4 years of PLOS Paleontology

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At the end of 2019, the PLOS Paleo Community came to an end after more than 4 years. This is a compilation of all of the articles I wrote as an Editor for the community during that time. Enjoy!

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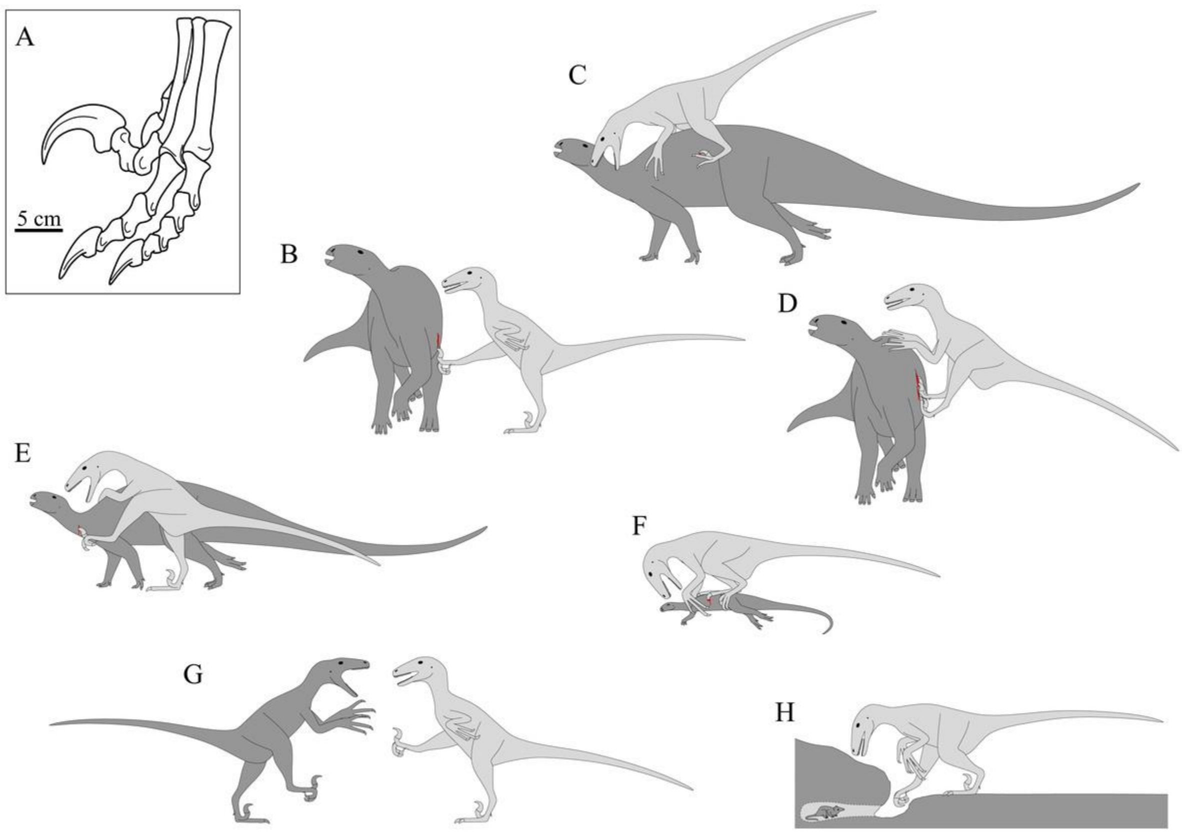
Killer claws or climbing crampons?

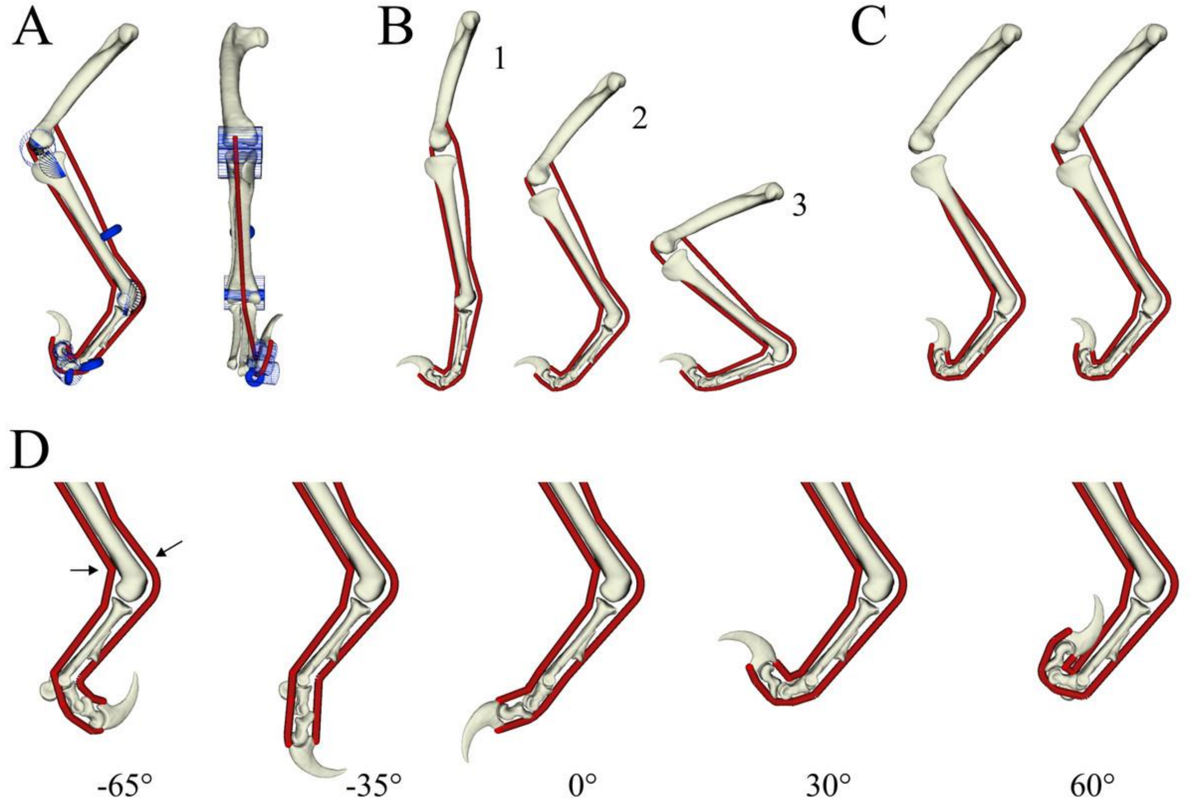
I still remember the first-time watching Jurassic Park as a kid. Watching the raptors leaping on to their prey, hooking and slashing away with their lethal sickle claws. The annoying "six foot turkey" kid's face as Alan Grant totally pwned him over just how a raptor would slice him open before devouring him alive. These were pretty memorable moments for me, and the vision of raptors as vicious little butchers.

But did raptors really disembowel their prey Freddy Krueger style, or was there a little more finesse? There has been a long-standing debate in palaeontology over what exactly raptors like *Velociraptor* and *Deinonychus* might have actually used their big claws for. The glorified version of it slashing out and ripping prey apart with disembowelling strikes, or more like a modern hawk or eagle, leaping on to its victim and pinning it down while gripping it with its large claws. Other studies have suggested *Deinonychus* used its claws like crampons, delivering small puncture wounds to their prey while climbing on them. The point is, you are alive when they start to eat you.



The famed ‘sickle claw’ of pedal digit II in dromaeosaurids and its hypothesized uses (Bishop, 2019).

There have been many methods used to analyse the function of *Deinonychus*’ killer claws, from robots to comparisons with modern cassowaries. Now, a [new study by Peter Bishop]() has used reconstructed muscle and skeleton modelling to offer a new perspective. By using three-dimensional models, and the known properties of the muscles, tendons, and bones, the forces associated with the claws can be assessed in a quantitative manner.



Musculoskeletal model of the right hindlimb of *Deinonychus* (Bishop, 2019).

Using mathematical models, Bishop was able to simulate the factors that would provide maximum force at the tip of the claw, and therefore what function it most likely possessed. The models showed that if *Deinonychus* adopted more of a crouching posture, then this increased the claw forces. However, even at the higher end of things, these forces remained relatively small.

This means that the claws were not likely to be too useful in the old slash and smash approach, as they just were not strong enough. However, they were still likely to be useful in grasping on to small prey, and restraining them while the teeth did their work. This behaviour has been seen in other dinosaurs too, such as the famed 'fighting dinosaurs' specimen, in which *Velociraptor* and *Protoceratops* were frozen in death's embrace, with the former gripping on to the other with its claws. Still, the thought of a 170kg eagle is pretty terrifying.

Reference

Bishop PJ. 2019. Testing the function of dromaeosaurid (Dinosauria, Theropoda) 'sickle claws' through musculoskeletal modelling and optimization. PeerJ 7:e7577 https://doi.org/10.7717/peerj.7577.

How did the turtle get its shell?

Turtles are a beautiful mystery in the animal kingdom. Anyone who has ever been lucky enough to see one swimming in the wild will know just how much of a heart-stopping sight they are to behold.

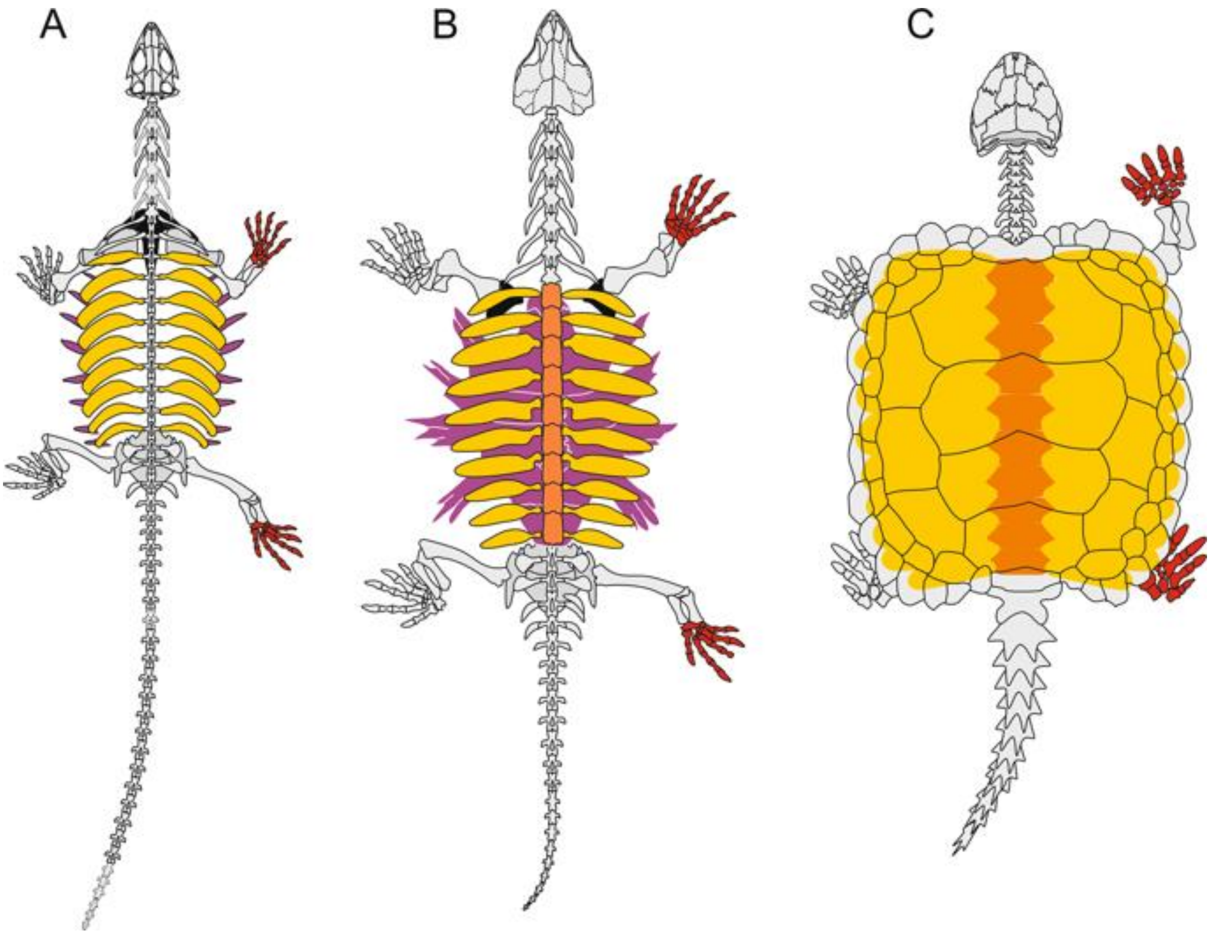
For scientists, one of the great and wonderful questions to ask is also one of the simplest: How did turtles get their shells? One of the most remarkable features about these graceful weirdos, we actually know very little about the evolutionary origins.

It has long been thought that the tough, bony shells of turtles and their ancestors are formed from their ribs. Becoming heavily modified over millions of years, they joined together to form the tough, protective armour that we know and love so much about modern turtles. This is distinct from say, crocodiles, where their bony carapace is formed from growths within their skin known as osteoderms. In turtles, the ribs and vertebrae grow into the outer skin layers and connect together like tectonic plates, forming a solid shell. This means that in turtles, unlike crocodiles, the outer shell is actually integrated into the rest of the skeleton.

But just how did this strange evolutionary feature come about? How did it start? To answer this, we have to consult that ever-giving encyclopaedia of the history of life, the fossil record.

The fossil record of turtles is quite incredible, covering dozens of now extinct species from a number of different. They have a history of repeatedly adapting to live on land or out at sea. The earliest known turtles stretch back in time to the Triassic period, around 240 million years ago, and perhaps even further.

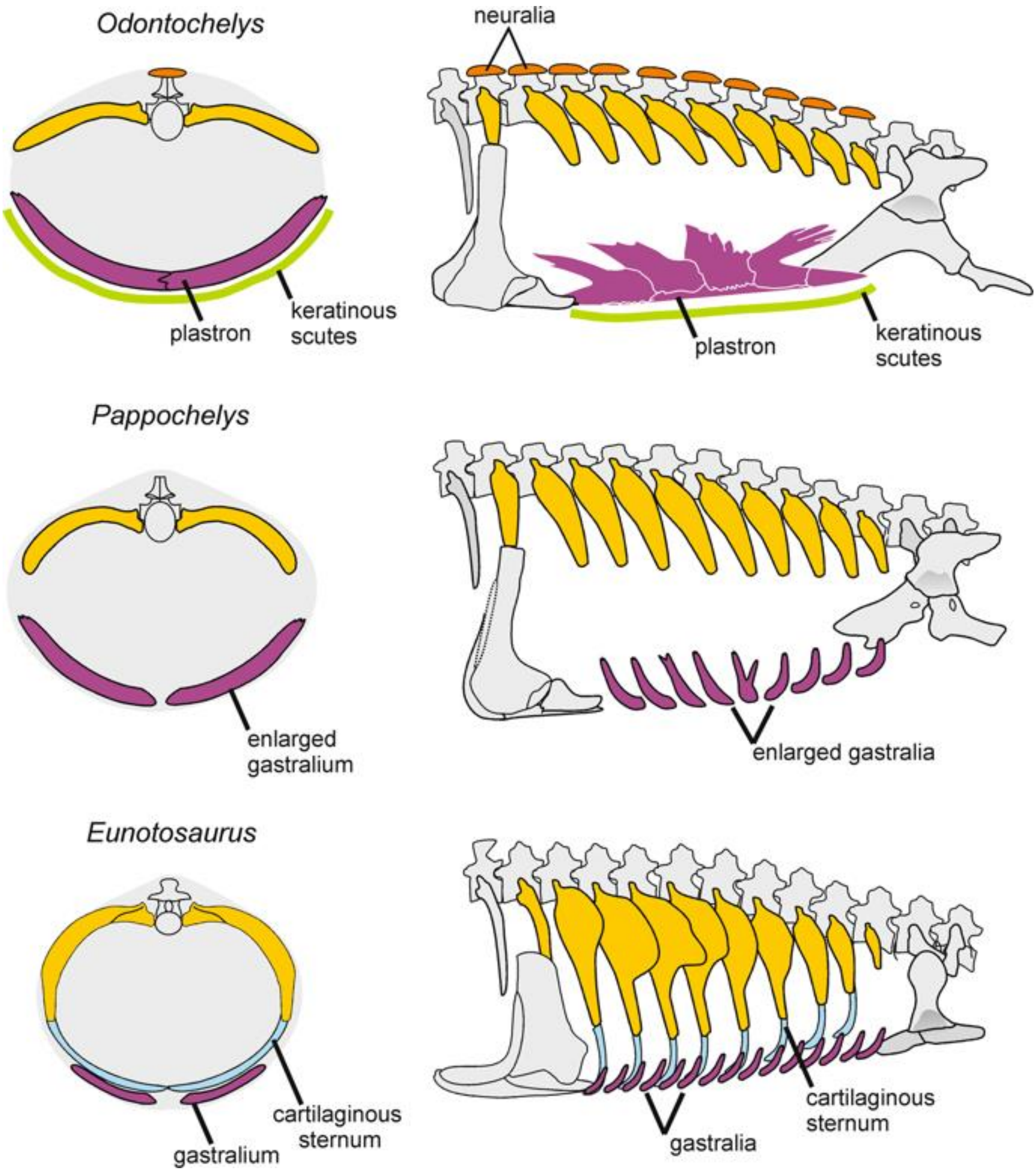
A new study has now tried to shed some light on this evolutionary conundrum. Researchers looked at three of the oldest species known from the Triassic, *Pappochelys*, *Eorhynchochelys* and *Odontochelys*, to try and see if they could trace the early evolution of the first shelled-turtles. For this, they used a technique called paleohistology, which is the study of the internal microstructure of bones. Histology works by carefully creating thin slices of bone and then looking at the texture and features under a microscope.



Outline drawings of stem-turtles *Pappochelys rosinae* (A), *Odontochelys semitestacea* (B), and *Proganochelys quenstedti* (C). (Schoch et al., 2019).

In particular, these three species are important as together they illustrate the earliest evolutionary stages of the development of the plastron. The carapaces for each species were not complete yet, but have different arrangements of their ribs and gastralia (underside body armour) that show different stages in the evolutionary sequence.

What the researchers found were two main things. In *Pappochelys*, the bone microstructure in the ribs was very close to the ‘turtle condition’, found in *Odontochelys*. This includes the presence of strain-resisting fibres within the bone structure itself, an important step in the evolution of the turtle shell. They may have been interconnected into a form of ‘protocarapace’.



Proposed sequence of structural changes to the carapace and plastron in *Eunotosaurus africanus* and the Triassic stem-turtles *Pappochelys rosinae*, *Odontochelys semitestacea*, and *Proganochelys quenstedti*. (Schoch et al., 2019).

The researchers also found information on how the animals might have lived. It seems that *Pappochelys* was most likely amphibious, and might have even dug burrows – a 'fossorial' mode of life. Its bone microstructure was distinct from any other aquatic reptiles, ruling out a free-swimming lifestyle. This is consistent with the fact that fossils of *Pappochelys* were found in rocks interpreted as being formed in a small, freshwater lake. Of course, having a sort of ‘proto-shell’ might have been useful in defence against some of the fearsome predators around during the Triassic. Furthermore, *Pappochelys* had short, robust arms, with long claws – similar to an armadillo – that would have been useful for digging.

However, not everyone agrees the evidence is so strong. Kai Casper, a PhD student at Duisburg-Essen University in Germany said on Twitter “I agree with the general conclusions but the histological evidence is actually rather weak. Comparisons with modern fossorial reptiles could be informative.”

However, it seems that the early stages of turtle shell evolution took place in a terrestrial environment. This means that it might have been a combination of environmental setting, as well as physical protection, that provided evolutionary pressure on the evolution of the turtle shell. The shell might have been critical in helping to provide support for the rest of the turtle body while digging, but ultimately have been secondarily useful in providing protection too.

Reference

Schoch, R. R., Klein, N., Scheyer, T. M., & Sues, H. D. (2019). Microanatomy of the stem-turtle Pappochelys rosinae indicates a predominantly fossorial mode of life and clarifies early steps in the evolution of the shell. Scientific reports, 9(1), 10430. https://doi.org/10.1038/s41598-019-46762-z.

Ancient killer whale snacked on fish, sharks, and…other whales

The fossil record of ancient whales is incredible, revealing to us how these sea-swimming giants evolved from their terrestrial ancestors, and adapted to a range of different lifestyles.

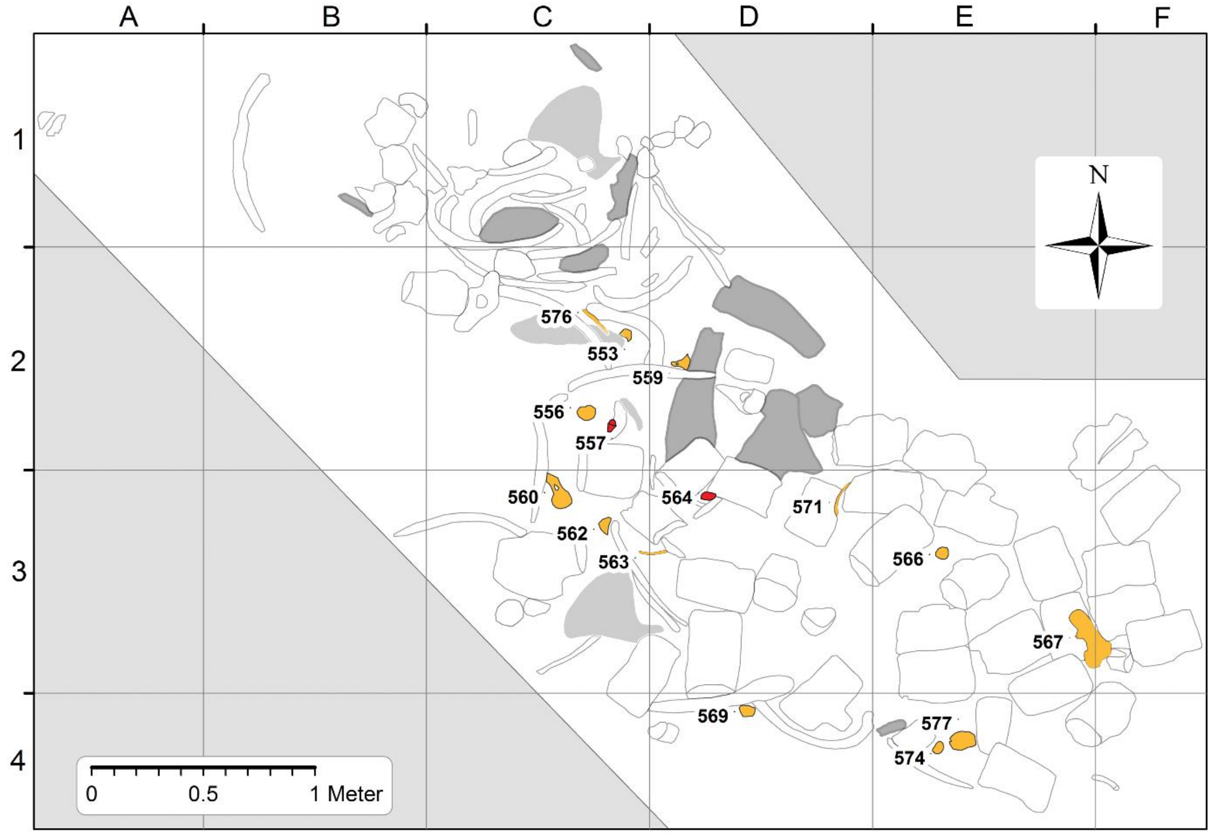
One extinct species called *Basilosaurus* was the largest apex predator of its time, reaching up to 18 metres in length – more than twice the length of a fully-grown killer whale! Now a new study has revealed what one individual consumed for its final meal before death.

The new fossil comes from a place called Wadi Al Hitan, or the 'valley of whales' near Cairo, Egypt. They were discovered by the team back in 2010, and identified as belonging to the species *Basilosaurus isis*.

