benthic adults. Their protoconchs tend to be small and tightly coiled.

In this system, the ontogenetic information carried by the shell increases over time – an almost perfect example of terminal addition.

(Original images by J. Vendetti)

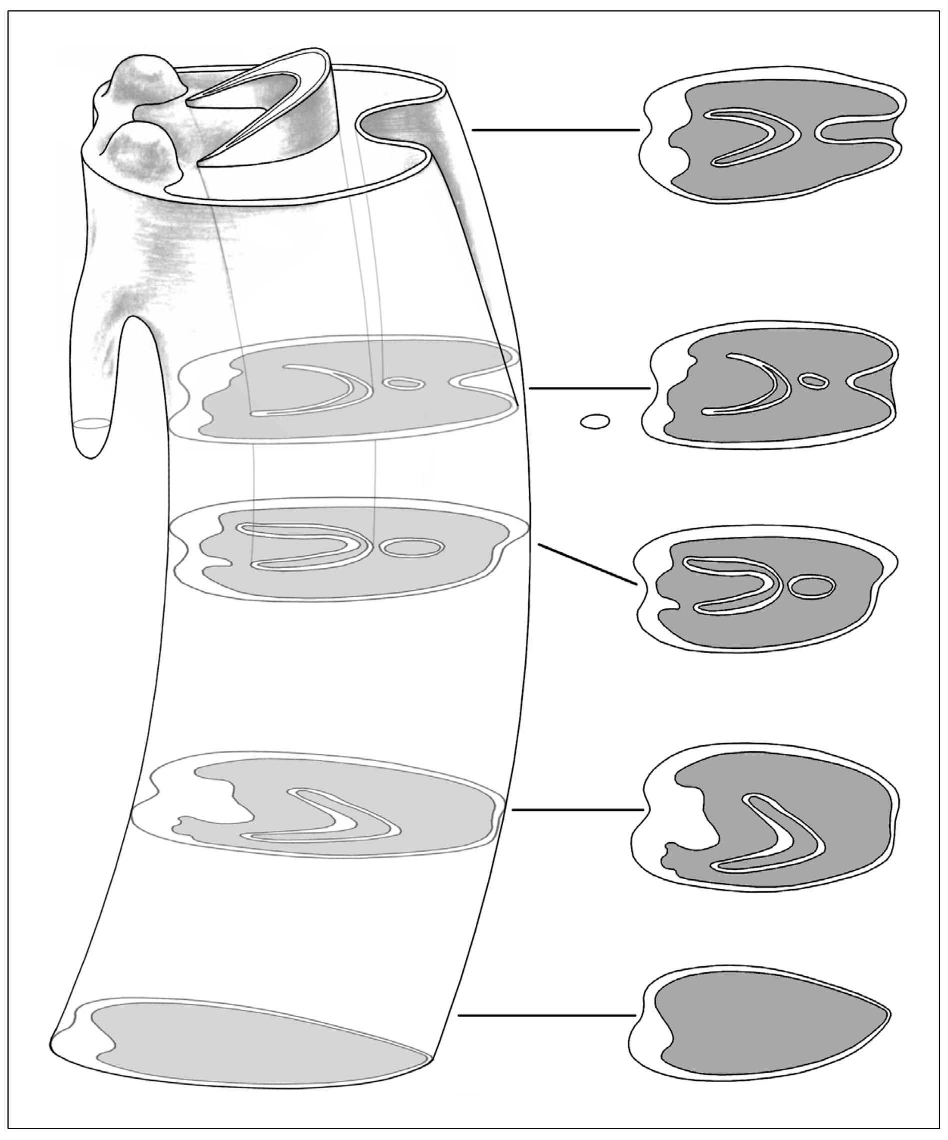
Lagomorph teeth wear down from their occlusal surfaces, revealing new characters as early stages are worn away.



In the Late Miocene *Hesperolagomys*, the molars 'unrolled' as they wore down, eroding the internal crescents of enamel and cementum, and dramatically changing both the size and shape of the occlusal surface.