Map showing the location of the Wadi Al Hitan UNESCO World Heritage Site in the Western Desert of Fayum Province, Egypt. (Voss et al., 2019).

During the late Eocene, around 38-34 million years ago, this locality was about as opposite to how it is now as possible. Much of Egypt was covered by a shallow sea, the remains of which are preserved in the geology and wealth of marine fossils known. Abundant fossils from the valley of whales include fish, sharks, crocodiles, sea snakes, turtles, and a number of different whale species.

One common species of whale found here is known as *Dorudon atrox*, much smaller than the giant *Basilosaurus*, growing only up to around 5 metres in length. The sharp, pointed teeth of *Basilosaurus* would have made light work of *Dorudon*, and this is well-evidenced by the new fossils. Many of the bones of *Dorudon* showed signs where they had been crushed or bitten by the teeth of *Basilosaurus*, and some were even found within their stomach cavity regions! Many of these bite marks were even on the skull bones of *Dorudon*, showing that they had been actively predated on by the ancient orcas. And possibly also chewed and swallowed alive…



Map of *Basilosaurus isis* with locations of other vertebrate specimens superimposed. (Voss et al., 2019).

Alongside the bones of at least two individuals of *Dorudon* were also those of the large shark, *Carcarochles sokolow* and the bony fish, *Pycnodus*. So, one thing we know is that *Basilosaurus* at least enjoyed a variable diet, and nothing in the ancient oceans was safe from its jaws.

This hunting behaviour is similar to the modern killer whale (*Orcinus orca*), which also often predates on other smaller whales and even sharks. They have been known to feed even on the calves or juveniles of humpback whales, but now we know this behaviour goes back many millions of years to the ancestors of modern orcas.

These predator-prey relationships are notoriously difficult to find direct evidence of in the fossil record, and are invaluable in helping to accurately reconstruct past ecological networks. Thanks to these new fossils, we now know that whale-on-whale predation dates back at least 34 million years.

Reference

Voss M, Antar MSM, Zalmout IS, Gingerich PD (2019) Stomach contents of the archaeocete *Basilosaurus isis*: Apex predator in oceans of the late Eocene. PLoS ONE 14(1): e0209021. https://doi.org/10.1371/journal.pone.0209021.

Armoured dinosaurs had an efficient internal cooling system

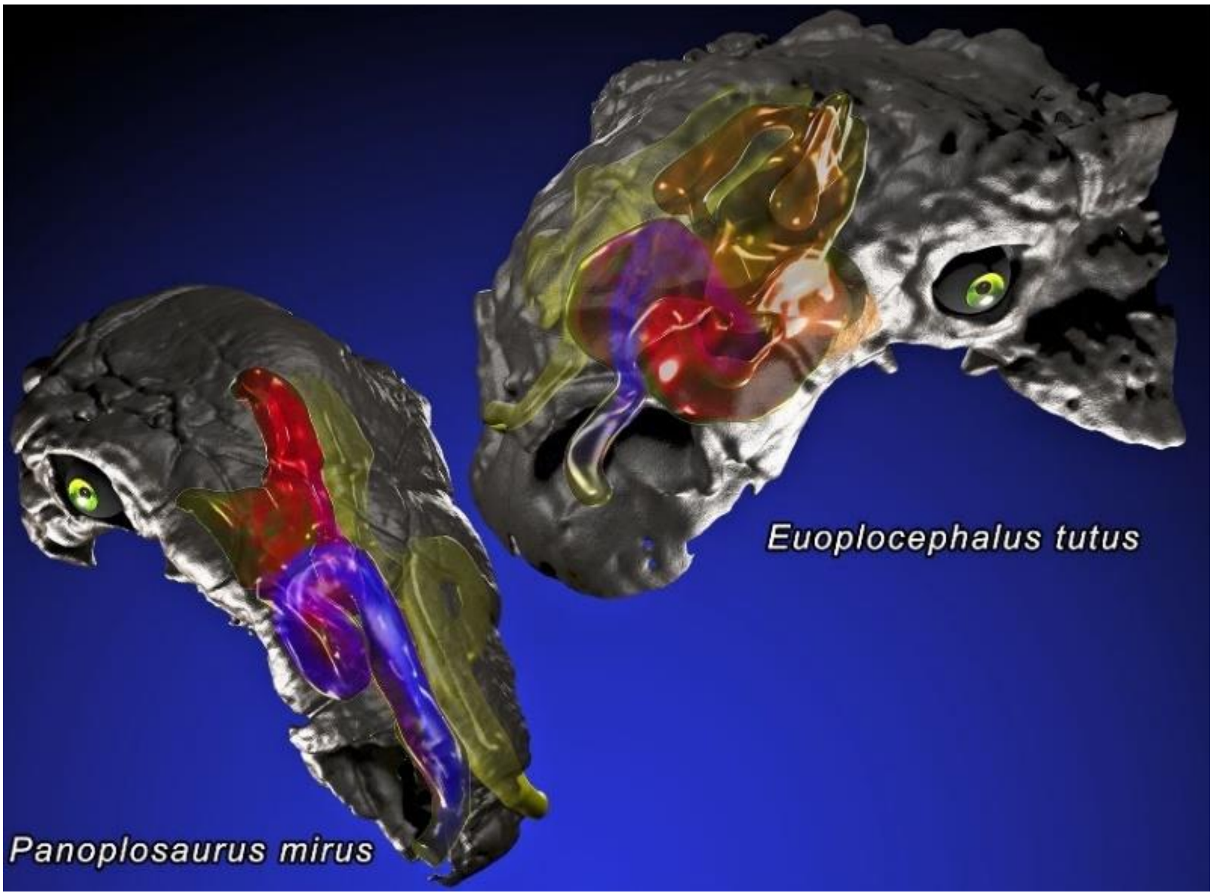
Ankylosaurs are the group of herbivorous ornithischians that looked like armoured-rhinos. Renowned for being covered in thick bony plates for protection against predators, many also wielded dangerous clubs on their tails – even lending some the nickname 'destroyer of shins' as a result.

But, as Ace Ventura let us know oh too well, it sure does get kinda hot in these rhinos. So, imagine for a second what it might be like for a rhino covered in armour plates.

Well, was it the same for ankylosaurs? A new study shows that ankylosaurs were able to regulate their body temperature using a system of nasal passages that allowed for more efficient exchange between the air and the body. This is similar to the process that some modern mammals and birds use, whereby air is warmed as it is inhaled, and cooled as it exhales to reduce heat loss.

Such a suggestion linking form and function has been proposed before for ankylosaurs, with research dating back to the 1970s. But one of the cool things about much of modern Paleontology is that it is about looking at old questions using new techniques. So, while much of this discovery is largely thanks to a wave of new ankylosaur discoveries, often with exquisite, three-dimensional preservation, much is also down to modern digitisation and imaging techniques. These are opening up new dimensions into how researchers can reconstruct and analyse extinct animals, and bring Paleontology into the digital 21st century of research.

What the researchers were able to do is construct 3D digital reconstructions of the fossilised nasal passages from two ankylosaur species, *Panoplosaurus mirus* and *Euoplocephalus tutus*. From this, they applied computational fluid dynamic analyses, the sort of tests designed for aeronautical or automotive engineering, to simulate airflow and heat transfer during a simulation of breathing.



Panoplosaurus mirus and *Euoplocephalus tutus*. (Bourke et al., 2018).

By doing this, they were able to quantify just how much heat energy would be preserved, estimating it to be between 65% and 84% per breath. This is comparable to many modern mammals that live on land, and also would have helped to save on energy bills. When you take in between 34-64 litres of air in each breath, as the researchers estimated, this equates to quite a bit of heat energy being conserved.

Lead author of the study, Jason Bourke said: “The large body sizes of dinosaurs like ankylosaurs, would have worked great for retaining heat, but they would also have put the small brains of these dinosaurs at a constant risk of overheating. Ankylosaurs appear to have solved this problem by greatly stretching out and coiling their nasal passages within their skull, allowing them to cool down blood destined for the brain and providing an effective air conditioner for their heads.”

It seems that by having a complex maze of air passages, ankylosaurs were able to therefore regulate their body temperatures much more efficiently. By coiling into a labyrinthine fleshy network, this helped to increase the relative surface area to volume to allow much more efficient transfer of heat during breathing. Evolution, you so crazy.

Reference

Bourke JM, Porter WR, Witmer LM (2018) Convoluted nasal passages function as efficient heat exchangers in ankylosaurs (Dinosauria: Ornithischia: Thyreophora). PLoS ONE 13(12): e0207381. https://doi.org/10.1371/journal.pone.0207381.

Crikey! We're gonna need a bigger boat…

The first fossils of a giant ancestor of the great white shark have been discovered in Victoria, Australia.

Philip Mullaly, a fossil enthusiast, was having a stroll down the beach at Victoria's popular surf coast, when something caught his eye. Sticking out of a boulder was part of a shark tooth, perfectly preserved, and still shining after millions of years of preservation as a fossil.

Carcharocles angustidens teeth. Credit: Museums Victoria.

Mullaly immediately recognised that these were an important scientific discovery, and contacted Erich Fitzgerald of Museums Victoria. After a preliminary examination, Fitzgerald then led a team on two further expeditions to the site at Jan Juc. There, they discovered more than 40 individual teeth within the original boulder of discovery, all coming from the same species.

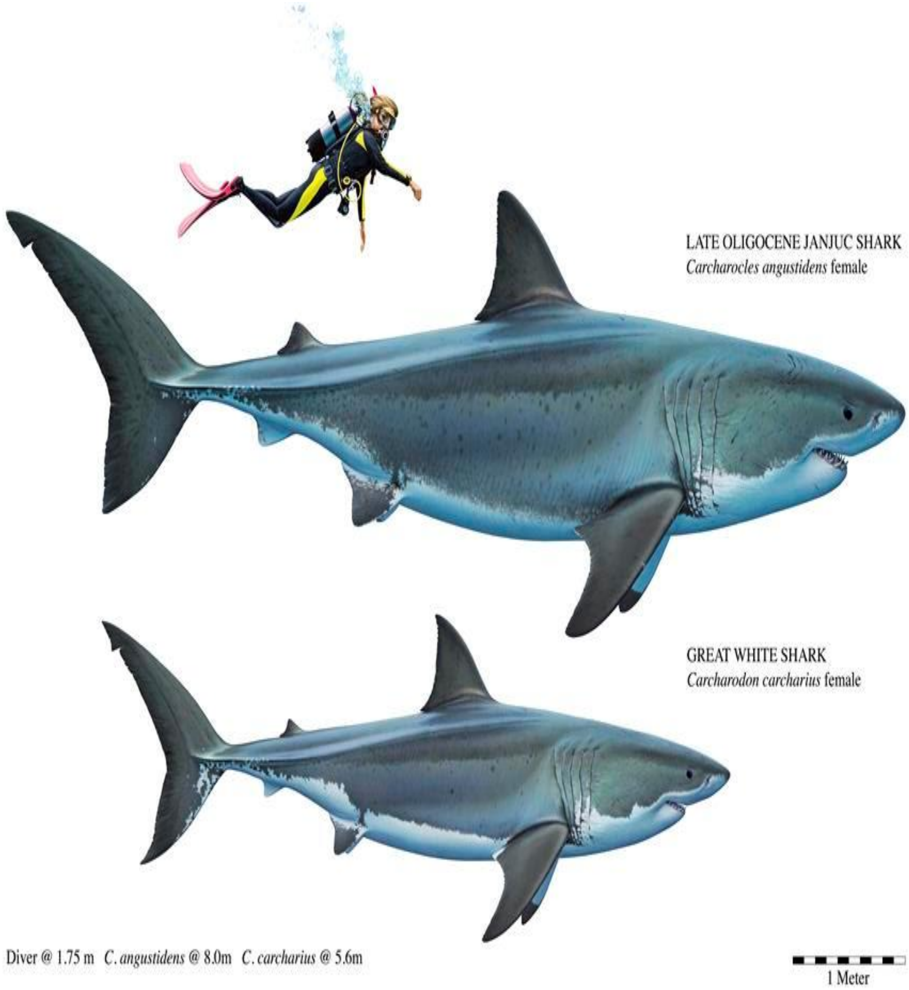
They belonged to a now extinct species called *Carcharocles angustidens*, which has a common name, the Great Jagged Narrow-Toothed Shark. This mega-toothed shark species would have swum the ancient seas around Australia around 25 million years ago, during a time known as the Oligocene.

The first discoveries of this species date back to 1835, when it was named by the Swiss naturalist Louis Agassiz. He originally identified it as a prehistoric species of the modern great white shark, *Carcharodon*. However, in 1987, French shark expert Henri Cappetta recognised it as a distinct lineage, and named the new genus *Carcharocles*.

The collection of teeth were up to 7cm long, which is big for a shark. Previous discoveries of the same species from rocks in New Zealand were even bigger, at almost 10cm in length. Shark teeth are fairly common in the fossil record, being one of the only parts of a shark that usually preserves. This is because shark skeletons are made of cartilage, not bone, which is softer and more difficult to fossilise. Finding multiple teeth from the same shark is still a rare discovery though.

These teeth are of international significance, as they represent one of just three associated groupings of *Carcharocles angustidens* teeth in the world, and the very first set to ever be discovered in Australia. – Dr. Fitzgerald.

This species grew to more than 9m in length, which is far larger than the modern great white shark, and almost twice its length. It is thought that it would have even preyed on small whales around at the time, as well as penguins, dolphins and fish. The teeth of *Carcharocles* were very pointed, and had sharp serrations along the sides, perfect for gripping on to fleshy prey.



C. angustidens and *C. carcharius* size comparison. Credit: Peter Trusler.

As well as the teeth of *Carcharocles*, the boulder also contained teeth from a small species, *Hexanchus* – the Sixgill shark, which still survives to this day off the coast of Victoria. The research team believes that these teeth come from several individual animals, which were scavenging on the huge carcass of the *Carcharocles* after it died and sunk to the sea floor. As they feasted, their teeth would have detached, which is not such a huge problem for sharks, which can rapidly regenerate lost teeth.

A prehistoric shark feast! *Carcharocles angustidens* being feasted upon by several Sixgill Sharks. Credit: Peter Trusler.

Mullaly has kindly donated the fossils to Museums Victoria's collection, where they can be further studied and used for educational purposes. They will be unveiled to the public at the Melbourne Museum on 9^{th} August as part of a Mega Shark Fossil Find display.

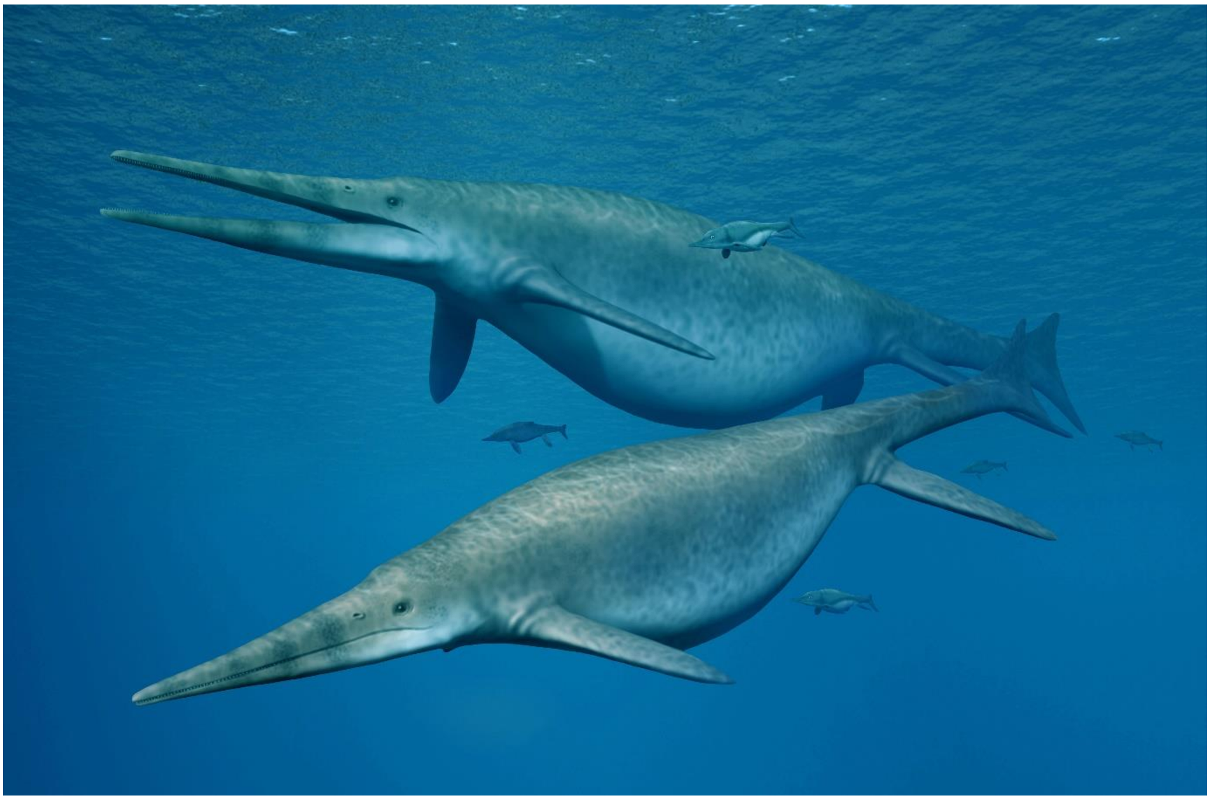
A case of Mesozoic misidentification

Did you know that sometimes scientists make mistakes? Yep, I know it might be shocking, but they're not always right, despite liking to think so some times. But this is one of the beautiful things about science. It is an inherently human endeavour, and therefore subject to human error and uncertainty. Scientists make deductions and conclusions based on the best possible evidence available to them at any given time. It's what sets science apart from, let's say, politics.

But what happens when the evidence changes? Well, so do our scientific conclusions, then. And palaeontology is no exception to this.

Often, for example, what might be identified as one animal or species in the fossil record turns out to be something completely different after new information comes to light. Known as the study of taxonomy, such reidentifications are actually fairly common as our knowledge improves with every new discovery. Each new fossil specimen we discover tells us a little more about the evolution of life on this planet.

Enter fossil collector Paul de la Salle. On the beaches of Lilstock in Somerset, UK, Paul recently discovered the ancient fossilised lower jawbone of an ichthyosaur. He contacted several ichthyosaur specialists about the discovery to see what they made of it.



Shonisaurus giant ichthyosaur. Credit and copyright: Nobumichi Tamura.

Dean Lomax (University of Manchester, UK) and Prof. Judy Massare (SUNY College at Brockport, NY, USA) carefully studied the new specimen, and realised that it was part of the lower jaw of an ichthyosaur, a bone called the surangular. The strange thing about this specimen though was that it was relatively huge compared to virtually anything the researchers had seen before.

The researchers also realised something very odd, related to a puzzling historical conundrum. Bones from Aust Cliff, Gloucestershire, UK, that were discovered in 1850 have been identified as limb bones of an early and huge dinosaur (or close relative), such as a stegosaur or sauropod. However, Lomax and Massare noticed that they actually looked almost identical to the newly discovered Lilstock specimen. Rather than being bits of dinosaur, it seems they too are jaw fragments of a long extinct and previously unknown species of giant ichthyosaur.

Jaw bone of giant ichthyosaur (image courtesy of Dean Lomax).

Dean said: “One of the Aust bones might also be an ichthyosaur surangular. If it is, by comparison with the Lilstock specimen, it might represent a much larger animal. To verify these findings, we need a complete giant Triassic ichthyosaur from the UK – a lot easier said than done!”

This case of mistaken identity reveals that there were ichthyosaurs that were even bigger than dinosaurs swimming around the UK at the same time as them.

The Lilstock specimen comes from a period known as the Triassic, around 205 million years ago. This was a period when the ancient seas were ruled not by mammals like today, but a weird variety of marine reptiles, including numerous ichthyosaurs.

Some ichthyosaurs, such as *Shonisaurus*, grew up to be around 21 metres in length. That’s pretty huge for an ancient fish lizard! However, estimates of the newly analysed specimens put it at around 26 metres in length, making it the biggest ichthyosaur currently known.

To test to see just how big this animal was, Lomax and Massare set off to Canada, to the Royal Tyrell Museum in Alberta. Here, they compared the metre-long jawbone to those of the largest ichthyosaurs otherwise known. What they realised is that the new specimen represents the largest individual currently known, with a hint of uncertainty as only a single bone from the animal exists.

They also recognised a lot of similarities with *Shonisaurus*, suggesting that the specimen from Lilstock represents a species from a group known as shastasaurids – the group with the largest ichthyosaur species. Whatever its affinities, this means that huge ichthyosaurs were alive and kicking in the Late Triassic period, even close to the time of the end-Triassic mass extinction.

So, how long now until the Hollywood monster movie..?

Reference

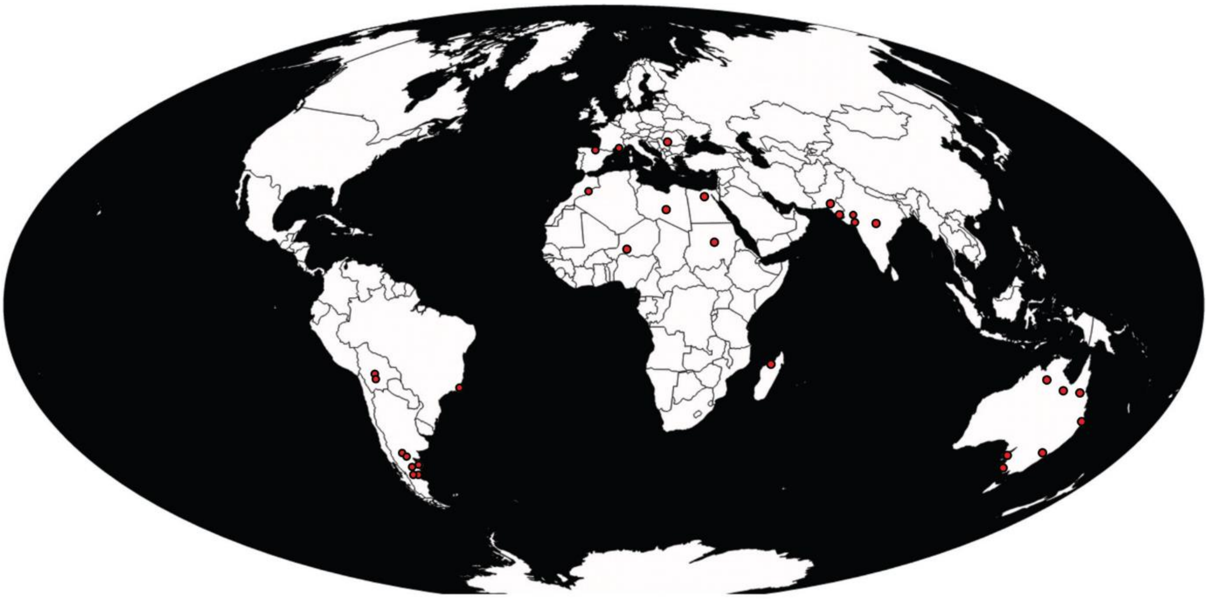
Lomax DR, De la Salle P, Massare JA, Gallois R (2018) A giant Late Triassic ichthyosaur from the UK and a reinterpretation of the Aust Cliff 'dinosaurian' bones. PLoS ONE 13(4): e0194742. https://doi.org/10.1371/journal.pone.0194742.

Snakes. Why did it have to be giant snakes?

Snakes are beautiful and bizarre animals. Limbless vertebrates, they have been around for more than 150 million years, and occupy almost every ecological role possible, including living under the sea!

Over geological time, they have come in all sorts of shapes and sizes (typically still sausage-ish shaped), and have a unique evolutionary history.

One particular group of snakes, Madtsoiidae, used to be widely distributed around the world back in the Cretaceous when the dinosaurs ruled. They are now extinct, with a range of around 100 million years, making them one of the longest-lived lineages ever.



Geographic distribution of Madtsoiidae, plotted on a present-day map (Rio and Mannion, 2017).

The first named madtsoiid was back in 1901, and called *Gigantophis garstini*. It was discovered from 40-million-year-old rocks in very, very ancient Egypt. From the name, you can probably tell that this was one hefty snake, bigger than an anaconda and making most modern species look like something you'd find in a pick n mix.

However, *Gigantophis* isn't that well understood by scientists, and only 20 vertebrae are known in total for the species. Previous research from the early 20th century only briefly figured and described the specimens, which have otherwise remained unstudied in the Egyptian Geological Museum in Cairo for more than a century.

Jonathan Rio and Phil Mannion (my old PhD supervisor!) recently undertook the mammoth task of redescribing and analysing these vertebrae. They compared them to similar fossils from across North Africa and Pakistan, to see what they could learn about the mystery giant snake.

What they discovered is that other material that had been referred to this species from Pakistan was markedly different, and most likely a new species altogether. Instead, *Gigantophis* appears to have been confined to the late Eocene of North Africa.

Life-sized model of *Titanoboa* devouring a dyrosaurid crocodyliform, from the Smithsonian exhibit (Credit: Ryan Quick, CC BY 2.0).

By comparing the vertebrae to those of living snakes, they were able to estimate that *Gigantophis* was around 7 metres in length. When discovered, researchers thought that *Gigantophis* was the biggest of all snakes ever known, and an analysis in 2004 estimated that it could grow to around 10 meters in length!

However, in 2009, *Titanoboa* was discovered from the Paleocene of Colombia, which has since gained notorious fame for its immense slithery size, coming in at around 12-13 metres in length. Down the ladder *Gigantophis* went.

A new analysis of *Gigantophis*' evolutionary relationships found that its closest relative was an Indian species called *Madtsoia*. Its scaly cousin was much older, living in the latest Cretaceous, before the great dinosaur extinction. This distinction in time and space suggests that during the Cretaceous, these strange snakes were much more widespread across the southern continents, although it is remains difficult to know exactly what happened. This is because the fossil record is notoriously bad at this time, and therefore we're probably just not finding the fossils needed to help fill the gaps in the puzzle.

So, you know what to do. Next time you're out exploring in SE Asia, South America, or Africa, keep an eye out for giant snake fossils!

Reference

Jonathan P. Rio & Philip D. Mannion (2017): The osteology of the giant snake Gigantophis garstini from the upper Eocene of North Africa and its bearing on the phylogenetic relationships and biogeography of Madtsoiidae, Journal of Vertebrate Paleontology, DOI: 10.1080/02724634.2017.1347179.

34-million-year-old carnivore named after the Egyptian god of the Underworld

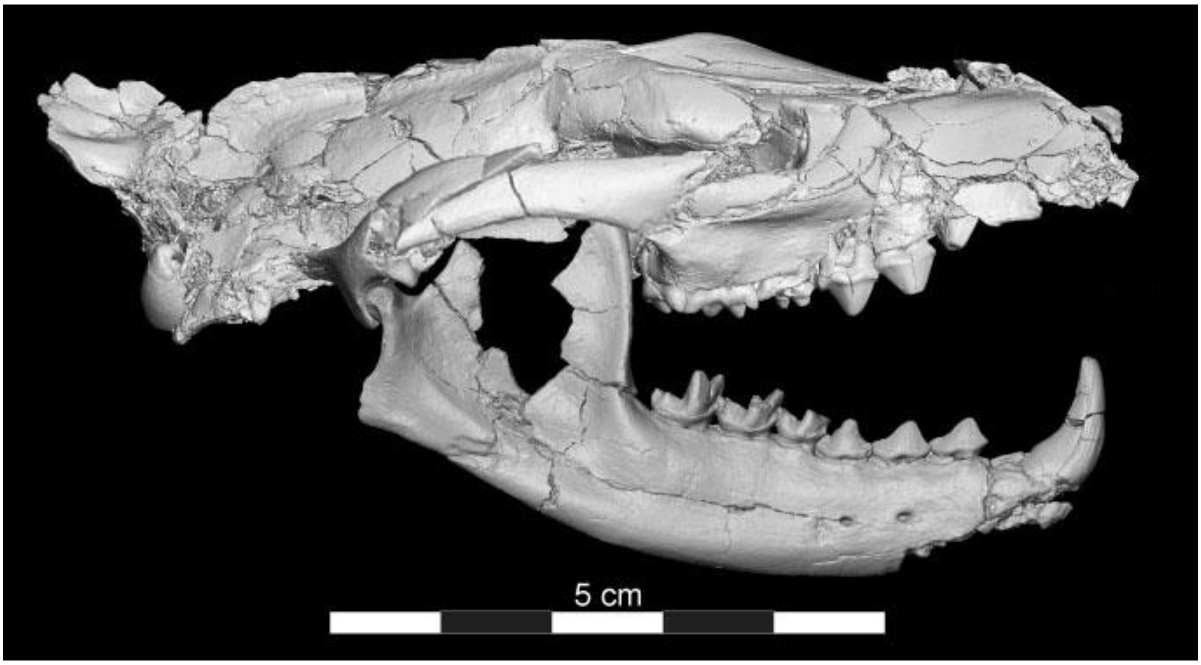
Naming a new species is a wonderful thing to do. It's a statement that you've discovered an entirely new organism to science, and naming it is a personal touch about how you perceive the importance of it.

Last year, researchers named a 34-million-year-old canine-like fossil from Egypt, with an exquisitely preserved skull. It was named after the ancient Egyptian god of the Underworld, Anubis, often associated with the afterlife.

Anubis attending to a mummy (Source: Wikipedia, public domain).

Its full name is *Masrasector nananubis*, the species name actually meaning “little Anubis” from Greek νάνος (nannos) for little and Anubis (Ἄνουβις). How appropriate for this little dog-like fossil!

The researchers who named it are Matthew Borths from Ohio University and Erik Seiffert from the University of Southern California. All specimens were collected over decades of excavation from a locality known as the Fayum Depression, 14.5 km west of Qasr el-Sagha Temple. Rocks the fossils were excavated from dated to the Late Eocene, making them around 34 million years old.



The skull of *Masrasector nananubis*. Credit: Matt Borths.

The animal is known as a hyaenodont, which you might be able to guess from the name is a relative of modern hyenas and other doggos. In the past, these carnivores lived widely across Africa, Europe, Asia and North America, radiating after the extinction of the predatory dinosaurs.

However, the relationships of these hyaenodonts has been difficult to resolve in the past due to their poor fossil record, which almost exclusively comprises tooth remains. This is especially the case for a sub-group called teratodontines, an Afro-Arabian group which *Masrasector* was part of.

Thankfully, due to the amazing preservation of *Masrasector*'s skull, as well as some of its jaws and limb bones, researchers were able to show that *Masrasector* and other teratodontines were closely related to other hyaenodonts that had a hypercarnivorous diet – eating almost exclusively meat.

The length of the limb bones also showed that *Masrasector* was a fast, agile hunter, just like modern hyenas. At only the size of a skunk though, and weighing only around 1kg, it's likely that *Masrasector* only fed on smaller prey items. Its teeth were quite similar to those of a mongoose, and *Masrasector* probably had a diet of mostly small vertebrates and insects, as well as some fruits and nuts.

“Hyaenodonts were the top predators in Africa after the extinction of the dinosaurs,” says Borths. “This new species is associated with a dozen specimens, including skulls and arm bones, which means we can explore what it ate, how it moved, and consider why these carnivorous mammals died off as the relatives of dogs, cats, and hyenas moved into Africa.”

Good doggy.

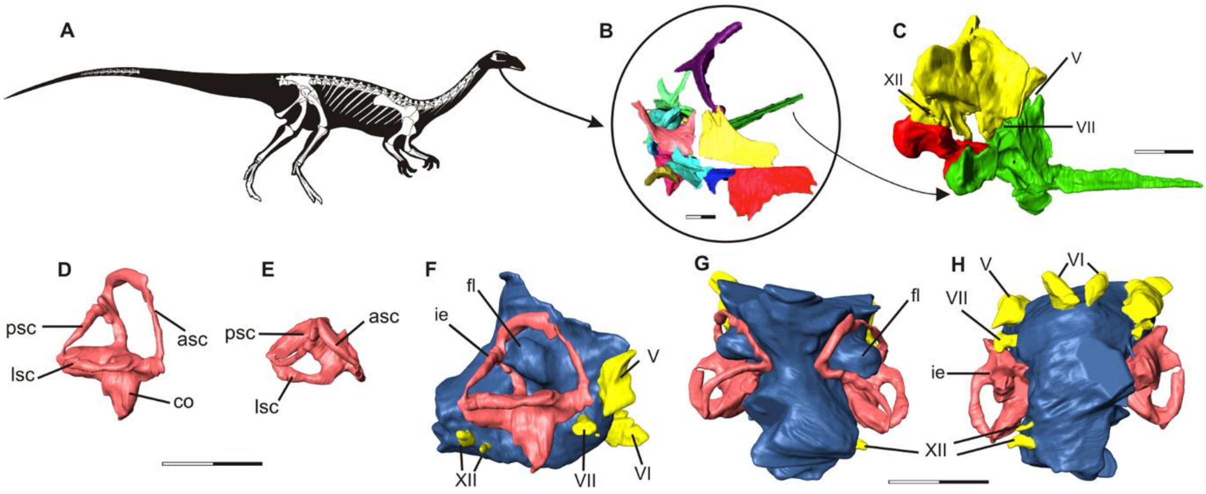
Reference

Borths MR, Seiffert ER (2017) Craniodental and humeral morphology of a new species of Masrasector (Teratodontinae, Hyaenodonta, Placentalia) from the late Eocene of Egypt and locomotor diversity in hyaenodonts. PLoS ONE 12(4): e0173527 https://doi.org/10.1371/journal.pone.0173527.

Was the ancestor of the giant sauropods a predator?

How cool would it be to go back in time and see how dinosaurs behaved in real life?? I think most people who’ve seen Jurassic Park (the original one…) would agree this would be pretty awesome. However, at the moment, the science behind both time travel and genetic manipulation of frog DNA is lacking (we’re looking at you, research funding bodies), so we’re a little stuck.

That is, unless you’re a master detective of the fossil record. By combining scientific research, the latest technologies, and the fossil record with a bit of imagination, researchers now are able to breathe a dimension of realistic life into even the most ancient dinosaurs.



The early sauropodomorph *Saturnalia tupiniquim*. Skeletal reconstruction (A). Virtual preparation of cranial bones as preserved inside the matrix (B), with braincase highlighted in right lateral (C) view. Reconstruction of the soft tissues associated with the braincase: right inner ear in lateral (D) and dorsal (E) views, and endocast in lateral (F), dorsal (G), and, ventral (H) views. Abbreviations: asc – anterior semicircular canal; co – cochleae; fl – Floccular Fossae Lobe; ie – inner ear; lsc – lateral semicircular canal; psc – posterior semicircular canal; V – trigeminal nerve; VI – abducens nerve; VII – facial nerve; XII hypoglossal nerve. Scale bars = 1 cm. (Bronzati et al., 2017).

CT, or Computed Tomography, is a digital scanning method borrowed from medical research. If you've ever had your brain scanned, chances are it was by a CT machine. Mario Bronzati, a grad student studying at the Ludwig-Maximilians-Universität in Munich, along with colleagues from Brazil, used CT scanning to create a high-resolution and detailed image of the skull and braincase of a dinosaur called *Saturnalia*.

Paleoneurology – interdisciplinary research at its finest!

Just to reiterate – they are studying actual dinosaur brains here, based on the structure of their braincases! That's pretty awesome, seeing as brains don't really preserve well over millions of years in the fossil record. Using digital reconstructions is the only way that we can really look at their brains in any sort of detail. Without breaking them, importantly.

Saturnalia is one of the earliest known dinosaurs, coming from Brazil during a time known as the Late Triassic, around 230 million years ago. It belongs to a group of dinosaurs called sauropodomorphs – including famously known species such as *Diplodocus* and *Dreadnoughtus*. These animals were true giants of the Mesozoic, with species weighing up to 90 tonnes, and growing up to 40 metres in length!

But not *Saturnalia*. This little dinosaur was the early precursor to its behemoth descendants, and only grew to around 1.5 metres in length, weighing only up to 10 kilograms.

During this period, dinosaurs weren't quite the dominant animals that we know often think of them as, and lived alongside and competed with a whole range of other strange reptilian groups.

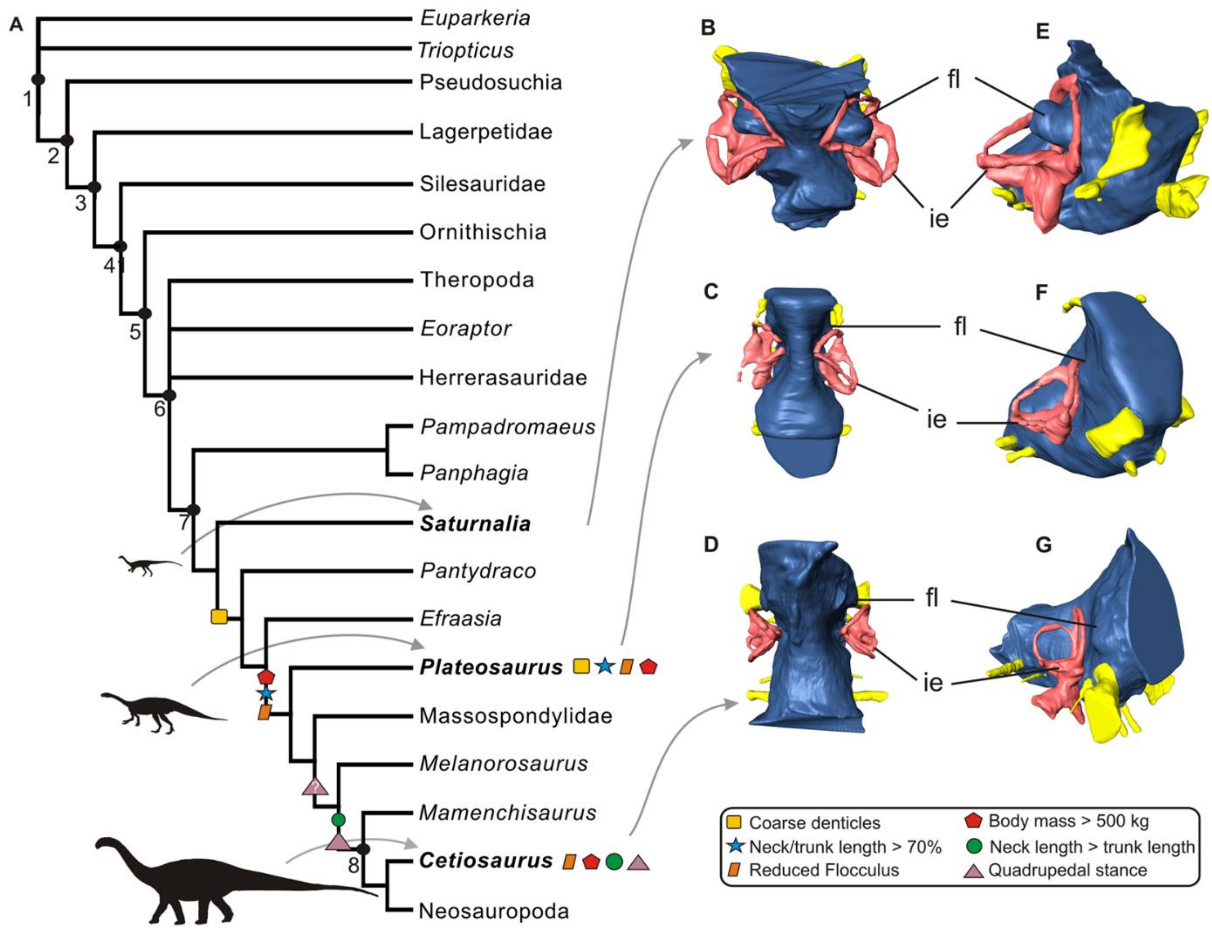
Why dinosaurs?

This Triassic diversity begs the question of why did dinosaurs go on to become the sole winners for so long? They reigned supreme on land for around 160 million years, going on to even give rise to modern birds – as such, dinosaurs are still in some ways the one of the dominant vertebrate groups on this planet!

This new study is the first time that the braincase of one of the earliest dinosaurs has ever been able to be reconstructed in such a way, and reveals exciting possibilities for what we can learn about their behaviour.

Brains > brawn

With dinosaurs, scientists can usually figure out roughly what they ate based on their teeth. If they're sharp and pointy, usually this means they liked to chow down on other animals. If they were more flattened or peg-like, they usually preferred a diet of plants – veggiesaurs. This includes the sauropodomorphs, and also their ornithischian cousins. Or at least, that's what scientists broadly understand based on their teeth.



Simplified Archosauriformes phylogeny highlighting character acquisition in Sauropodomorpha (A). Endocasts of *Saturnalia tupiniquim* (MCP-3845-PV), *Plateosaurus* (MB.R.5586-1), and a sauropod specimen tentatively reffered to *Cetiosaurus* (OUMNH J13596) in dorsal (B,C,D) and anterolateral (E,F,G) views showing the morphology of the Floccular Fossae Lobe in sauropodomorph dinosaurs. Abbreviations: fl – Floccular Fossae Lobe, ie – inner ear, 1 – Archosauriformes, 2 – Archosauria, 3 – Dinosauromorpha, 4 – Dinosauriformes, 5 – Dinosauria, 6 – Saurischia, 7 – Sauropodomorpha, 8 – Sauropoda. (Bronzati et al., 2017).

By looking at the brain of *Saturnalia*, Bronzati found that the earliest sauropodomorphs most likely actually had a diet of meat – they were predators! This is because two regions of the brain – the flocculus and the paraflocculus lobes – were both found to be surprisingly large compared to other herbivorous sauropods; what Bronzati calls an “enlarged protuberance”. Reduction of these brain sections is usually associated with the adoption of a four-legged, quadrupedal, stance in later sauropodomorphs. Which works nicely, as *Saturnalia* most likely frolicked around on just two legs, unlike its giant descendants.

Both of these brain sections are part of the cerebellum, and are responsible for moving the head and neck, as well as in stabilizing the gaze of an animal. The large size suggests that *Saturnalia* was quite smart in the way it co-ordinated its head and neck, much like we see in modern predators when hunting their prey. For example, think of a wolf chasing a rabbit – small, rapid movements enable a predator to respond fast to an elusively darting prey.

Previous research based on their anatomy suggested at most an omnivorous diet, with their teeth being curved backwards and with small serrations on the tips. Bronzati's study shows us that by looking at old animals in new ways, we can unlock a whole new understanding of dinosaurs and their evolution. In the paper, it is stated "making inferences on the lifestyle of extinct taxa using a single criterion can be misleading. Form/function correlations should be very carefully made, and other parameters (historical and ahistorical) should be taken into account when inferring the ecology of extinct taxa."

For example, *Saturnalia*, like other sauropods, had a small head and a long neck. Typically, these features have been associated with adaptations for herbivory and grazing – swinging your head from side to side like a rake to pull in foliage. But what if actually these features were originally triggered by adaptations to predation? This would flip our understanding of their evolutionary history around, as well as change our interpretation of the evolution of the feature in itself.

Bronzati is already on the lookout for more dinosaur skulls to scan, hoping that he can build up a more complete picture of their brain evolution through time.

Reference

Bronzati, M., Rauhut, O. W., Bittencourt, J. S., & Langer, M. C. (2017). Endocast of the Late Triassic (Carnian) dinosaur *Saturnalia tupiniquim*: implications for the evolution of brain tissue in Sauropodomorpha. *Scientific Reports*, *7,* https://doi.org/10.1038/s41598-017-11737-5.

Life after death: Largest discovered *Ichthyosaurus* preserves a fossilised embryo

Ichthyosaurs, meaning 'fish lizards', are a bizarre group of ancient marine reptiles that went extinct around 90 million years ago. They looked suspiciously similar to dolphins, but are only very, very distantly related to the modern mammals. They captivated the attention of scientists and the public alike due to numerous discoveries by Victorian palaeontologist, Mary Anning, who collected dozens of skeletons from the Dorset coast in the UK.

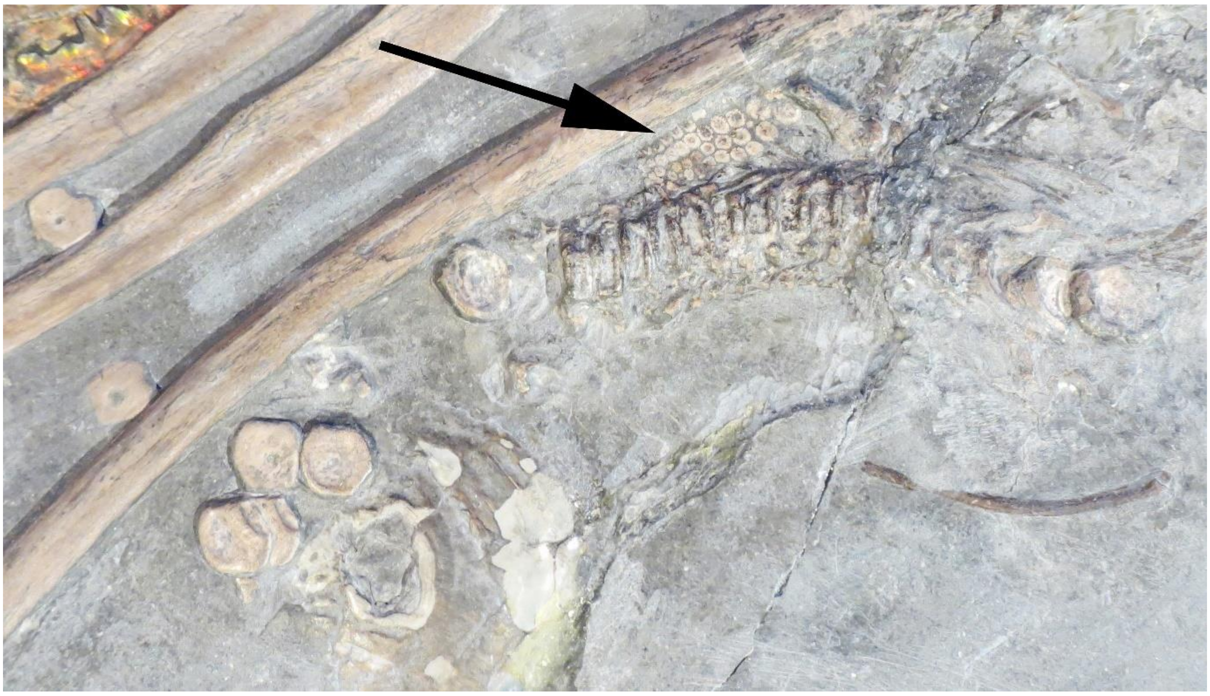
Now, researchers have described the largest known *Ichthyosaurus* on record, measuring a whopping 3-3.5m in length. *Ichthyosaurus* was one of the more common and well-known ichthyosaurs, with thousands of fossils known from the UK. But *Ichthyosaurus* was still a small fry compared to some such as *Shonisaurus* which could grow to around 20 metres in length!

Dean Lomax and Sven Sachs carefully studying the skeleton. Photo © Dean R. Lomax. Used with permission.

The specimen has actually been known for more almost 30 years, discovered in the 1990s by professional fossil collector, Peter Langham, at Doniford Bay on the Somerset coast in the UK. In 2007, it made its way to the collections of the Lower Saxony State Museum in Hannover, Germany, where it came under scrutiny from local palaeontologist Sven Sachs.

Sachs, of Bielefeld Natural History Museum in Germany, first saw the specimen back in August 2016 while on a routine research visit. Noticing that this was not your ordinary ichthyosaur specimen, Sachs contacted Dean Lomax, a palaeontologist and ichthyosaur expert from the University of Manchester in the UK. Together, they studied the specimen closely, identifying it as a species called *Ichthyosaurus somersetensis*, which Lomax had only newly identified and named earlier this year.

The researchers identified the skeleton as belonging to an adult female. How? Well, the animal was pregnant at the time! Encased for more than 200 million years in stone, the researchers discovered the delicately fossilised remains of an ichthyosaur embryo inside the ribcage of the adult.



The preserved immature skeleton of the embryonic ichthyosaur. Photo © Dean R. Lomax. Used with permission.