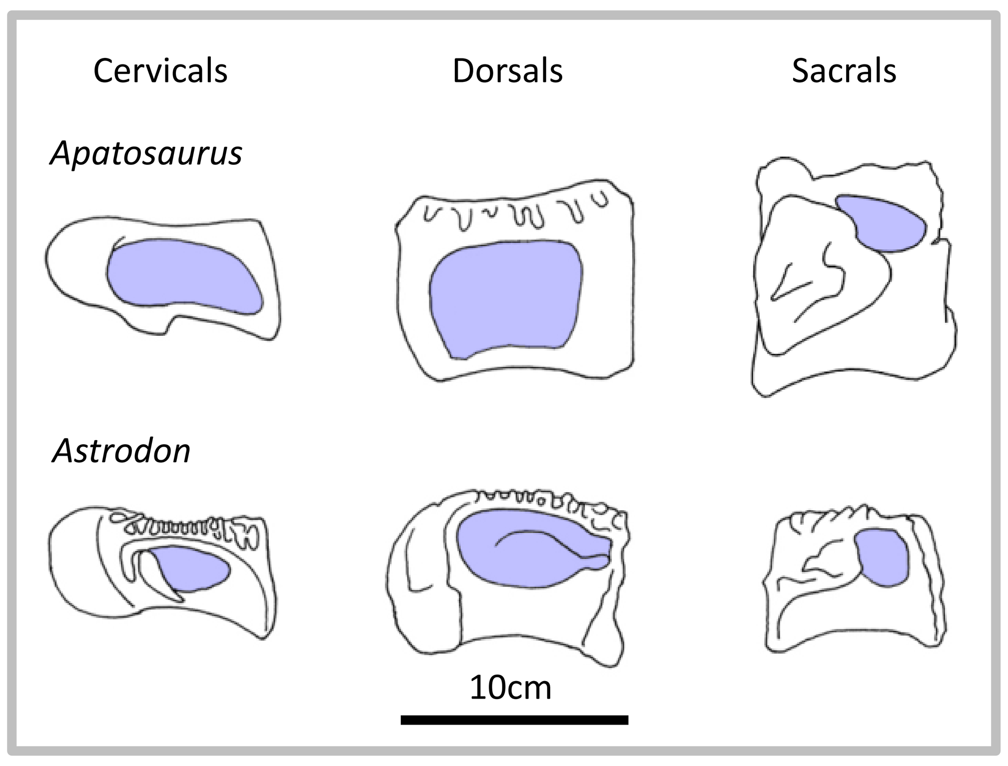
(Bair 2007:fig. 1, as modified by Kraatz et al. 2010)

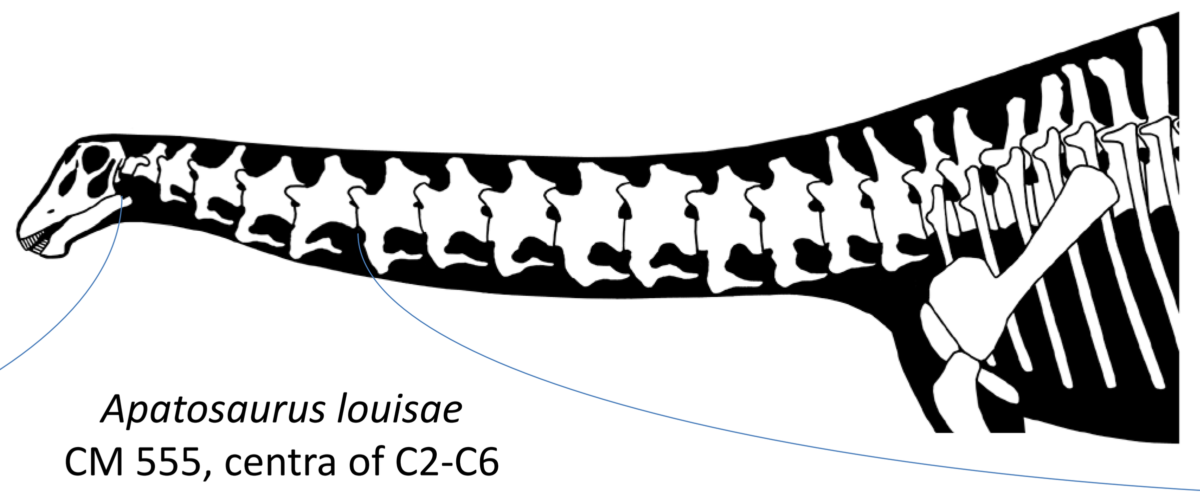
Lucjan Sych used the "synthetic PM" model shown here (modified from Sych 1975: fig 1) to illustrate how the occlusal morphology of the upper premolars and molars changed over ontogeny in *Desmatolagus gobiensis*, from the Oligocene of Mongolia. Earlier authors had named 8 species in 4 genera based on morphological variations that Sych recognized as wear stages of *D. gobiensis* and the closely related *D. robustus*.