According to Lomax, this is only the third known fossil of an *Ichthyosaurus* with an embryo, making it a rare and special discovery.

"With over a thousand *Ichthyosaurus* specimens known it is surprising that this (the largest) has gone unnoticed for such a long time," said Lomax. "When I heard of this specimen I instantly arranged to visit and study it! As it is the biggest known, it will help in understanding how these ichthyosaurs developed and changed over time."

The embryo fossil itself is contained within the fossil of the mother, and is therefore the first which can be confidently assigned to a particular species of ichthyosaur. It is only partially complete, preserving some of the 6-7cm long vertebral column, a tiny fore-fin with a spongy texture, characteristic of immature skeletons, as well as several ribs and other bones.

Does this mean *Ichthyosaurus* gave birth just to one individual at a time? Or was this just an unlucky individual who died before giving birth to its final offspring? Only with more specimens and research will these questions be answered!

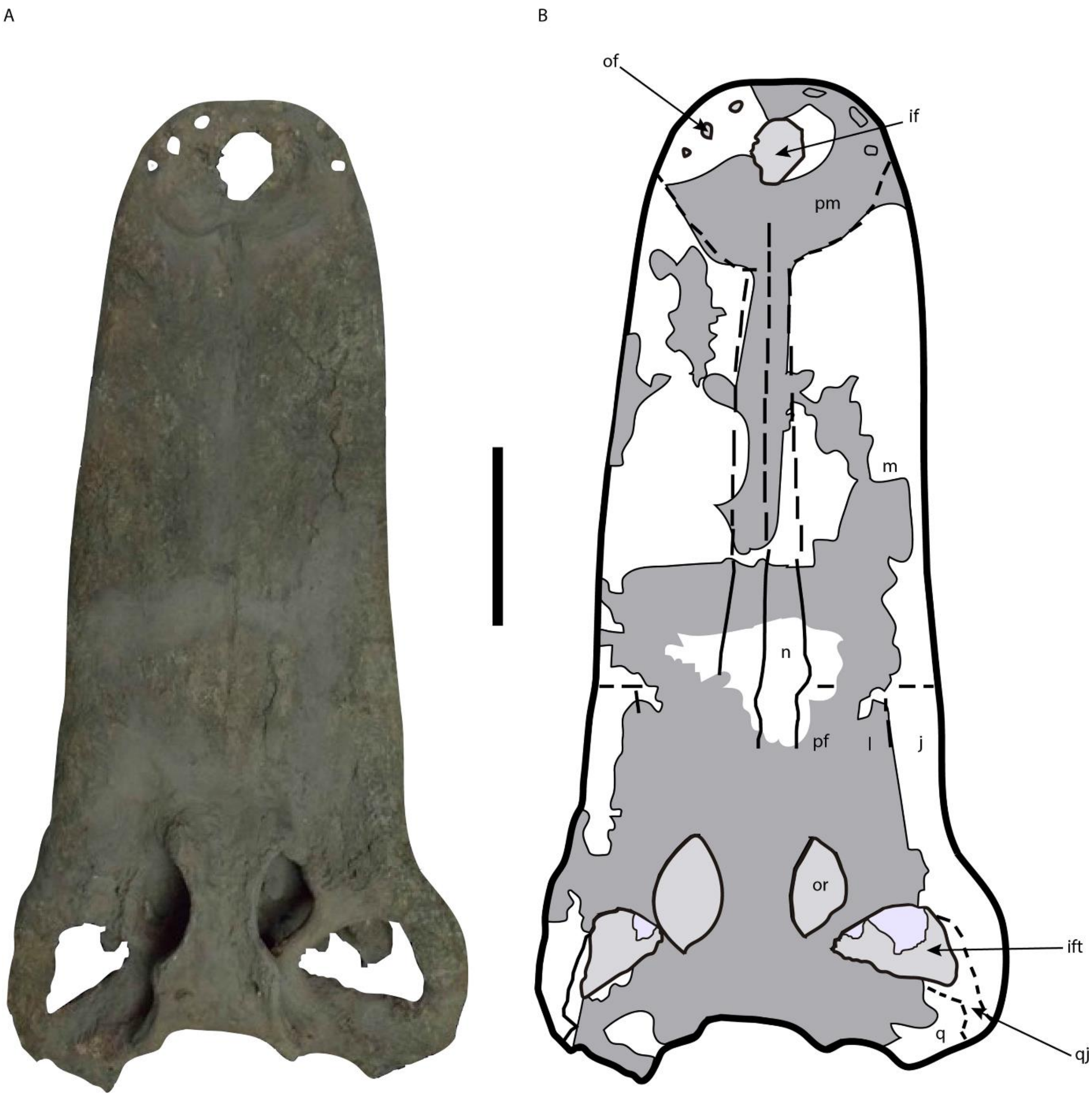
Reference

Lomax, D.R. and Sachs, S. 2017. On the largest *Ichthyosaurus*: A new specimen of *Ichthyosaurus somersetensis* containing an embryo. *Acta Palaeontologica Polonica*, 62(3), 2017: 575-584, doi: 10.4202/app.00376.2017.

South American caiman ancestor gulped its prey like a pelican

Modern crocodiles and their ancestors, the crocodyliforms, have a weird and wonderful evolutionary history. If you look back in time through the fossil record, we see that we have a huge diversity of species with peculiar forms. This includes giant sea-swimming species, armoured armadillo-like ones, and even some which were more boar-like and herbivorous.

One of these now extinct crocodyliforms, known as *Mourasuchus*, had an unusually wide and flat snout, sort of like an elongated pancake. Its mandibles were very long and slender, not like the strong and robust jaws we see in most modern predatory crocodiles.



The skull of *Mourasuchus pattersoni* (Cidade et al., 2017).

Mourasuchus is part of a group called Caimaninae, which includes the modern caiman, and are found mostly in South America – both the fossils and the living species. In a recent study, a team of researchers from Brazil and Venezuela identified a new species of this animal, named *Mourasuchus pattersoni*. This joins the other three named species of this genus, all also known from the Miocene (5-23 million years ago) of South America.

Vital statistics

Country: Venezuela

Location: NE of the town Urumaco, Falcón state, Venezuela

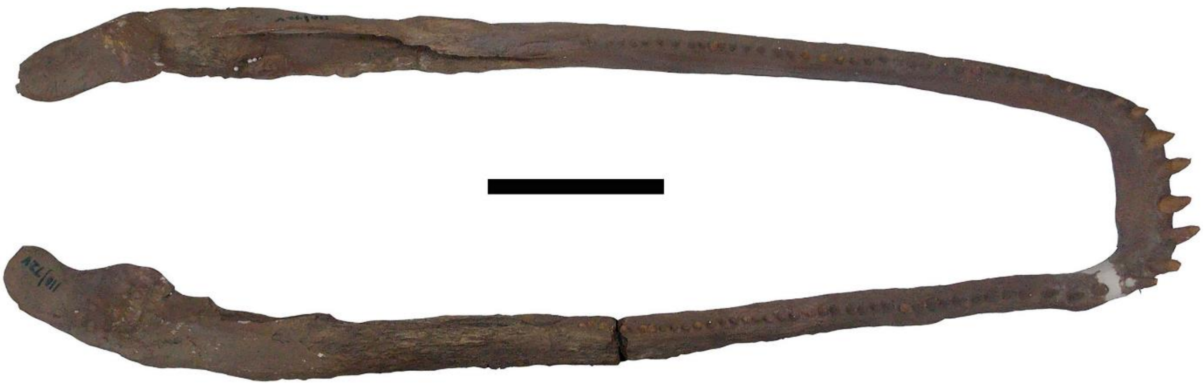
Age: ~6 million years old

Rocks: Urumaco Formation

Giovanne Mendes, lead author of the study, explained “Well, it is a cool finding by itself, but the history itself is also interesting. The specimens were collected in 1972 in Venezuela, and then went to Harvard where it underwent restoration. It returned to Venezuela in 2002, and only came to be described now in 2017.”

Please note any unusual dietary preferences

The sheer size of *Mourasuchus*, as well as its wide, flat skull, suggests that it had a very unusual diet. Mendes and team even refer to the poor animal as “duck faced” in their article! Maybe that’s where humans picked it up from after all then… The long, slim jaws and relatively small teeth would have been unable to capture and dismember large prey, like we see in modern crocodiles. So just what was *Mourasuchus* doing?



The slender mandibles of *Mourasuchus pattersoni* (Cidade et al., 2017).

Mendes said “We explored the feeding habits of *Mourasuchus*, a very different taxon from other crocodylians. What we suggest is that they performed ‘gulp-feeding’ on large amounts of small animals such as molluscs and crustaceans.”

This is the sort of thing having a large mouth area is really great for, just like we see in modern filter-feeding whales too. *Mourasuchus* would have scooped up its prey like a fishing net before swallowing them whole, similar to how we see modern pelicans feeding.

A croc diversity hotspot

The new species was named in honour of palaeontologist Bryan Patterson (1909-1979), who was an eminent researcher of vertebrate fossils in the Americas. Fossil discoveries indicate that there were now no less than 7 different caimanine species in the Urumaco Formation alone, making it one of the true biodiversity hotspots of crocodylian evolution!

Mourasuchus lived alongside another peculiar, and gigantic, caimanine called *Purussaurus*. This beast was an apex predator of its time, and would have hunted larger animals, very distinct from the more modest diet of *Mourasuchus*. By looking at the diets of *Purussaurus* and the other caimanines that *Mourasuchus* lived alongside, we can see that there were a whole range of different ecologies present, including fish-feeding types, generalist predators, and even shell-crushing species.

One of the reasons for this high ecological diversity might be related to the climate in South America at the time. During the Miocene, the continent was generally warmer and more humid than it is today. Crocodilians love these tropical climates, which also help to create a large range of different habitats to occupy in an environment. This means lots of animal diversity, which then means there's a lot of different prey on the menu. Crocodilians seem to have taken advantage of this, and adapted different feeding styles to suit the different food sources available to them.

Reference

Cidade GM, Solórzano A, Rincón AD, Riff D, Hsiou AS. (2017) A new *Mourasuchus* (Alligatoroidea, Caimaninae) from the late Miocene of Venezuela, the phylogeny of Caimaninae and considerations on the feeding habits of *Mourasuchus*. PeerJ 5:e3056 https://doi.org/10.7717/peerj.3056.

Giant, bone-crushing croc was the top predator of its time

Imagine an armoured crocodile, 3 times the length of a human adult, and with a bulky head filled with razor sharp, bone crunching teeth. Now imagine that thing was very, very real. But thankfully, only more than 160 million years ago.

A reconstruction of the newly identified beast. (Credit: Fabio Manucci).

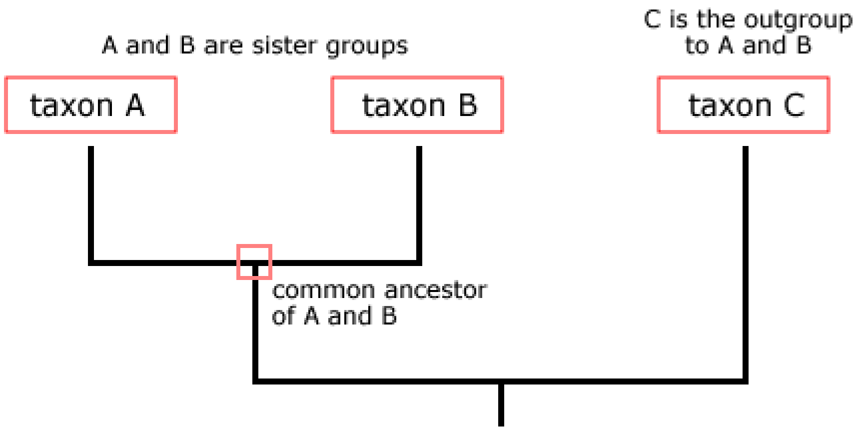
Thanks to a new fossil discovery, one of the major extinct groups of crocodile-ancestors received a small re-write of their evolutionary history. The geologically oldest discoveries of the now extinct Notosuchia help solve a long-standing riddle about their evolutionary origins.

A bit of background science first

Back in the Cretaceous, between 66 and 145 million years ago, the ancestors of modern crocodiles formed two major groups. The **neosuchians** were often small-bodied, lived in shallow lagoons or coastal environments, and would eventually go on to give rise to modern species.

The other group, **notosuchians**, were utterly bizarre animals. Known mostly from Africa and South America, these were built like small tanks, with thick armour-plating covering their bodies. Some looked more like armadillos than crocodiles! They also lived in inland environments, and oddly had a diet composed mostly of plants. Their short, stout heads had mouths full of little teeth, similar to some herbivorous dinosaurs. These were great for slicing up tough plant matter as opposed to meat.

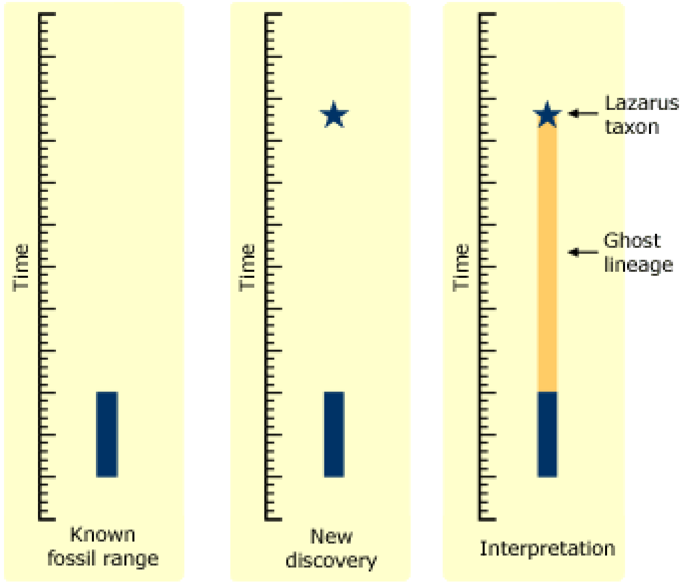
Notosuchians and neosuchians are what we call sister taxa – they are the closest relatives to each other, and share a common ancestor. This means that they originated at the same time, from the same ancestral stock of animals. Together, they form a bigger group known as mesoeucrocodylians.



The concept of sister taxa (source). Here, Notosuchia would be taxon A, and Neosuchia would be taxon B.

Where are all the Jurassic notosuchians?

But what is weird is that we have found fossils of neosuchians all the way back into the Middle Jurassic. This is around 40 million years before we find the oldest notosuchian fossils, which are all known from the Cretaceous period. We call this phenomenon a 'ghost lineage', where we know that notosuchians must have also existed in the Middle Jurassic, but we just haven't found them yet.



Simple explanation of a ghost lineage (source).

This has actually puzzled palaeontologists for quite some time now. Where are all the Jurassic notosuchians?! Part of this is probably because Middle and Late Jurassic sedimentary rocks of the type that we would find notosuchians in are actually very rare in the southern hemisphere. Most of our knowledge of neosuchians from this time comes from Europe and North America, where the geological record is quite different.

Now, a new discovery from the Middle Jurassic of Madagascar has helped fill in this ghost lineage. We knew the fossils had to be out there, and now finally they have turned up!

History of discovery

Nicknamed 'Razana', the new specimens belong to an existing, but previously very poorly understood, animal called *Razanandrongobe sakalavae*.

Razana was actually first described back in 2006 on the basis of just a few teeth and cheek bones. Due to the scrappiness of the material, researchers could not really identify with any certainty whether it was actually from a meat-eating theropod dinosaur or a weird croc. All they knew was that it was very big and very predatory, and for a decade, that's how it stayed.

The new specimens come originally from a private collection. Researchers were able to identify as being the same as *Razanandrongobe* by comparing the bits of the specimens that overlapped. Discovered originally between 1972 and 1974, no-one knew their potential until now as they remained locked away in private hands. They were first collected by the assistant director of technical services of Société Sucrière de la Mahavavy, D. Desouens, and eventually transferred to the Muséum d'Histoire Naturelle de Toulouse in France in April 2012. Here, they came under the scrutiny of Cristiano Del Sasso and colleagues, and were published with some great illustrations in PeerJ.

What do we know about this croc?

Fact sheet:

- Location: Hills west of Ambondromamy, Mahajanga Basin, northwest Madagascar
- Age: 167-164 million years old, the Middle Jurassic period (Bathonian)
- Geological strata: Sakaraha Formation
- Group: Mesoeucrocodylia
- Diet: meat

Based on these new specimens, researchers were able to show that Razana cannot possibly have been a theropod. They identified key anatomical features of the skull and jaws that do not match those of theropods in any way, but are in fact much more similar to mesoeucrocodylians. They confirmed this by running a phylogenetic analysis including the new specimens of Razana, which confirmed its new status as a notosuchian.

Evolutionary implications of Razana

Razanandrongobe tells us much about the Middle Jurassic evolution of crocodyliforms. It is the oldest known Jurassic notosuchian, and therefore closes the long ghost lineage between them and neosuchians by around 42 million years!

What is perhaps even weirder is that Razana might be the first known notosuchian, but it doesn't have the most primitive position in the evolutionary tree. The analysis of its phylogenetic position found it to be closely related to a rather advanced group of notosuchians called sebecosuchians. Razana probably represents a very early sebecosuchian. What this means is that the origin times for the other 'deeper' notosuchian groups are pushed even further back. In many cases, the origins of other groups are now hyopthesised to be in the Early Jurassic. So, in the future, we can probably expect to find even more weird notosuchians as we unlock new places to discover fossils.

With Razana being the oldest known member of its group, we can infer that notosuchians probably had their evolutionary origins in the southern landmasses of the southern hemisphere, which during the Jurassic were called Gondwana. With still some 30 million years of ghost lineage remaining, it is possible that this evolutionary origin could be over-turned in the future.

Feed me!

The biggest teeth of *Razanandrongobe* were 15cm long, like large steak knives. These were designed for punching from hard tissues such as bone and tendon. The serrations, or denticles, on these teeth were larger than even those found in the largest predatory theropods, including *T. rex*. This is extremely unusual, as other members of Notosuchia typically had teeth useful for an herbivorous diet of plants.

Razan might have even been the biggest land dwelling mesoeucrocodylian of the Jurassic! It was certainly the largest of its notosuchian kin, and with those giant chompers would have been one of the top predators around at the time, and was certainly king of its ecosystem.

As always, new discoveries raise more questions too! Why did notosuchians start so big but then evolve smaller bodies over time? Why did they switch from carnivory to herbivory over millions of years? Did they compete with theropod dinosaurs in their early evolution?

As always, palaeontologists rally to the cry of ‘We need more fossils!’, and only time will tell.

Reference

Dal Sasso C, Pasini G, Fleury G, Maganuco S. (2017) *Razanandrongobe sakalavae,* a gigantic mesoeucrocodylian from the Middle Jurassic of Madagascar, is the oldest known notosuchian. PeerJ 5:e3481 https://doi.org/10.7717/peerj.3481.

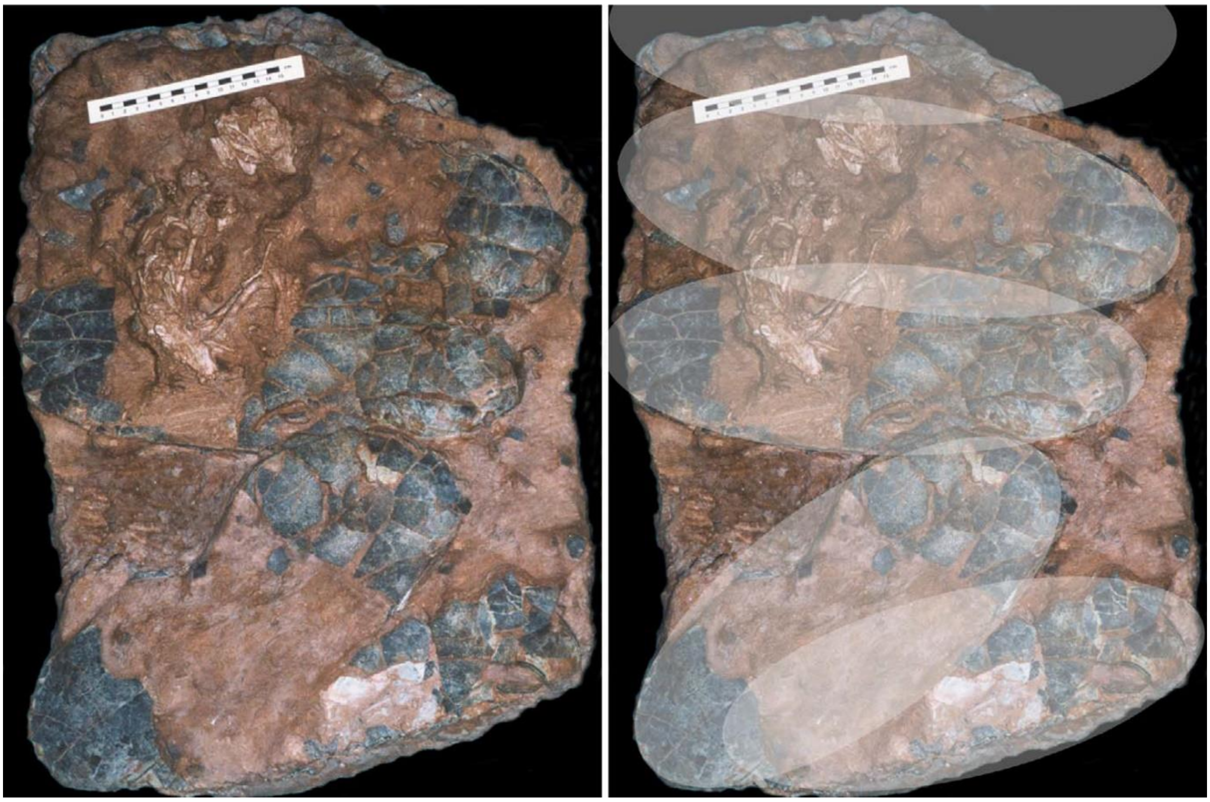
Let sleeping dragons lie

Mistaken identity

In Palaeontology, there is perhaps no greater story of an accidental mix-up than the story of *Oviraptor*. When this dinosaur was first discovered back in 1924, it was alongside a clutch of fossilised eggs thought to belong to the ornithischian *Protoceratops*. Branded 'egg seizer', which is what the genus name means in Latin, for more than half a century *Oviraptor* was relentlessly depicted as a notorious thief. The palaeontologist who named *Oviraptor*, the infamous Henry Fairfield Osborn, suggested at the time not to take the name too literally, as it "may entirely mislead us as to its feeding habits and belie its character." Years later, and with closer examination of the fossils, Osborn's caution was realised, as scientists realised that the notorious beast wasn't stealing the eggs of another dinosaur. It was actually brooding its own clutch, and died on the nest itself. Poor *Oviraptor* had been mis-characterised in the history books, but thanks to science, re-written eventually as a caring parent. If fossils could sue for libel, this would probably be case of the century.

Repatriate our dragons

Recently, a clutch of large dinosaur eggs has been repatriated to China, along with a small theropod skeleton. These were probably discovered by farmers in the late 1980s and early 1990s and sold overseas at rock and gem shows and other markets, with some being lost to science forever, and others being snapped up by museums and prepared to reveal exquisitely preserved embryos.



Photograph of eggs and skeleton of *Beibeilong*. Right image shows overlay of approximate locations of individual eggs. Eggs 1 through 4 are in an upper layer just beneath the skeleton, whereas Egg 5 is in a lower layer of the block. Scale bar is in centimetres. (Pu *et al*., 2017).

Researchers realised that this little dinosaur specimen was something completely new to science, and named it *Beibeilong sinensis*. The named comes from Chinese Pinyin, with '*Beibei*' meaning 'baby', and '*long*' meaning dragon, making this little dinosaur even cuter than it already was! *Beibeilong* is a close cousin of *Oviraptor*, which is an oviraptorid, and is part of a sub-group called caenagnathids. Both together form a larger group called Oviraptorosauria. This discovery is the first time that a caegnanathid has been found associated with egg remains.

Beibeilong already has a history in the spotlight, being imported to the USA in 1993 where it was prepared, eventually ending up on the front cover of National Geographic. There, it was nicknamed 'Baby Louie' after the photographer for the article, Louis Psihoyos. Baby Louie spent 12 years after this on public display at the Indianapolis Children's Museum, until finally in 2013, 20 years after its discovery, it made its way back to China and the archives at the Henan Geological Museum, Zhengzhou.

Oo Beibei do you know what that's worth?

A team of international researchers have identified the associated eggs as belonging to the oogenus *Macroelongatoolithus*, which literally translates as 'big long stone egg'. Baby Louie itself is actually an embryonic skeleton, not a fully grown dinosaur, which means it either hatched just moments before its unfortunate death or was forcibly removed as it was entombed in sediment.

Reconstruction of *Beibeilong* embryo in ovo. (Vladimir Rimbala).

What is interesting about these eggs is that they are the largest known of any dinosaur, and much larger than those of their oviraptorid cousins. Many that have been found previously reach lengths of over half a meter! This tells us that *Beibeilong*, despite the tiny size of the only known specimen, could grow to ginormous sizes for a caenagnathid.

Strangely, this type of egg is found in abundance all over North America and Asia. Yet, the remains of the egg layers themselves are as rare as a shiny Pokémon. In fact, *Beibeilong* is about the only one, and thanks to it being found alongside these eggs, we now know that they must have belonged to caenagnathids. And giant ones at that!

What this is reveals to us then is a 'ghost record' – one which we know must exist out there somewhere, but just either hasn't been found yet, or has not been preserved. We know that giant caenagnathids must have been as widespread as their eggs, so, where are they?

Only time will solve this one for us, and much more delving into the Earth's life archives. Of course, if you happen to come across any large caenagnathid fossils in the meantime, please do report them to your local palaeontologist.

Reference

Pu, Hanyong, Darla K. Zelenitsky, Junchang Lü, Philip J. Currie, Kenneth Carpenter, Li Xu, Eva B. Koppelhus et al. "Perinate and eggs of a giant caenagnathid dinosaur from the Late Cretaceous of central China." *Nature communications* 8 (2017): 14952. https://doi.org/10.1038/ncomms14952.

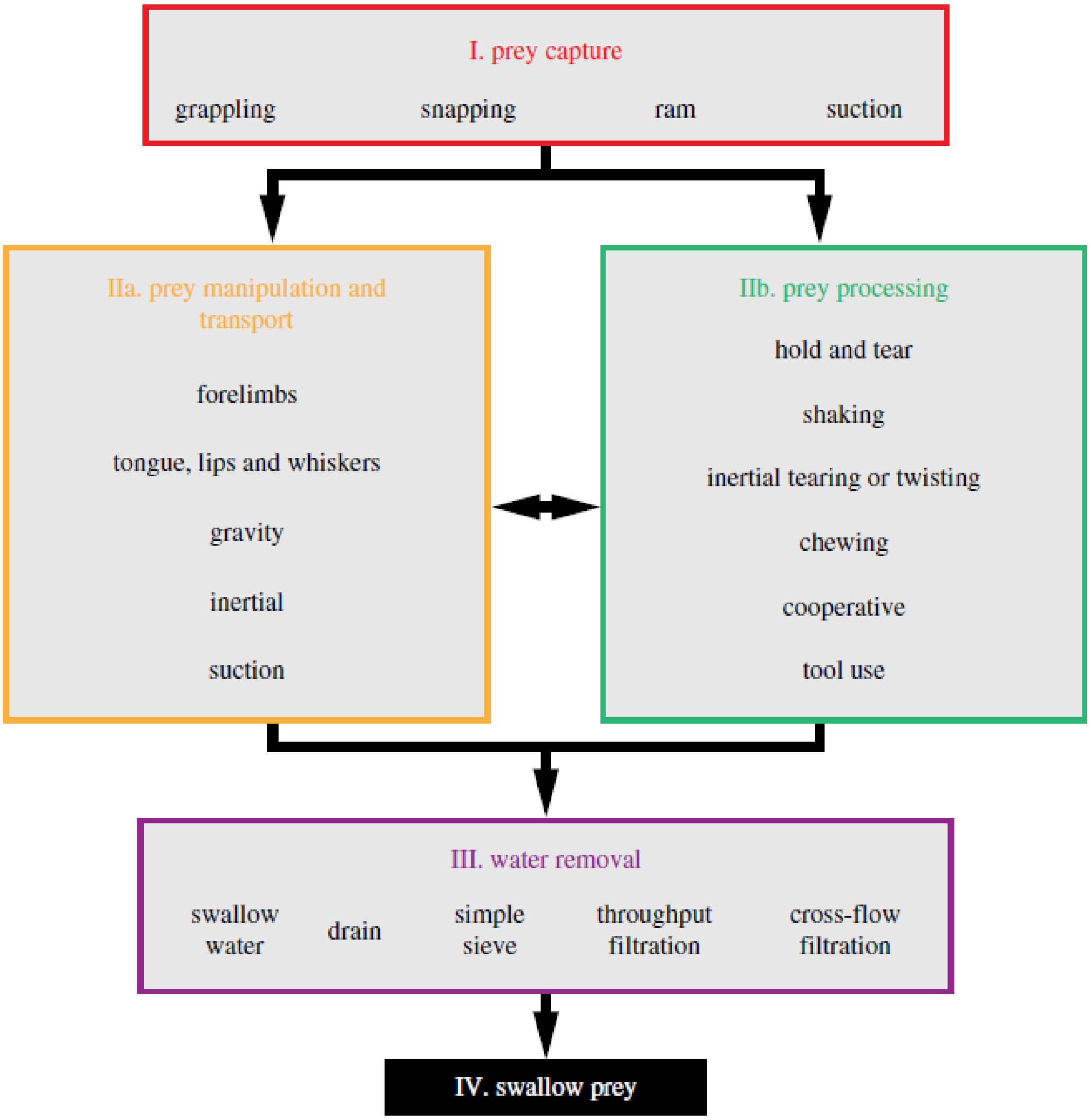
Whales, dolphins, and seals all follow the same evolutionary patterns

From the poles to the equator, marine mammals such as seals, dolphins, and whales, play an important role in global ecosystems as apex predators, ecosystem engineers, and even organic ocean fertilisers. They occupy a diverse range of habitats, from deep sea environments to the Earth’s rivers and coastlines, and continue to astound us with their natural beauty.

But did you know that all marine mammals descended from common land-dwelling ancestors? It might be difficult to see that by looking at modern species alone, but that’s where the fossil record comes in handy. An accurate picture of their evolution is crucial for helping us to understand the structure of increasingly threatened aquatic ecosystems.

By looking in detail at the fossilised ancestors of marine mammals in order to understand their ecology, we can see that terrestrial mammals returned to the seas millions of years ago – this makes them secondarily aquatic. A major part of this involved the morphological and behavioural adaptations required to become specialised oceanic feeders. Anyone who’s ever tried to eat underwater will know exactly what we mean.

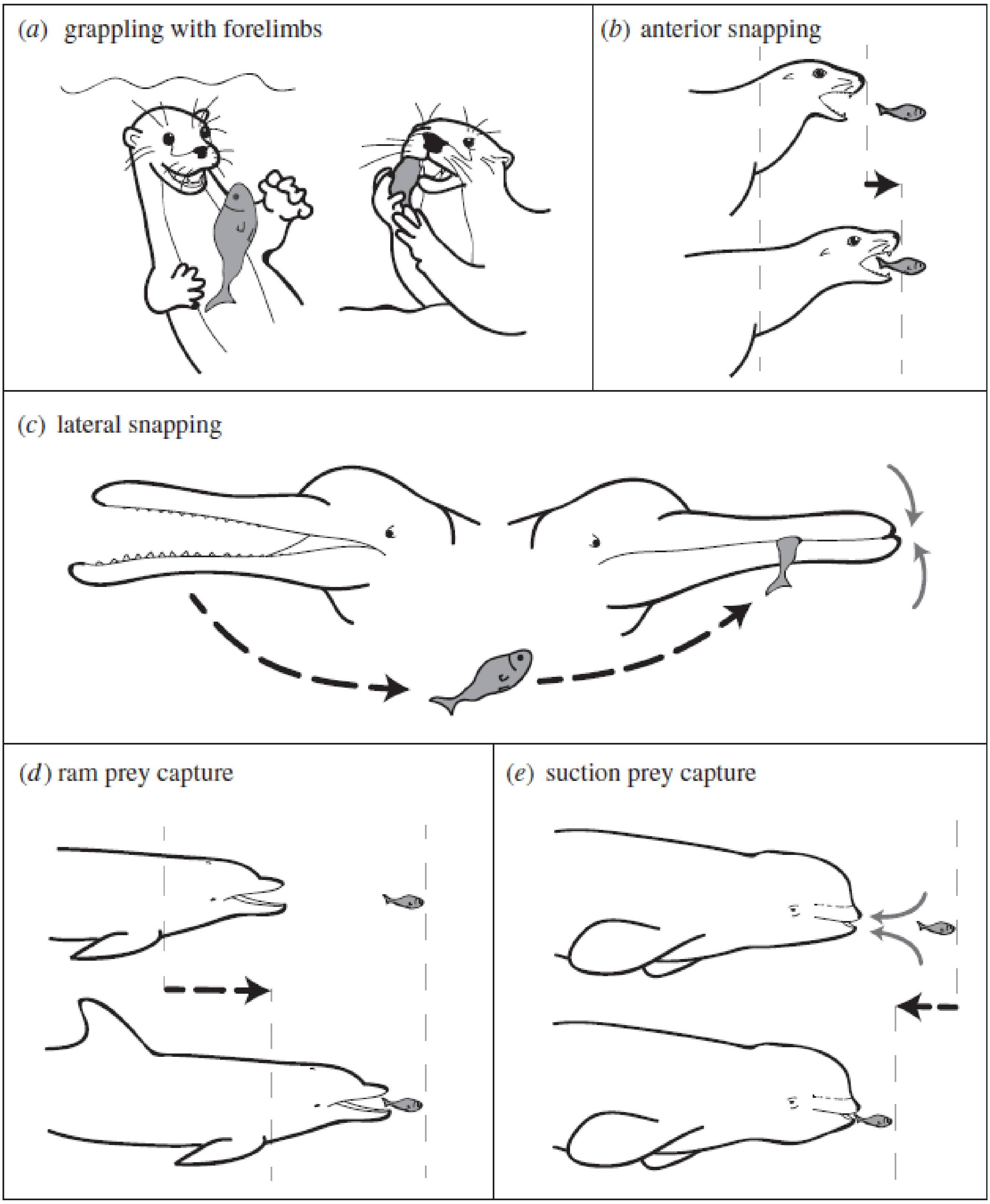
Researchers in a recent study have reviewed the patterns of evolution in predatory marine mammals, and constructed a behavioural framework that helps to explain the transition to being able to successfully feed in water.



Overview of the aquatic mammal feeding cycle, split into consecutive stages of prey capture, manipulation and processing, water removal and swallowing (Hocking *et al*., 2017).

What they found is that all the different types of marine mammals seem to follow the same large-scale patterns, the same sequence of adaptations, as they became more specialised for underwater feeding. This has resulted in three distinct feeding groups in modern and extinct species: those that use their teeth and jaws to capture prey (raptorial feeders), suction feeders, and filter feeders, such as the largest whale species.

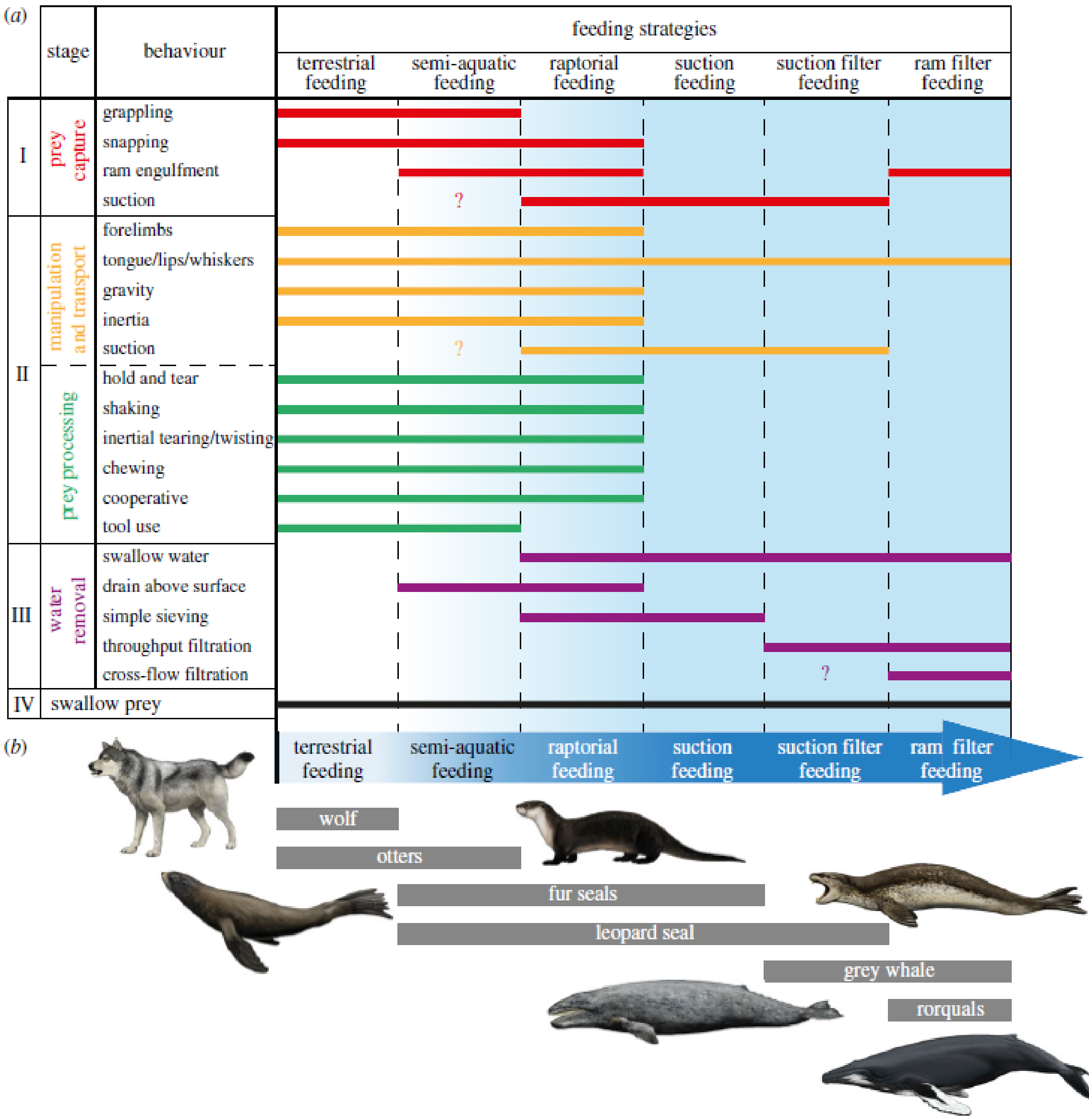
The new framework seeks to explain these adaptations by involving a cycle consisting of four different stages: prey capture, prey manipulation and processing, water removal, and prey swallowing. Each stage is part of a logical sequence that follows a terrestrial origin through to an increasingly marine feeding style.



Overview of the prey capture behaviours employed by aquatic mammals (Hocking et al., 2017).

Each part of the cycle also requires a distinct set of morphological adaptations in order to achieve, and therefore a different behaviour, but remains common as a process for each marine mammal lineage. Some animals even have the ability to use two different strategies on different prey types. For example, a leopard seal might use a ‘raptorial’ style when hunting a penguin, but can also filter feed when consuming krill (the other way around might be more difficult).

This implies two things, evolutionarily. Firstly, that an ability to feed underwater is constrained in terms of the process of adaptation – you need to follow a specialised set of rules in order to survive. The same sort of pattern can be seen in birds, pterosaurs, and bats – all distinct lineages that independently learned how to fly. Secondly, as marine mammals also occupy a range of different feeding styles, from filter feeders to hypercarnivores, this process of adaptation seems to ultimately open up a wide diversity of possibilities for feeding behaviours.



Comprehensive overview of the feeding strategies employed by aquatic mammals (Hocking et al., 2017).

This is important, as it shows us how using the fossil record opens up the process of evolution, as opposed just to looking at a product of it by focusing exclusively on modern animals.

Lesson: Don't try and understand evolution without looking at the fossil record.

Reference

Hocking, D. P., Marx, F. G., Park, T., Fitzgerald, E. M., & Evans, A. R. (2017). A behavioural framework for the evolution of feeding in predatory aquatic mammals. In *Proc. R. Soc. B* (Vol. 284, No. 1850, p. 20162750). The Royal Society. http://dx.doi.org/10.1098/rspb.2016.2750.

Oldest known crocodiloid eggs discovered in Portugal

150 million years ago, Portugal was a completely different place to now. While much of the beautiful landscapes still existed, the animals living there were alien compared to those living there now. Ecosystems were dominated by a dizzying array of weird dinosaur species, along with the ancestors of modern groups like mammals, amphibians, and crocodiles.

Fossils from the Late Jurassic of Portugal are very common. Some of the greatest discoveries are those of early crocodile-ancestors, collectively called crocodylomorphs. While dinosaur eggs have been fairly common among the fossilised remains of these animals, crocodylomorph eggs have rarely been found or studied, until now.

Global distribution of fossil crocodiloid eggs. (Russo *et al*., 2017).

Russo and colleagues discovered and recently reported several new occurrences of 'crocodiloid' egg from the ancient Portuguese rocks, together representing two different and previously unknown types of egg.

Now, the naming and identification of eggs is a bit different to normal fossils. Their remains are called ootaxa, instead of just taxa, and these are broken down into oofamilies, oogenera, and oospecies. This comes from the Greek term “oolithus”, which literally means “stone egg”.

One clutch of 13 fossilised eggs were like nothing the researchers had seen before, and distinct enough for them to create the new name *Suchoolithus portucalensis* for them. Some of the other material they found was similar to an existing genus, and newly named as *Krokolithes dinophilus*. The latter oospecies name is due to the occurrence of these eggshells with dinosaur nests and eggshells, which suggests an interesting ecological nesting association between dinosaurs and crocodylomorphs here. For example, the crafty crocs might have hidden their nests among those of theropods to trick the larger predators into thinking they were their own, and therefore not eating them.

Both different types of egg were also of different sizes, which suggests that they were laid by females of different sizes and species too. This is really cool, as it supports a lot of recent evidence that different species of crocodylomorphs, often of vastly different lifestyles, often co-existed alongside each other in the Late Jurassic of Europe. This is called ‘sympatry’, and is a way of different but closely-related species sharing an ecosystem by taking on different ecological roles within it.

These eggs also represent the oldest known crocodylomorph eggs in the fossil record. What is remarkable about this is that over 150 million years of evolution, the structure of these eggs seems to have changed very little compared to modern crocodylians, while the egg-layers themselves have often changed quite a bit – crocodylomorphs were quite the evolutionary explorers.

Despite crocodiloid eggs being first identified in the 1930s and 1940s, and even with the advance of modern chemical imaging and analytical techniques, this conservatism seems to be the rule for all remains that have since been discovered. As the saying goes, if it ain’t broke, don’t fix it!

Crocodiles and their ancestors remain a huge success story in reptile evolution, and it seems that their eggs might have been a big part of that.

Full disclosure: I was one of the peer reviewers for this paper.

Reference

Russo J, Mateus O, Marzola M, Balbino A (2017) Two new ootaxa from the late Jurassic: The oldest record of crocodylomorph eggs, from the Lourinhã Formation, Portugal. PLoS ONE 12(3): e0171919. https://doi.org/10.1371/journal.pone.0171919.

A 180-million-year-old dinosaur dinner

While artistic reconstructions of dinosaurs preying on each other are a fantastic way of illustrating the real-life behaviours of these fantastic creatures, direct evidence of dinosaur-food interactions in the fossil record are surprisingly rare.

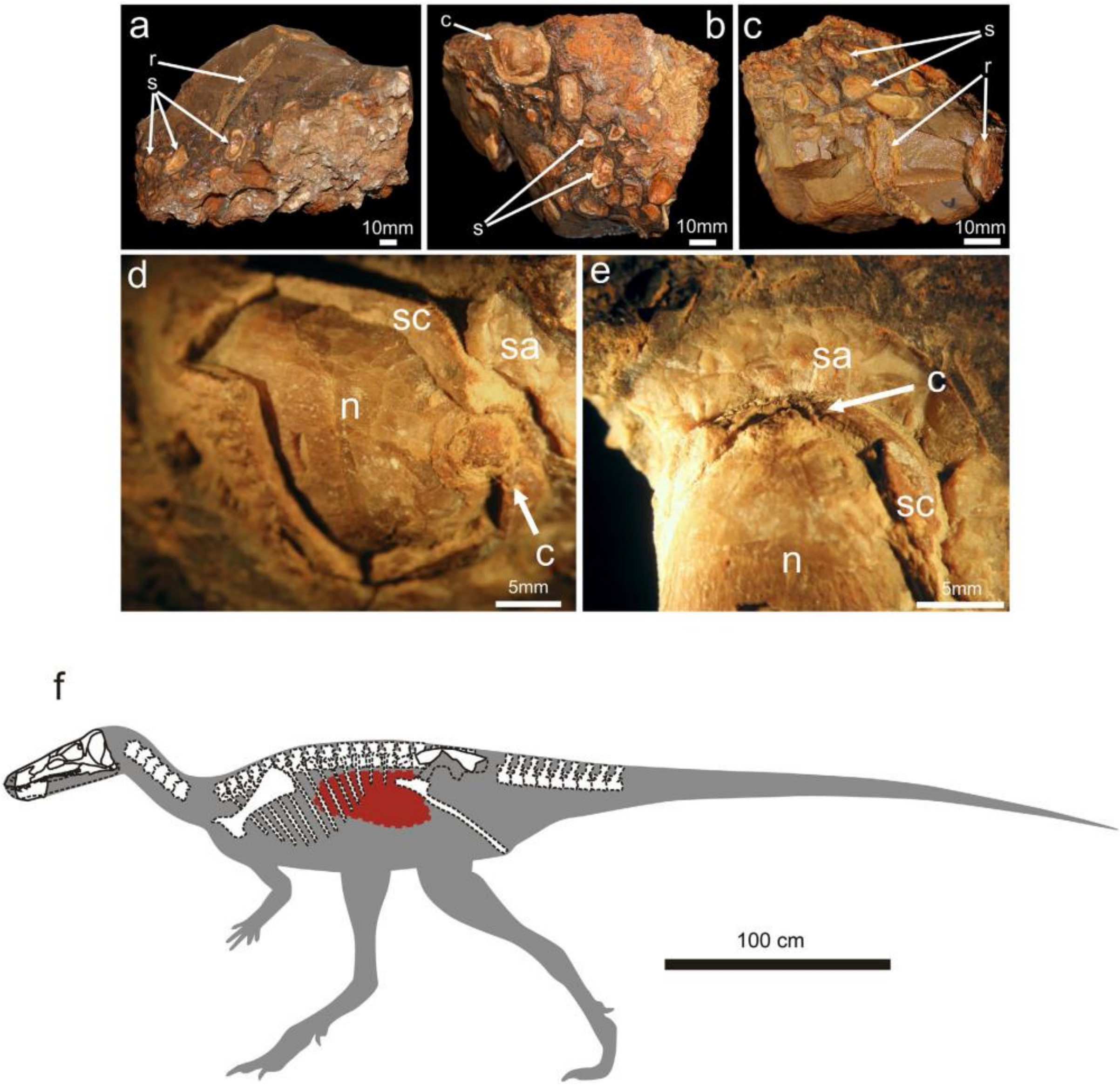
In modern ecosystems, it's quite easy to establish ecological interactions between predators, prey, and plants – we simply have to look at who is eating who or what. But in the fossil record, this is quite difficult, as the animals we look at often tend to be dead.

Sometimes, though, we know what a dinosaur ate by looking at the remains in their fossilised poop, and every now and then we even get extraordinary glimpses of direct predation from dinosaurs that died locked in a deathly duel.