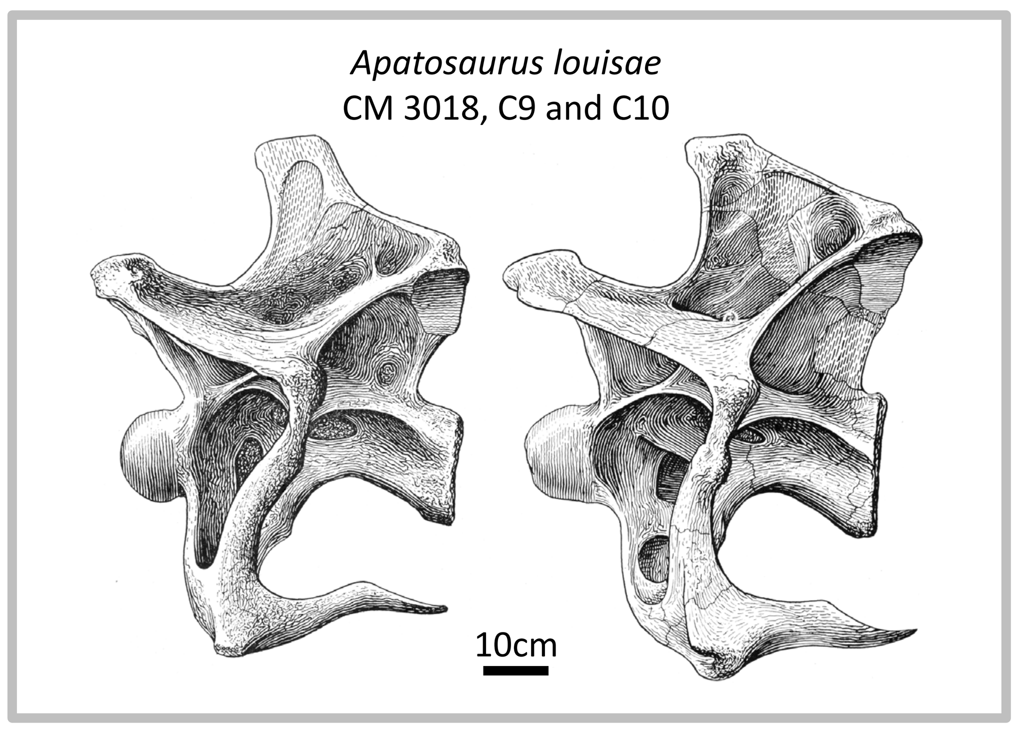
In this system, ontogenetic information carried by the teeth decreases over time, as early morphologies are erased by wear.

In the **necks of sauropodomorph dinosaurs**, serial position recapitulates both ontogeny and phylogeny.