Rarely though, the fossil record reveals to us actual digested remains of food, preserved for millions of years in the ghost-guts of dinosaurs. These remains, or trace fossils, are called cololites, and tell us exactly what the dinosaur was eating at the time of death, providing a tantalising window into their real-life behaviours.

A recent discovery from the Jurassic period of Patagonia now shows us the last meal of a dinosaur, still fossilised in its guts!

The discovery was of a new dinosaur species, called *Isaberrysaura mollensis*, and it comes from one of the major dinosaur groups called Ornithischia – the bird-hipped lizards (ironically, not the dinosaur lineage that led to birds, but that's another story). The 5-6-metre-long herbivore inhabited the deltas of Argentina, now the Neuquén Province, back in the early part of the Jurassic.



Gut content of *Isaberrysaura* (a–c), seeds of cycads (c), and other seeds (s); rib (r). (d,e) Detail of seeds of cycads: sarcotesta (sa), sclerotesta (sc), coronula (c), nucellus (n). (f) Location of the gut content in the reconstructed skeleton of *Isaberrysaura* (Salgado et al., 2017).

The new dinosaur somewhat resembles an early stegosaur, but extensive analysis of its anatomy shows its more closely related to the early ancestors of dinosaurs such as *Iguanodon* and *Hypsilophodon*.

The special thing about this discovery though is that some of its last meal are still preserved after 180 million years in the space where its gut used to be, but has long since decayed away. The name *Isaberrysaura* has nothing to do with berries, but is named in honour of Isabel Valdivia Berry who was the first to report the discovery back in 2009.

The seeds have been permineralised, which means replaced by hard minerals that allowed their preservation over millions of years. Some of the seeds were still largely complete too, which suggests the hungry little dinosaur gobbled them down (is this the first time "gobbled" has ever been used in a dinosaur research paper?), instead of taking the time to chew them. These toughened seeds probably would have passed through the digestive tracts of the dinosaur, to be 'expelled' as seed kernels, meaning they would still have been capable of germination.

The teeth of *Isaberrysaura* seem to have been quite poor at food processing, especially compared to their later hadrosaur cousins and their immense 'dental batteries' for grinding plant matter into oblivion, which helps to explain why the seeds are preserved in such good condition.

Researchers identified these seeds as belonging to an ancient type of cycad, as well as from other plants.

This is interesting, as it shows that some dinosaurs, much like modern mammals, might have been important in helping to disperse the seeds of plants along landscapes through plants' ingenuity of exploiting the fact that dinosaurs like to poop from time to time.

Reference

Salgado, L., Canudo, J., Garrido, A. *et al.* A new primitive Neornithischian dinosaur from the Jurassic of Patagonia with gut contents. *Sci Rep* 7, 42778 (2017). https://doi.org/10.1038/srep42778.

Congratulations! Your *Platychelys* learned the move 'Neck retraction'

One of the unique and most iconic features of many modern turtles is that they can withdraw their neck and head to hide and protect them within their shells. The group name of species which do this, Cryptodira, even means 'hidden-necked turtles' to reflect this unusual adaptation.

Turtles and their ancestors have been around for more than 200 million years now, and are a remarkable evolutionary success story. We know that by studying their fossils, the earliest turtle ancestors had rigid necks though, and were unable to retract them as modern species do.

Life reconstruction of *Platychelys* in its palaeoenvironment (Credit: P. Röschli).

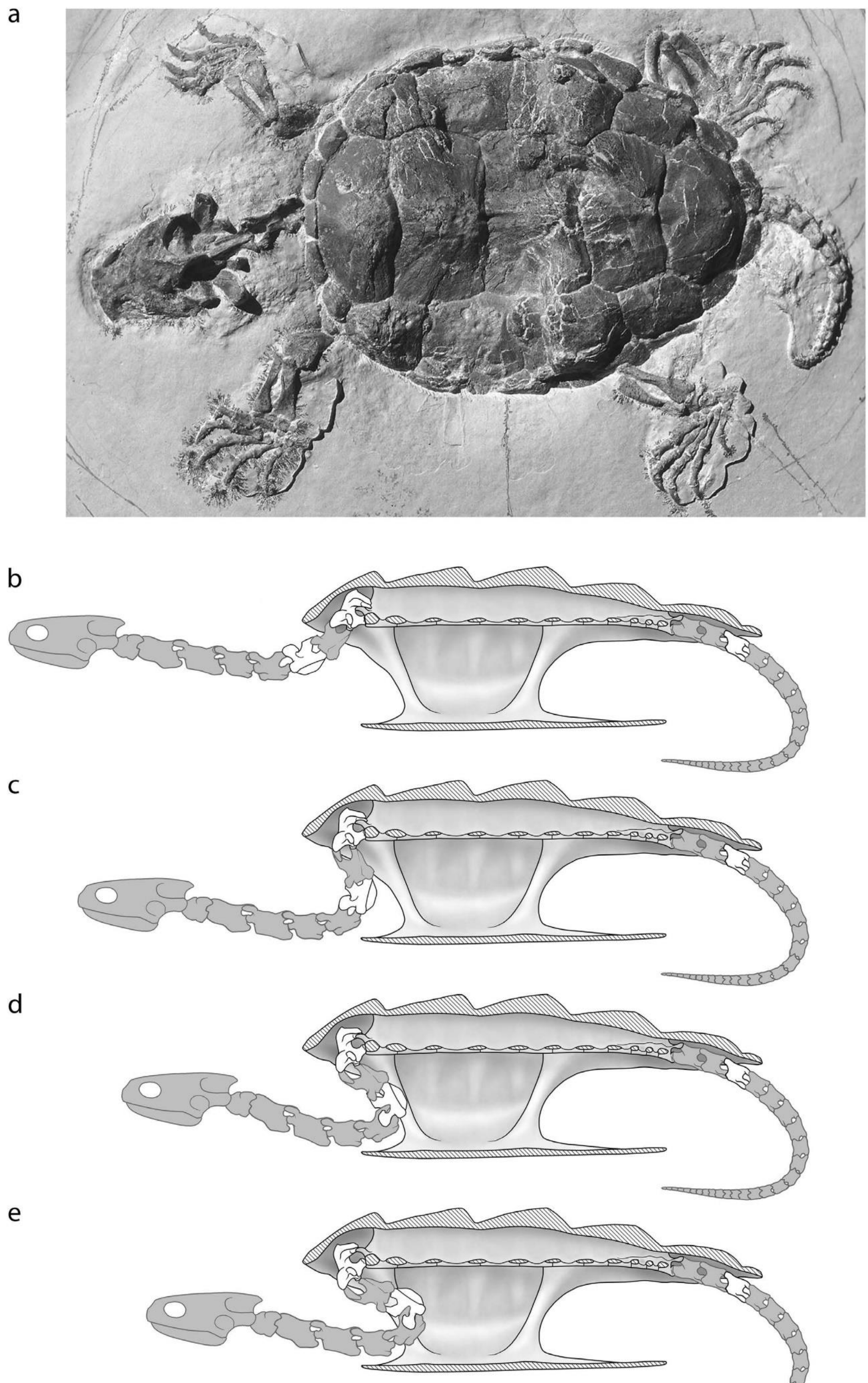
New research from Jérémy Anquetin and colleagues has provided insight now into the reason this bizarre act evolved in turtles, showing that actually it occurred twice in their long history.

The team investigated a fossil turtle known as *Platychelys* from the Late Jurassic, around 150 million years ago, of Europe. Europe at this time was completely different to now – it was more like an island archipelago, with warm shallow seas inhabited by a range of unusual and now extinct turtle species.

Intriguingly, the neck morphology of *Platychelys* was remarkably similar to its modern cryptodire relatives, indicating that it was at least partially capable of retracting its neck. It is able to do this by folding the neck muscles vertically, causing the neck to move inwards towards the torso, but apparently not quite enough to actually be of any use for protection.

Although the muscles of *Platychelys* are not preserved, the researchers were able to infer this based on the broad shape of the neck, or cervical, vertebrae, and the wide spacing between the parts of the bones that the muscles attached to. Cryptodires also have a double articulation on their neck vertebrae, a feature worth pointing out here only because the condition has the awesome name of 'ginglymoidy'.

As well as partially retracting its neck, it also seems that *Platychelys* was able to shoot it back out again. This is a method to ambush and capture its prey underwater, like some modern turtles are capable of doing, and especially useful to catch rapidly darting fish. This means that neck retraction for protection might even have evolved as a sort of additional, non-intentional function driven by the evolution of this mode of feeding in *Platychelys*.



a
b
c
d
e
5 cm

Neck mobility in *Platychelys.* (Anquetin *et al*., 2017).

As we see this sort of behaviour in modern turtles that are distantly related to *Platychelys* and separated by around 150 million years, this is an example of what is known as 'convergent evolution'. This is where different species have similar adaptations to their environment or ecology that are acquired independently but for the same purposes. In this case, neck retraction seems to have evolved multiple times to make capturing prey even easier, and originally had absolutely nothing to do with protection, as is commonly thought.

This adds an additional layer of complexity to our understanding of the early evolution of turtles, and the team will investigate this in more detail in the future by examining more fossils and trying to work out their feeding habits.

The article finishes by saying "We hope that this study will inspire other to continue exploring the evolution of cervical vertebrae in early crown group turtles."

Reference

Anquetin, J., Tong, H. & Claude, J. A Jurassic stem pleurodire sheds light on the functional origin of neck retraction in turtles. *Sci Rep* **7,** 42376 (2017). https://doi.org/10.1038/srep42376.

Early baleen whales contended for title of ocean's Barry White

Until now, it has been a bit of a mystery about the evolution of hearing capabilities in those graceful ocean behemoths, the baleen whales.

We know that modern baleen whales can hear the lowest frequency sounds, known as infrasonics, of any living mammal. At times, the sounds get so low (less than 20 hertz, Barry White eat your heart out..*) that even humans cannot hear them.

The modern blue whale is an example of a baleen whale, and comes in at a whopping 30 metres in length. They have low frequency hearing still, but unlike their modern dolphin cousins they cannot echolocate. Echolocation is a sensory system that requires an ability to hear high frequencies to hear, often achieving ultrasonic levels of more than 20,000 hertz.

Early baleen whales were a bit weird, being a lot smaller than their living cousins, and still having teeth, looking more akin overall to modern whales and other toothed whales.

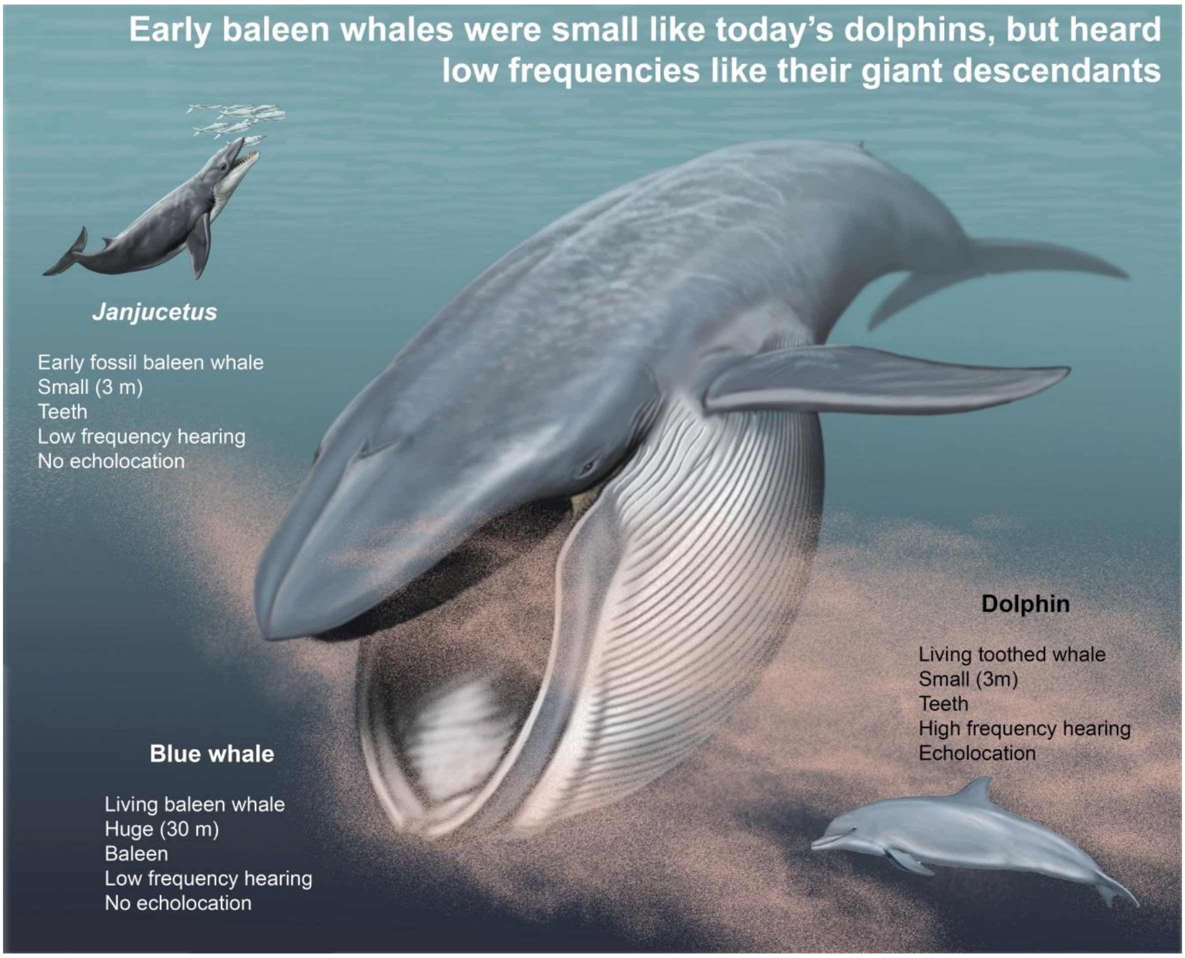


Image provided by Museums Victoria, by Carl Buell.

We can determine the frequency that whales, both fossils and living ones, can hear by analysing the shape and structure of the inner ear, or cochlea. In animals that are millions of years old, like the earliest baleen whales, this can be quite complicated due to the fragility of preserved specimens.

By using methods adopted from medical research, like CT scanning, scientists can digitally reconstruct and examine the anatomy of fossils in astonishing detail, and safely.

When looking at the cochlea of early baleen whales that still possessed this primitive toothed condition, researchers have now found that they were remarkably similar to those of modern baleen whales, such as the blue whale. This was despite being a whole order of magnitude smaller, more around the size of a modern dolphin.

What this means for ancient baleen whales possessed low frequency hearing like modern baleen whales, but still couldn't echolocate. So, they had the primitive conditions of both main groups of modern whales and dolphins, and almost certainly communicated much in the same fashion as modern baleen whales (see Finding Nemo for reference).

Now, we know that the songs of modern whales are both beautiful and complex. But were these same songs being heard in oceans 30 million years ago too?

Travis Park, recent PhD thesis-submitter and lead author of the study, said "This at last reveals that the earliest baleen whales heard low frequency sound. The similarities of baleen whale cochleae to older whales shows us that this ability evolved well before other extreme adaptations such as baleen, filter feeding and gigantic body size. Although there's no way of testing the idea, it's tempting to think that mysticetes [baleen whales] have been singing their complex, beautiful whale songs for millions of years."

This discovery also means that the echolocation and high frequency hearing of dolphins and toothed whales evolved *after* the initial evolution of low frequency hearing, contrary to a whole host of studies on this that lacked the detailed information on the inner ear that Park and colleagues obtained.

Furthermore, it demonstrates that low-frequency hearing evolved prior to the evolution of low body size in baleen whales. Why it evolved then, is still a mystery waiting to be solved!

*Please can someone name an early whale species after Barry White now.

Reference

Park, T., Evans, A., Gallagher, S. J. and Fitzgerald, E. M. G. (2017) Low-frequency hearing preceded the evolution of giant body size and filter feeding in baleen whales, *Proceedings of the Royal Society B*, https://doi.org/10.1098/rspb.2016.2528.

Synapsida – Gotta catch 'em all!

Let's go back to the Permian period, around 260 million years. Life was quite blissful, with no dinosaurs tearing up the turf as of yet.

Animals from this period were bizarre experimentations, with early ancestors evolving for some of the well-known groups still around today, like crocodiles, turtles and mammals.

Some of these include the dicynodonts, who despite looking more 'reptilian', are actually the precursors of early mammals. They were pretty weird looking, like a cross between a turtle and a wild boar. Dicynodonts, mammals and all other animals more closely related to mammals than any other egg-laying animals are called 'synapsids', and a pretty important group. Even humans are synapsids, so dicynodonts are like our great, great, great (etc.) grand-cousins.

A new species of dicynodont has been described from the Karoo Basin of South Africa, which researchers have dubbed *Bulbasaurus phylloxyron*. Pokémon fans around the world rejoice!

Reconstruction of what *Bulbasaurus* may have looked like while alive. Art by Matt Celeskey.

The name actually refers to the 'bulbous'-shaped nose that *Bulbasaurus* has, rather than being a fan-based dedication to the chubby but lovable lizard-like original starter Pokémon.

"There is nothing alive today quite like them, but they were the most successful herbivores of their time," said lead author Dr. Christian Kammerer of the Museum für Naturkunde Berlin.

The specimens were originally collected by Dr. Roger Smith of the Iziko Museums of South Africa and the University of Witwatersand. But while visiting the museum collections for research, Kammerer and his keen eye and love for synapsid taxonomy (his Twitter handle is even @synapsida), noticed something unusual about the specimens.

It was all in the tusks. *Bulbasaurus* has much larger tusks than any other species around at the time. “I knew that these skulls couldn’t be from one of the usual species of that age, because their tusks were huge compared to other, co-existing dicynodonts,” says Kammerer.

Bulbasaurus wasn’t exactly a heavyweight, with a skull only 16 centimetres long, so about the same as a medium-sized dog. But its tusks were as large as the largest of the dicynodonts, showing that even the smaller dicynodont species were equipped with pretty awesome face gear.

Bulbasaurus is the oldest known member of a group of dicynodonts called geikiids. This is important, as it helps to fill a gap in the early fossil record of this group. Scientists have long recognised that geikiids should have been around in rocks older than those they are typically found in. This is because we find their closest relatives in those older rocks too.

This problem is known as a “ghost lineage”, where we know that a group of organisms must have been present at a certain time as they share an equal origination time with their closest ancestors, but no fossils of that age have been found. Yet.

Bulbasaurus then is a delightful discovery to early synapsid researchers. “That specimens of a rare species like this were collected at all is a testament to the exhaustive, multi-decade field program of Roger Smith” said Kammerer. “Dicynodont skulls tend to look a lot alike, so if you are not a specialist in the group it is easy to overlook species-specific differences between specimens. I am sure that the solutions for a lot of gaps in the fossil record are already sitting in museums waiting to be studied, it just takes time and researcher expertise.”

Kammerer’s research highlights just how important preserving museum collections can be, as well as how crucial taxonomical skills are to our basic understanding of the evolution of life.

Reference

Kammerer CF, Smith RMH. (2017) An early geikiid dicynodont from the *Tropidostoma* Assemblage Zone (late Permian) of South Africa. *PeerJ* 5:e2913 https://doi.org/10.7717/peerj.2913.

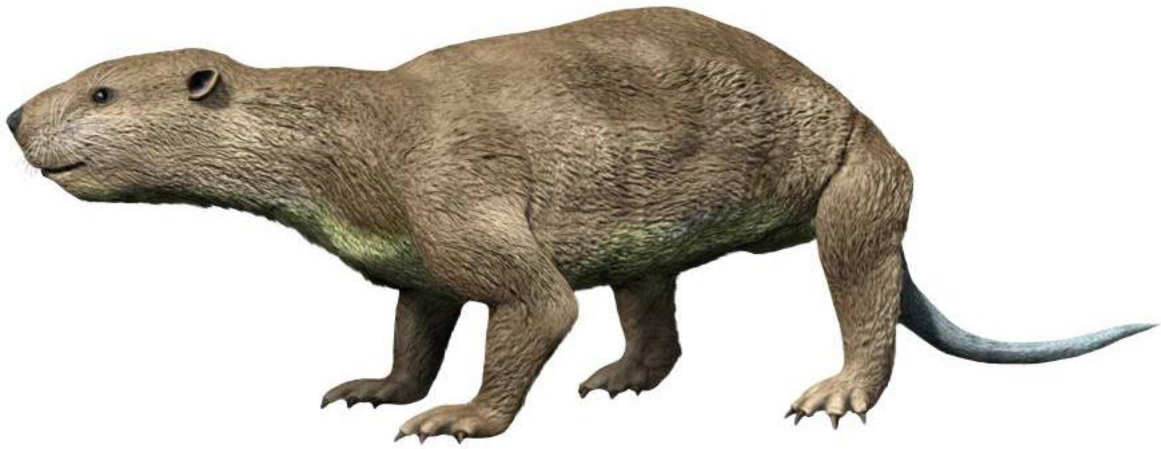
Earliest, dinosaur-hunting marsupial-ancestor had the strongest bite of any mammal pound-for-pound

The earliest mammals are often portrayed as minor elements of Mesozoic ecosystems, often literally in the shadows of dinosaurs as they scurried and scampered around their feet. During this time though, the earliest mammal precursors were already laying the foundations to become an incredibly successful evolutionary radiation.

Modern marsupials are totally outshined in diversity and geographic extent by placental mammals, which together with their ancestors make up the group Eutheria. But this was very different back in the Cretaceous, with early metatherians being more diverse both in numbers and ecologies than their early eutherian cousins.

Some of the earliest ancestors of marsupial mammals (those which carry their young in a pouch), known as 'stem metatherians', are known from the Cretaceous fossil record. Sadly, they are mostly only known from isolated teeth or jaw elements, so we really don't know much about them and their early evolutionary history.

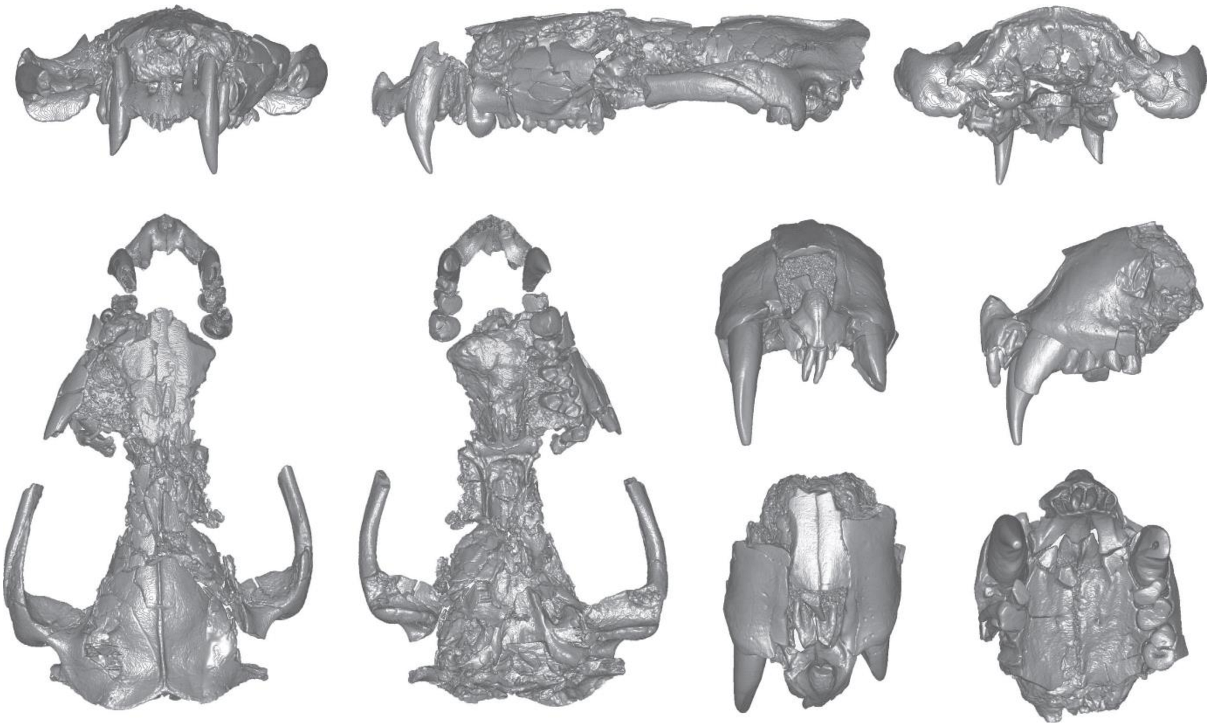
Now, new specimens of a metatherian have been discovered from the Late Cretaceous of North America, which despite being from a species already known to science, challenge our traditional views of mammals from this time. The specimens are from the Hell Creek Formation, making them around 66 to 69 million years old, and from right towards the end of the reign of the non-avian dinosaurs. Known from a near-complete skull, researchers showed that the specimens belong to a species actually described back in 1889 by renowned American palaeontologist, Othniel Charles Marsh, *Didelphodon vorax*.