Apatosaurus louisae
CM 555, centra of C2-C6

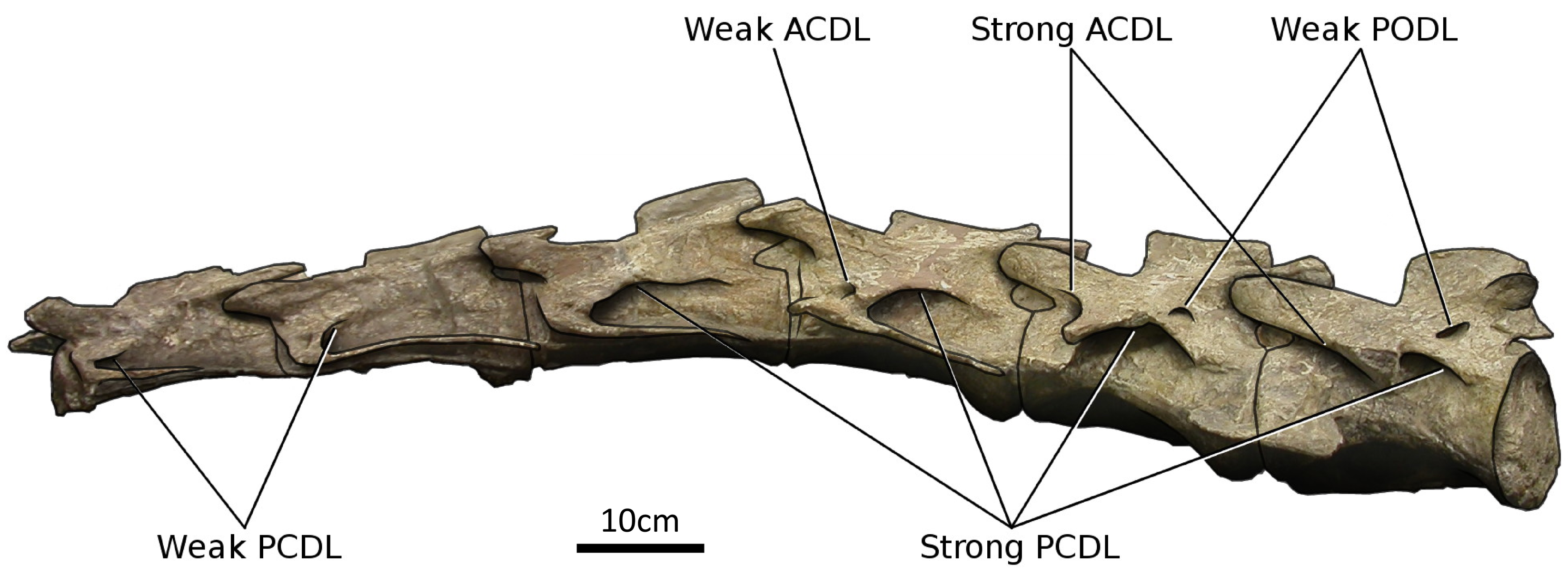


CM 555 is a subadult *Apatosaurus louisae*, approximately 2/3 the size of CM 3018, the holotype. Anterior cervical vertebrae of CM 555 have simple pneumatic fossae like those of juvenile neosauropods (above left) and adults of more basal sauropodomorphs, such as *Plateosaurus* (below).

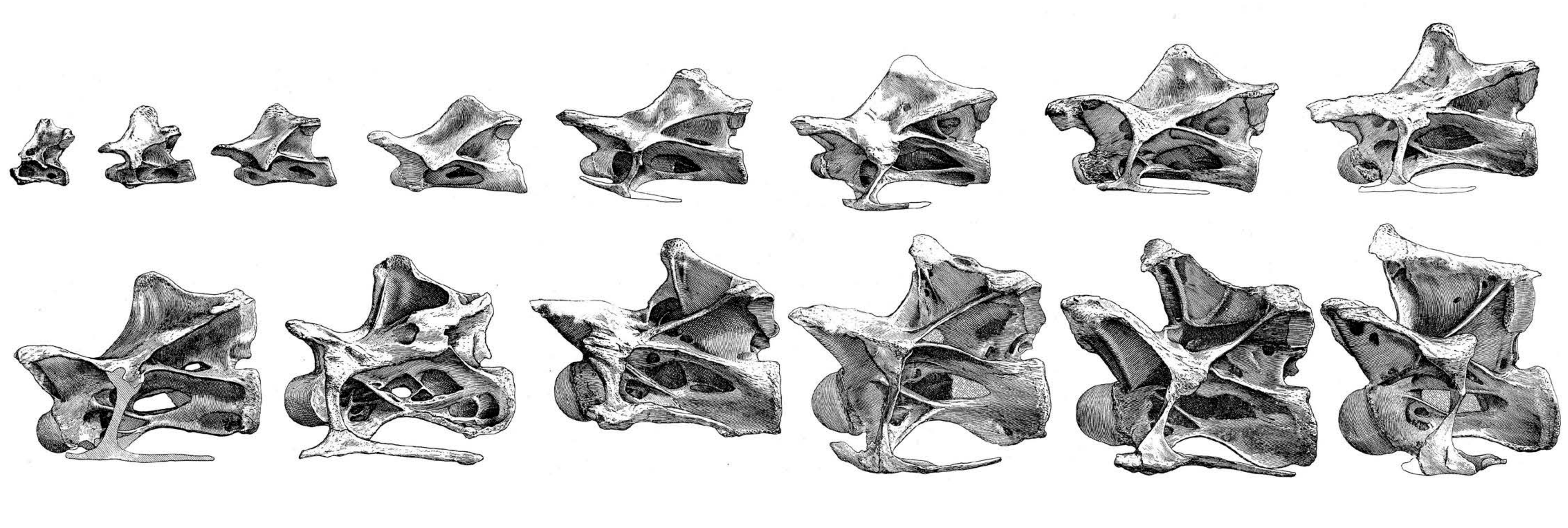
Images modified from Wedel et al. 2000: fig 14 (above left) and Wedel and Taylor 2013: fig 14 (below).

More posterior cervicals of CM 555 have paired lateral foramina divided by an oblique lamina, a derived state present throughout the cervical series in most adult neosauropods, including large individuals of both *Apatosaurus* (above right) and the closely related *Diplodocus* (below).

Images modified from Gilmore 1936: plate 24 (above right) and Hatcher 1901: plate 3 (below, reversed).



Cervical vertebrae 3-8 of *Plateosaurus engelhardti* SMNS 13200.



Cervical vertebrae 2-15 of CM 84, the holotype of *Diplodocus carnegii*.

Note the increase in complexity along the cervical series in adult individuals of both the basal sauropodomorph *Plateosaurus* and the derived neosauropod *Diplodocus*. The pattern is consistent throughout Sauropodomorpha.

For more information, including a complete bibliography, please email the lead author. Thanks for reading!