Didelphodon vorax, by Nobu Tamura. CC BY-SA 4.0 (source). Don't let that smile fool you.

"What I love about *Didelphodon vorax* is that it crushes the classic mould of Mesozoic mammals," Dr. Gregory Wilson, Burke Museum Adjunct Curator of Vertebrate Paleontology and University of Washington Associate Professor of Biology, said. "Instead of a shrew-like mammal meekly scurrying into the shadows of dinosaurs, this badger-sized mammal would've been a fearsome predator on the Late Cretaceous landscape – even for some dinosaurs." (source)

By incorporating new information from these specimens, Wilson and colleagues were able to show that marsupials and their closest Cretaceous relatives originated and radiated in North America, before making their journey down to South America.



What a pretty skull you have... (Wilson *et al*., 2016).

Even though *Didelphodon* was quite small-bodied, it was still the largest of any therian mammal from the whole of the Mesozoic (Theria is the major group comprising Metatheria along with Eutheria). Body mass estimates based on the length of the skull show that it would have reached a maximum of 6.2kg.

They were also able to show that for its size, *Didelphodon*, packed quite a spectacular crunch. The animal had a bite much worse than its bark, and would have had a durophagous, or 'bone-crushing' feeding style, making it the oldest of its kind to adopt this strategy. Wilson and colleagues were even able to show that mandible was even strong enough to resist the sorts of movements that, for example, a struggling prey item would inflict upon being bitten. Neat. The maximum estimated bite force at the animal's canines was 218N, around the same strength as a modern caiman.

Based on the size of the biggest *Didelphodon* specimen, the largest maximum prey size would have been around 5kg – it could have even chomped on a small dinosaur! This means that even before the end-Cretaceous mass extinction, mammals had diversified to such an extent as to occupy the predatory-scavenger ecological role.

“Our study highlights how, despite decades of palaeontology research, new fossil discoveries and new ways of analysing those fossils can still fundamentally impact how we view something as central to us as the evolution of our own clade, mammals,” Dr. Wilson said. (source)

Reference

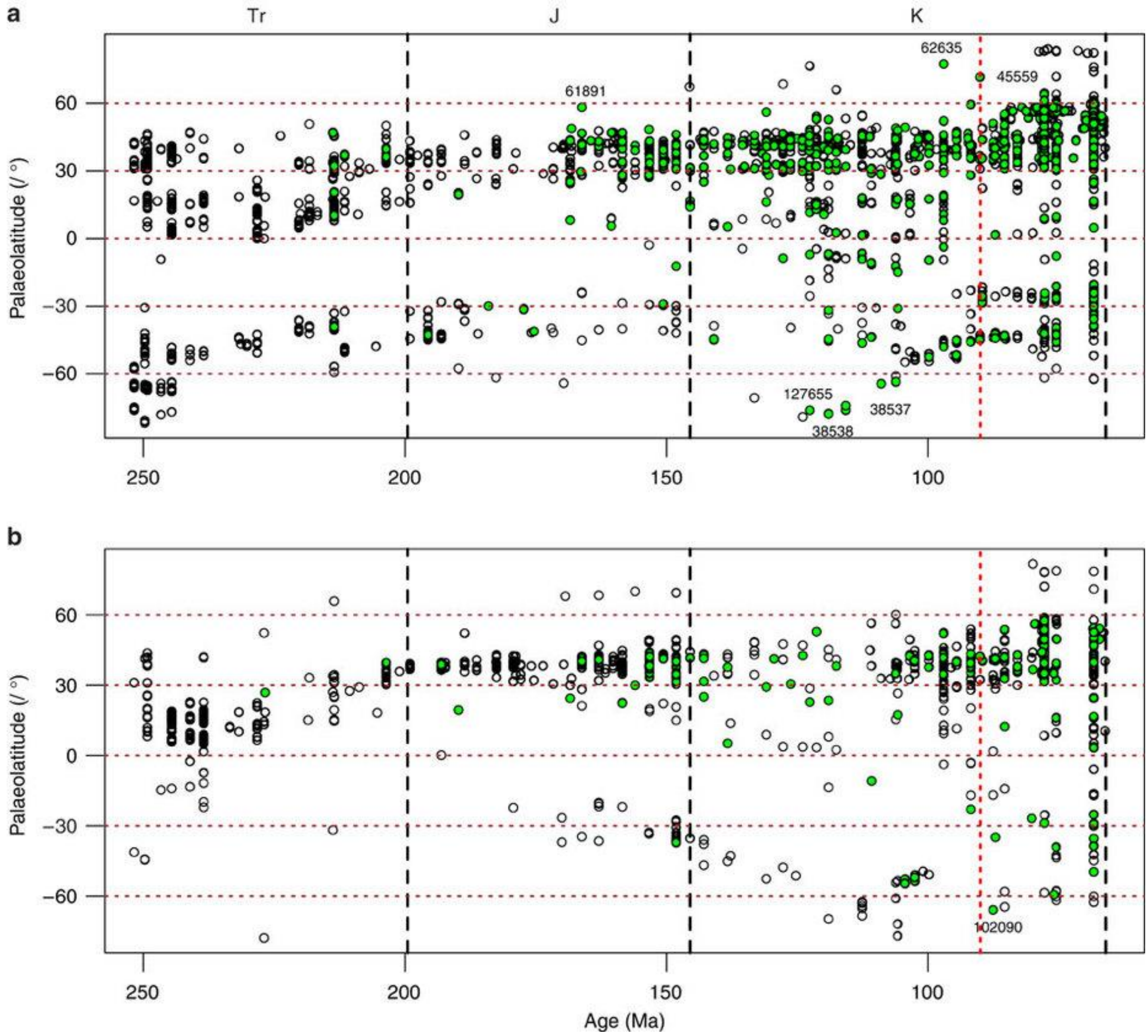
Wilson, G., Ekdale, E., Hoganson, J. *et al.* A large carnivorous mammal from the Late Cretaceous and the North American origin of marsupials. *Nat Commun* 7, 13734 (2016). https://doi.org/10.1038/ncomms13734.

Terrestrial Mesozoic ninja turtles

Turtles are an incredible evolutionary success story, with about 350 extant species that inhabit all major oceans and landmasses and from tropical to temperate climates. The fossil record of turtles is incredibly rich, and documents the adaptation of various sub-lineages to a broad range of habitat preferences, including several marine radiations. They’re also ridiculously cute, although whether their evolutionary accomplishment is down to this remains to be studied.

A slew of recent research articles have revealed much about the deep time evolutionary patterns in turtles and their ancestors (a couple of examples here, here and here). These large-scale, non-dinosaury studies get a frustratingly disproportional amount of public/media attention due to a low snarl/gore factor. However, they are arguably more significant due to the increasing importance of understanding the interaction of animals with their environments with ongoing major climatic disruptions and ongoing extinction severity.

The latest turtle-infused delight comes from David Nicholson as part of his post-doctoral research at the Natural History Museum in London, UK. Building on his research on global and continental diversity and niche partitioning (see links above), David and colleagues investigated the latitudinal diversity patterns that turtles and their ancestors (Testudinata, but here just ‘turtles’ to keep things simple) exhibited during the Mesozoic period based on their fossil record.

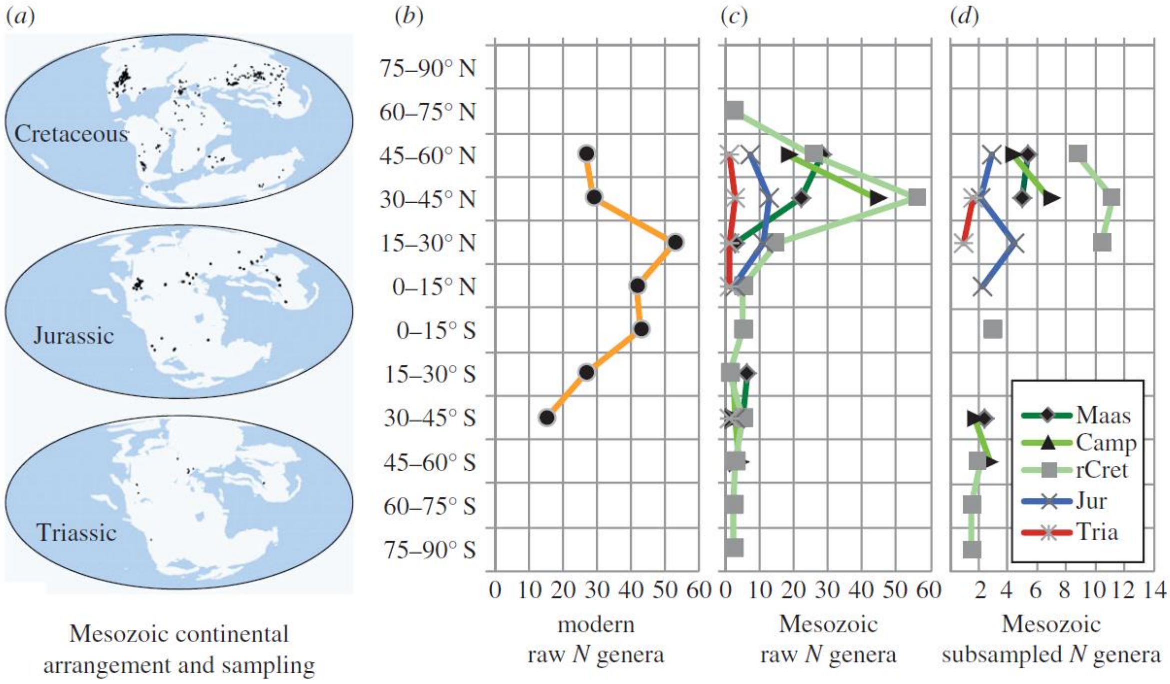


(a) Non-marine and (b) marine: open circles – tetrapod occurrences; green circles – turtle occurrences. J, Jurassic; K, Cretaceous; Tr, Triassic. (Nicholson *et al.*, 2015).

Why is latitude important? Well, the ‘latitudinal biodiversity gradient’ describes the pattern of increasing biodiversity as you go from the poles towards the equator, and is generally considered to be one of the first-order controls on much of modern life. Extant turtles, terrapins, and tortoises (collectively Testudines) are most diverse at around 25°N, so different to this general observation, and a feature of their global distribution that can probably be explained by bursts of species diversification related to changes in climate. But was this always the case?

What David and colleagues found peering back in time is a quite similar overall pattern throughout the evolutionary history of testudinatans – the group that includes modern Testudines and a whole bizarre array of now extinct turtle-like ancestors. During the Jurassic, they were most diverse at 15-30°N, after accounting for the way in which the continents have shifted since then. For the majority of the Cretaceous period, they were most diverse at 30-45°N, but at the very end of the Cretaceous, just before the mass extinction, this changed and expanded to a 30-60°N latitudinal belt. This 'last minute play' from turtles just prior to the extinction can be explained largely by the North American fossil record, in which we see the increasingly northward expansion of other groups such as dinosaurs at this time. Such range migration is coincident with short-term continent-level temperature increases around this time, which would have enabled turtles to migrate northwards and increase their geographical ranges, similar to what we see in the fossil record of crocodiles and their ancestors.

As well as this, turtles were able to survive in much higher latitudes in the northern and southern hemispheres throughout the Mesozoic compared to their living counterparts. This is because throughout the Mesozoic, the Earth was what we call a 'greenhouse' world, with overall much warmer climates than today which means that reptiles would have been able to survive a much broader range of latitudes.



Latitudinal generic richness of non-marine turtles in the Recent and Mesozoic. (b) Raw counts of Recent non-marine turtle genera by latitude (c) Raw counts of Mesozoic non-marine turtle genera by latitude. (d) Subsampled estimates of relative non-marine turtle generic richness using Shareholder Quorum Subsampling (SQS). Maas, Maastrichtian; Camp, Campanian; rCret, Berriasian–Santonian; Jur, Jurassic; Tria, Triassic. (Nicholson *et al.*, 2016).

Interestingly, the fossil record also tells us of a dearth of turtle diversity in the southern continents (Gondwana), much like in many other vertebrate groups, throughout the Jurassic and Cretaceous. It seems rather than this being due to a failure of the fossil record (i.e., we just haven't found that many fossils there due to sampling histories or lack of 'proper' rocks), this lack seems to be due to the absence of suitable habitats in Gondwana during this time, so turtles preferred to stay up North.

What this shows is that, firstly, latitudinal diversity gradients are not always stable and linear, and do change through time due to varying factors such as continental shifts, dispersal events and vicariance, or environmentally-mediated changes such as major climatic disruption (sound familiar?). However, for turtles, their modern latitudinal diversity distribution does seem to have a deep time origin, going back some 150-200 million years or so, which is pretty cool! Or hot. Or whatever.

This discovery also challenges the commonly held assumption that latitudinal diversity gradients are both static and widespread among all living groups. This is probably due to at least a partial failure to appreciate the patterns that the fossil record reveal to us among researchers who focus exclusively on extant taxa. Naughty... (not that we're biased at all as palaeontologists)

Reference

Nicholson, D.B., Holroyd, P.A., Valdes, P. and Barrett, P.M., 2016. Latitudinal diversity gradients in Mesozoic non-marine turtles. *Royal Society Open Science*, *3*(11), p.160581. https://doi.org/10.1098/rsos.160581.

Dinosaur bonebeds and biogeography: what the tiniest fossils tell us about the largest patterns

Discovering new dinosaurs is very romantic, isn't it? A team of plucky explorers stumbles across a small bone sticking out of a cliff, and after a bit of digging around it reveals a complete dinosaur skeleton, and a totally new species to science! I mean, that's how it always happens, right?

Wrong. Discoveries of complete dinosaurs, or even partial skeletons, are actually incredible rare. They often get the most glory and attention because this is how our media machine functions. The majority of dinosaur discoveries are actually disarticulated, broken, disassociated and fragmentary remains, often comprising no more than a few bones that somehow managed to survive the Earth's never-ending ravages for tens of millions of years. This is the rule, and 'good' fossils, no matter how incredible, are the exception.

More commonly than complete skeletons, 'bonebeds' are incredibly fossil-rich deposits that occur in single layers, comprising numerous small fragments of bone, or 'microfossils'. They typically form as 'lag deposits' in coastal environments or river bends where changes in the flow energy of water that transports the fossils leads to their deposition and concentration in clusters. Most of the time, the fossils aren't identifiable to the species level due to their fragmented nature and small size, but they still give us a good idea about the faunal composition based on sheer numbers alone. This is because we can obtain fossils from them in bulk through methods like sieving, and accrue massive sample sizes. So, an actual time where quantity over quality actually comes in useful!

We've had a post all about the value of bonebeds before on the network by Don Brinkman. Don described the kinds of patterns we could detect for dinosaur communities and their ecology from these bonebeds, such as trophic (feeding) structures. But what can bonebeds tell us about larger biological patterns too? Can they yield information about dinosaur biogeography, or how dinosaurs changed between different environments? This is what Thomas Cullen from the University of Toronto, Canada, set out to discover as part of his PhD focusing on the vertebrate faunas of North America during the Late Cretaceous.

The Belly River Group of southern Alberta is a renowned fossil hunters dream, containing numerous fossil deposits that have been well-sampled historically and represent a great diversity of dinosaurs and at a very high geological resolution. From this, Thomas helped to build and apply the largest Cretaceous vertebrate microsite dataset yet assembled to test different evolutionary and ecological associations between the faunal assemblages represented by the different microfossil sites.

The Belly River Group exposed along Oldman River close to the mouth, seen from Veteran Memorial Highway, Alberta, Canada (Source: Wikipedia).

What he found by applying a cadre of sophisticated statistical methods do this dataset is that changes in palaeoenvironment seem to have been most responsible for changes in the structure of the preserved faunal assemblages. In particular, where the rocks record a shift from a marine to a more inland (terrestrial) environment, major shifts in faunal composition are recorded, as we might expect. Personally, I kinda like this result as it supports some of my own research showing that sea level changes are important in controlling tetrapod diversity through time, but here on a much more localised scale and using different techniques and data.

What Thomas also found is that dinosaur faunas appear to be quite stable in terms of changes to latitude and altitude, distinct from numerous studies that have found this at larger scales within North America. For example, the existence of a dinosaur 'latitudinal diversity gradient' has been long debated, but evidence for the existence of this pattern on a more localised scale appears to be lacking. Furthermore, dinosaur faunas did not appear to differ substantially based on occupation of different terrestrial environments, for example coastal versus rivers. Again, this is contrary to some recent evidence that found a strong partitioning between sauropod dinosaurs and palaeoenvironment, but again at a different scale.

What this implies overall is that dinosaurs are perhaps less sensitive than previously thought to more subtle changes across terrestrial landscapes, and that additional parameters must therefore be responsible for their relatively high diversity at this time. Thomas suggests that additional ecological or evolutionary factors such as niche partitioning among species or high rates of evolution might be important here, but that's an avenue for future research!

Reference

Cullen, T.M. and Evans, D.C., 2016. Palaeoenvironmental drivers of vertebrate community composition in the Belly River Group (Campanian) of Alberta, Canada, with implications for dinosaur biogeography. BMC ecology, 16(1), p.52. https://doi.org/10.1186/s12898-016-0106-8.

How sauropods gobbled their way to gigantism

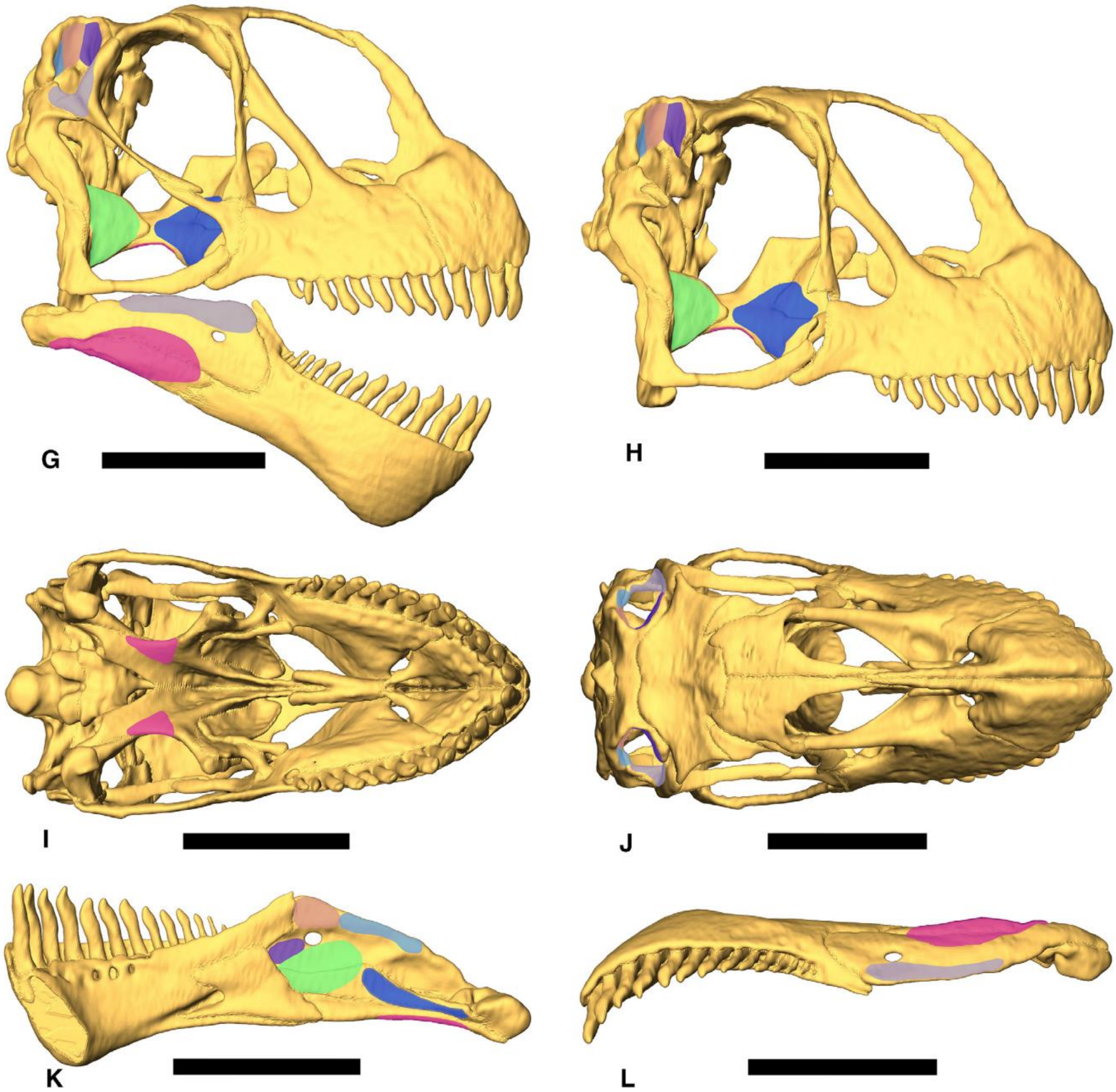
Sauropod dinosaurs are the biggest of all the wonderful behemoths to have ever roamed the Earth. Standing on four solid tree trunk legs, these giants are emblazoned in our hearts, minds and history books as towering Mesozoic monoliths, with long swooping necks, whiplash tails, fermentation-factory torsos, and weirdly tiny heads totally at odds with their immense bulk.

Many of these strange features sauropods possessed are underpinned by one key and unique aspect of sauropod life: how the hell did they eat enough to sustain such a massive body size? This question has had palaeontologists pondering for decades now, and is part of an ongoing puzzle that seeks to reveal how sauropods became some of the most diverse and abundant dinosaurs in spite of their sheer enormity.

Feeding is one of the most important ecological aspects to study for animals, as it influences their life style, metabolism, habitat, and general life strategy. Figuring this out for sauropods then is pretty important as it can tell us about how feeding links to evolutionary constraints on gigantic body sizes in land-dwelling animals.

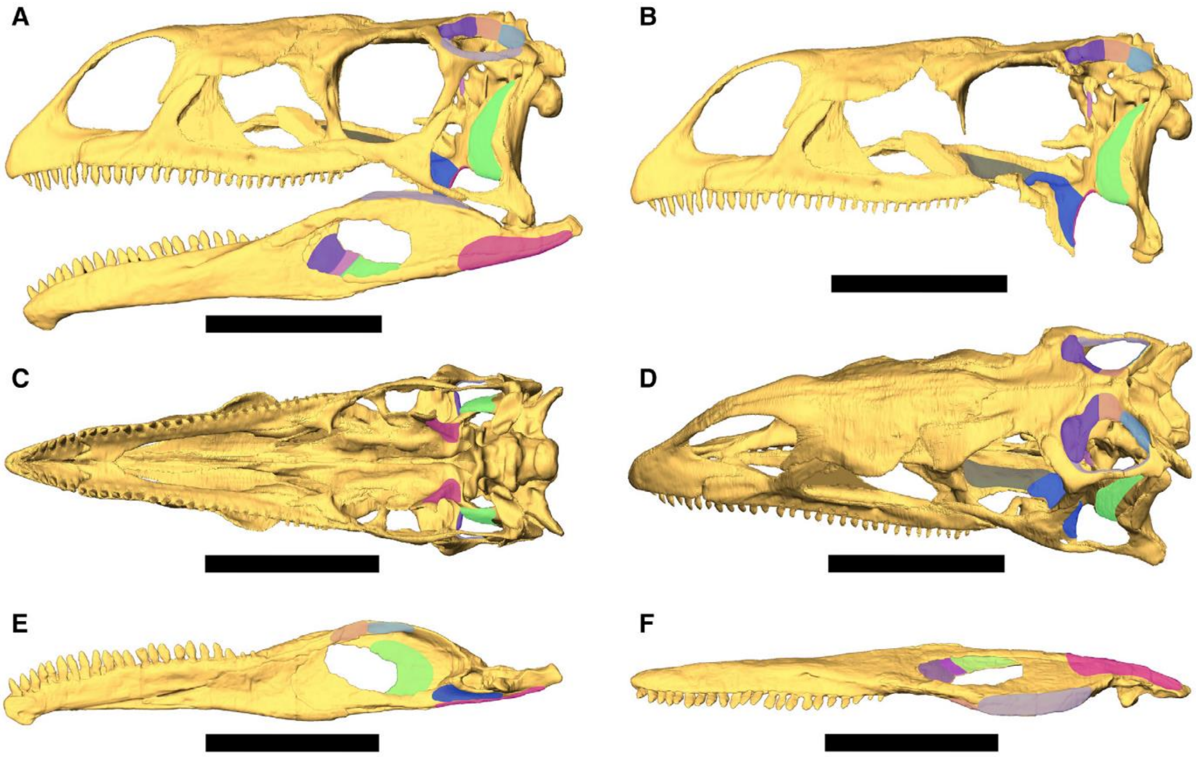
Thankfully, computer-assisted engineering studies of biological organisms has really taken off in the last few years, especially in dinosaur studies. The field, generally known as biomechanics, applies our knowledge of materials and their physical properties to ask questions about how animals behaved in different ways, such as how fast they could run, or what bite forces they could achieve.

A team of researchers from the UK led by Dr. David Button decided to apply biomechanical methods to investigate the evolution of herbivory in sauropods and their ancestors, together called sauropodomorphs (palaeontologists win full points for originality...). To do this, they created 3D computer models of the skulls two iconic dinosaurs, *Plateosaurus* from Europe, and *Camarasaurus* from North America. Sauropodomorph skulls are unusual in that despite being so small compared to their gargantuan bodies, they were highly specialised and effective cropping machines. But how this varied between different species is still relatively poorly understood.



A happy looking *Camarasaurus* (Button *et al*., 2016).

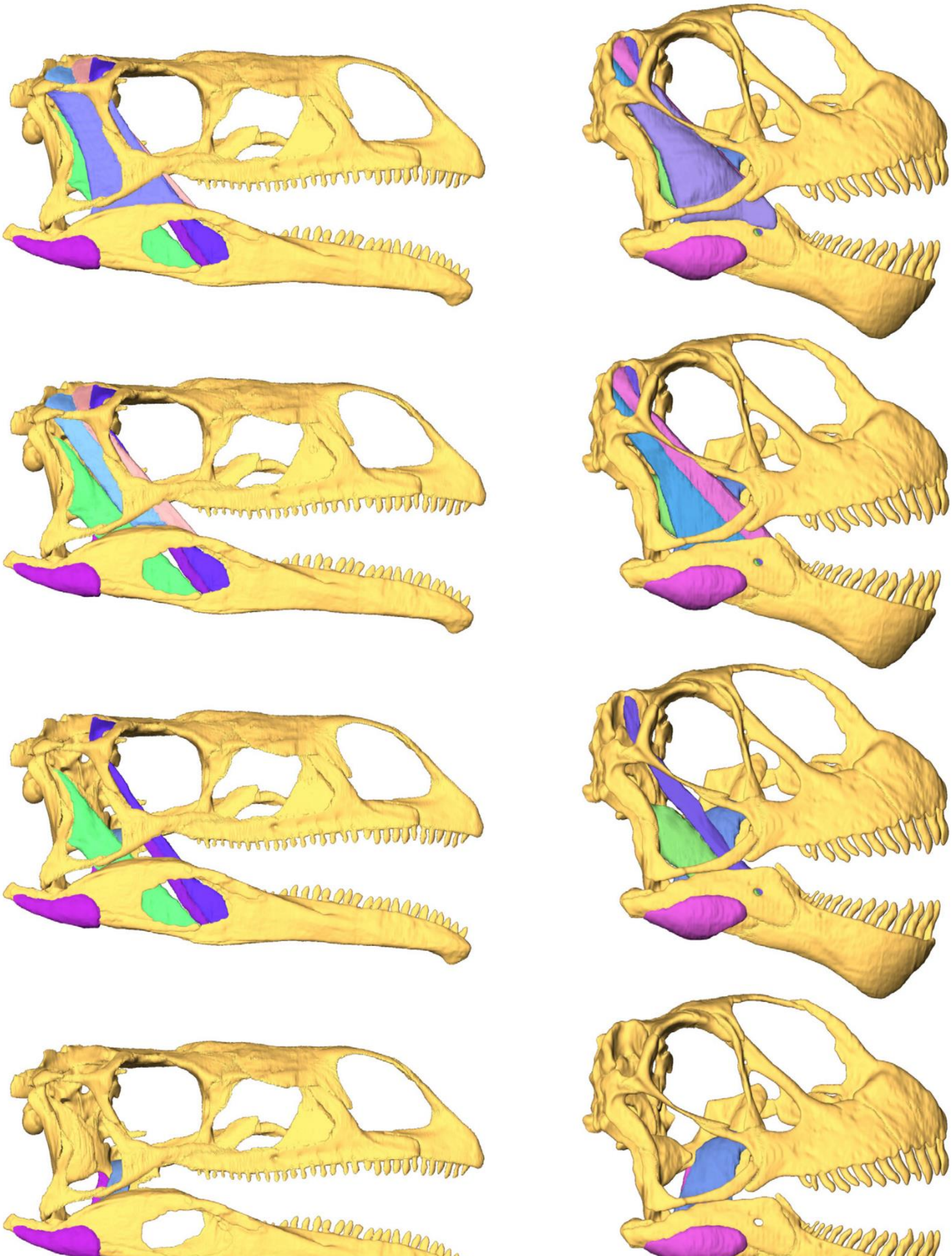
What the team found then is that *Camarasaurus* had a much stronger bite force than the geologically older *Plateosaurus*. This was due to the former having greater chomping musculature – the adductor muscles – and also due to shape changes in the lower jaw, or mandible. By changing the jaw shape in particular ways, it is possible to increase bite efficiency by increasing the amount of muscle force that gets converted into bite force.



Plateosaurus, with muscle insertion sites highlighted (Button *et al*., 2016).

Woah, wait one second. Muscles? That's crazy! We don't have fossilised dinosaur muscles. Well, you're right, we don't (yet). But we do have skulls, and by comparing dinosaurs with other modern reptiles such as crocodiles and birds, we can actually be pretty confident about what the reconstructed skull muscles of dinosaurs looked like. By looking at both the reconstructed skull muscles and bones, Button and colleagues were able to gain a much more accurate mechanical picture of how sauropodomorph skulls function, as opposed to just using the skulls alone like the vast majority of previous studies.

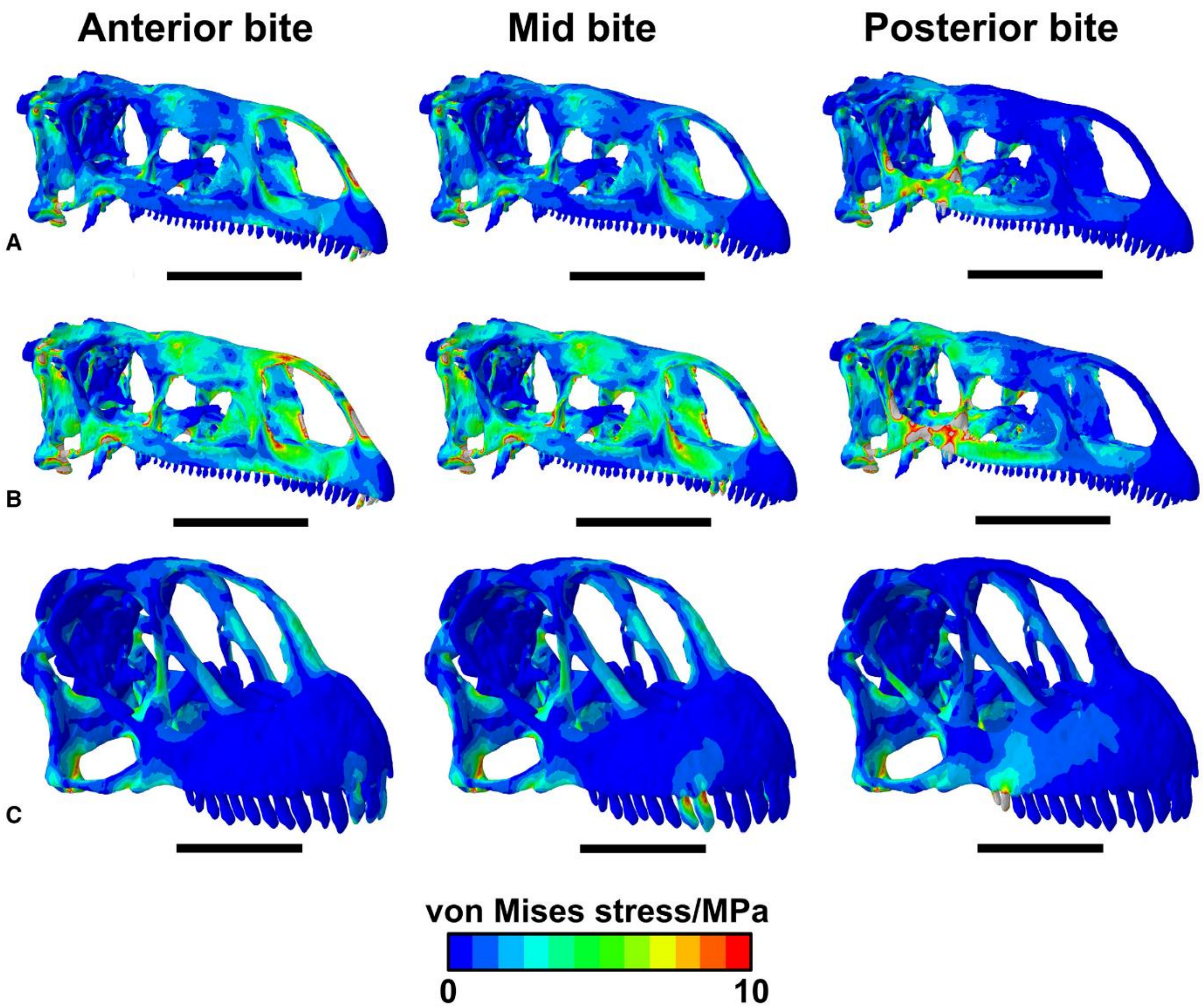
This increase in bite force which they found on an evolutionary time scale is mirrored in the acquisition of additional key features that would have been critical in the ability of sauropods to bulk feed. For example, their tooth crowns became wider and were able to slide past, or occlude with, each other, making them much more efficient at cropping and slicing tough, fibrous plant matter.



Face off! Reconstructed muscles of *Plateosaurus* (left) and *Camarasaurus* (right) (Button *et al*., 2016).

In *Plateosaurus*, the jaw mechanics are quite different. The ability to distribute forces through the chewing gear and the structural strength appear to be much lesser in favour of being able to chew faster by opening and closing the jaws. This is due to features such as a relatively longer tooth row in *Plateosaurus*, which changes how the jaw operates as a mechanical 'lever'.

Button and colleagues suggest that this could be due to *Plateosaurus* being at least partly omnivorous, as many other early sauropodomorphs might have been. This is because jaw closure speed isn't exactly important when your sole 'prey' are, well, leaves, but is when your prey can try to run or wriggle away from you. In fact, *Plateosaurus* even has different types of teeth in the same individuals, a feature called 'heterodonty', that indicates the animals fed on different types of material, perhaps even small animals.



Stressful... Different stresses imposed on their skulls during feeding (Button *et al.*, 2016).

The shift from this structurally weaker skull in *Plateosaurus* to one in *Camarasaurus* that can accommodate increasing food-related forces would undoubtedly have been significant in sauropods' increasing ability to bulk feed, and ultimately their enormous size as part of an 'evolutionary cascade'.

Reference

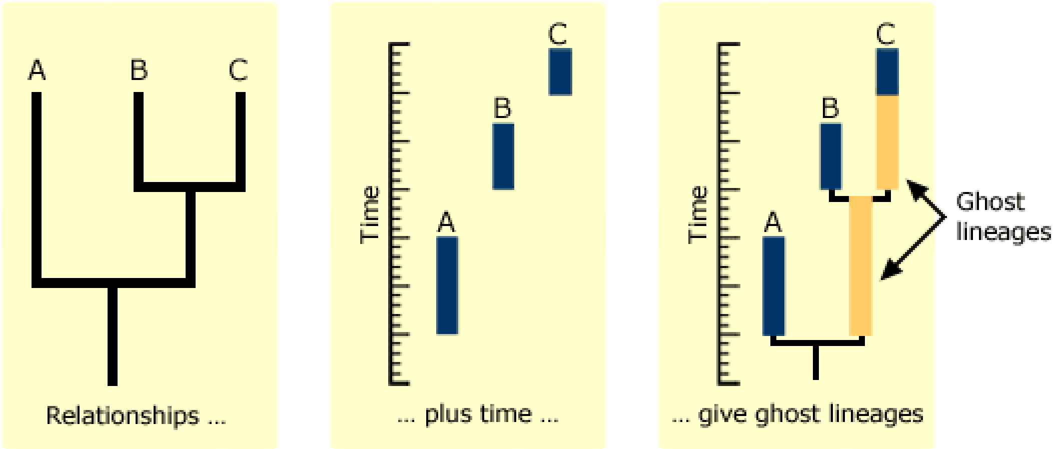
Button, D.J., Barrett, P.M. and Rayfield, E.J., 2016. Comparative cranial myology and biomechanics of Plateosaurus and Camarasaurus and evolution of the sauropod feeding apparatus. Palaeontology, 59(6), pp.887-913. https://doi.org/10.1111/pala.12266.

How and why to date a dinosaur

You might think dating dinosaurs would be an easy task, but in reality, it's actually quite difficult. We date dinosaurs based on where we find their fossils, using the ages of the rocks that they're found in. This means that the 'ages' of different dinosaurs is actually indirect and constrained by how well we're able to date the rocks they were found in.

Ghosts in the machine

As well as this, we know that the occurrences of dinosaur fossils are not accurate representations of their age either. If we know one dinosaur species A was around 120 million years ago, and its closest relative species B known only 100 million years ago, then species B must have existed 120 million years earlier too as they must have shared an origination time due to the way speciation works – we just haven't found any fossils of it during this 20 million year gap though. And we call these ghost ranges or lineages.



(Source)

What these ghost ranges do, when combined with trees that illustrate the relationships between different organisms, is alter the timings or dates of important events based on exactly how we time-scale the trees and the ghost and true ranges of species.

Why date a dinosaur?

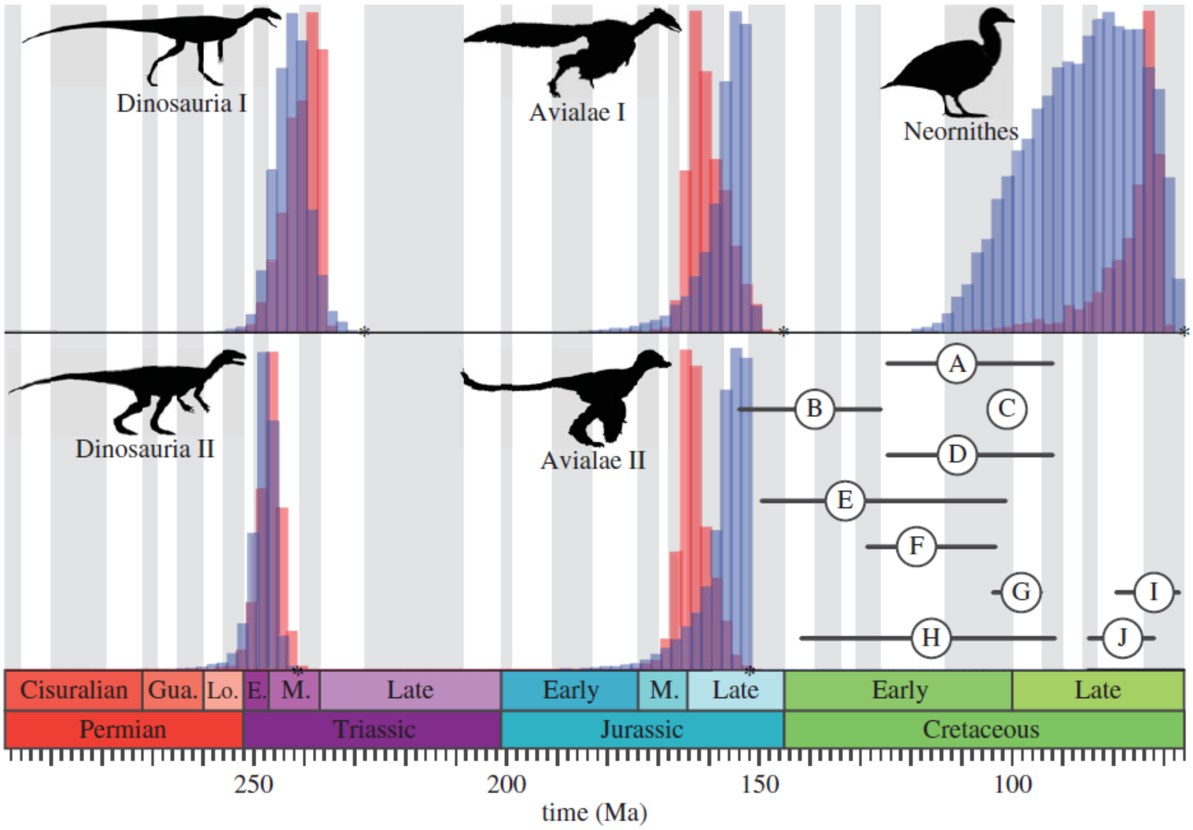
This uncertainty in dating and the methods we use actually has quite important implications for significant events in the evolutionary history of dinosaurs. A team led by Graeme Lloyd of Macquarie University, Australia, recently set out to investigate three questions:

1. What was the origination time for Dinosauria (all dinosaurs)?
2. When did the earliest birds originate?
3. When did crown birds (the group that includes all modern birds) originate?

They used a cadre of time-scaling methods on a brand-new evolutionary tree for all dinosaurs, making this the best test of these questions so far. So, what did they all discover?

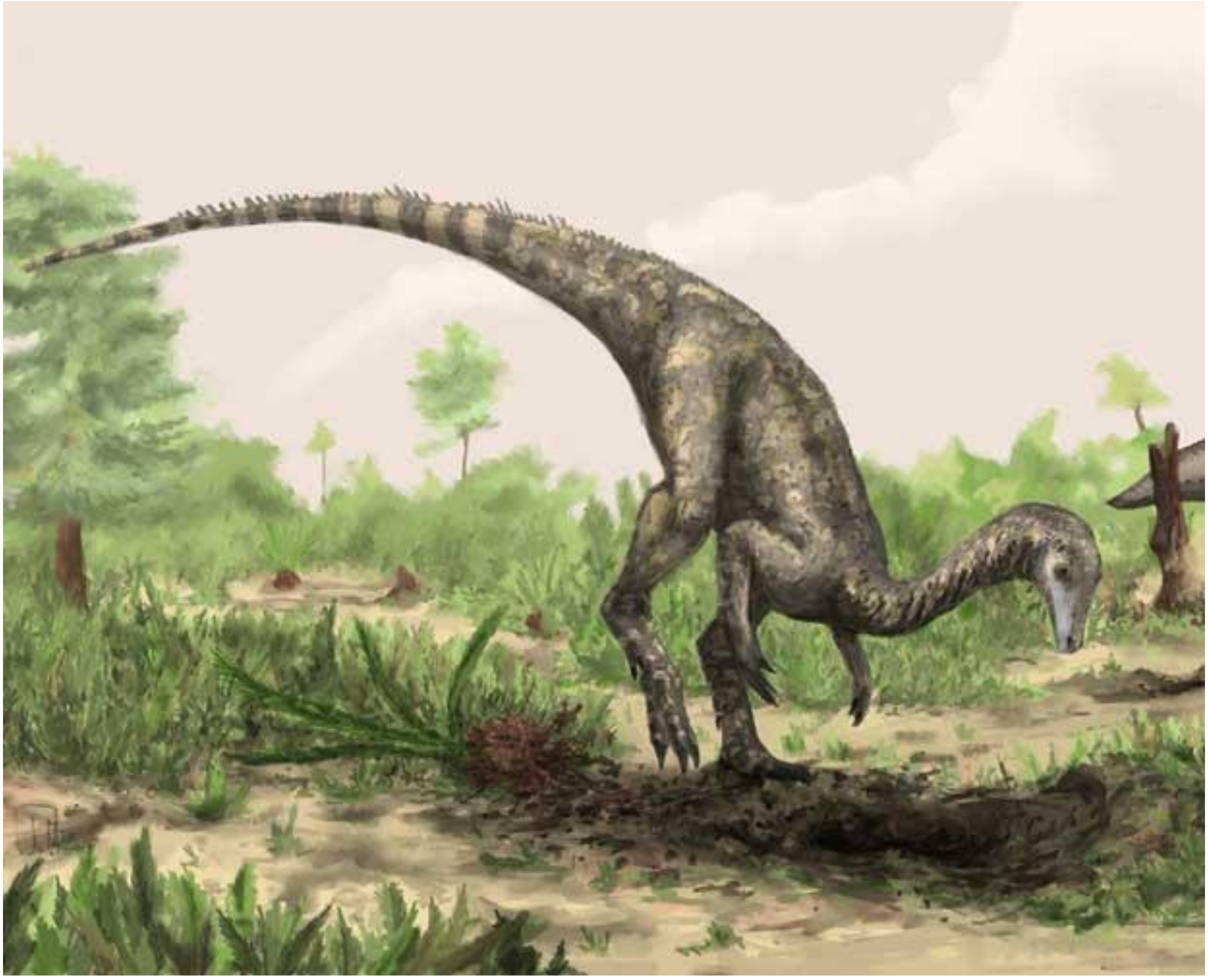
Whence came thee, dinosaur

What was the first dinosaur? That's a tough question, and the reality is we'll probably never actually know. The fossil record preserves little fragments and snapshots of life through time, so while we may never find the first real dinosaur, we can have a good whack at what the earliest dinosaur species was based on what the fossil record yields to us.



From Lloyd *et al*. (2016). Distributions represent the range of dates from using different tree-dating methods. The bottom right panel is for different methods applied for Neornithes.

As with all good things in palaeontology, this is still up for debate too. A reasonably new species to science called *Nyasasaurus* might be the earliest dinosaur we know of, or just outside the group and actually what we call a dinosauriform. Depending on this uncertainty, the origin of Dinosauria seems to have most likely occurred in the Early or Middle Triassic, much earlier than the oldest fossils might suggest.



Nyasasaurus (Source).

And an Archaeopteryx in a phylogenetic tree

As with the first dinosaurs, the contender for the earliest bird is still up for debate, with researchers unable to pick between *Archaeopteryx* and the more recently discovered *Aurornis*, which might be a troodontid. Irrespective of this, the origin of the earliest birds, the clade Avialae, seems to hone in on around a Middle to Late Jurassic age, so around 160-145 million years ago. This is fairly close to when we see the oldest potential bird fossils, and some of the oldest evidence of feathered dinosaurs.

Birds of a feather

The group that includes all modern birds, Aves, or Neornithes, is what we call the 'crown group' for birds. Other dinosaurs like *Triceratops* belong on the stem of this group, and can actually be considered as 'stem birds'. The origin of Neornithes is the most uncertain of all three groups analysed, stretching from the end of the Cretaceous around 66 million years ago all the way until the middle Early Cretaceous, around 120 million years ago. The reason for this uncertainty is simply due to the state of the fossil record during the Late Cretaceous, in which the taxonomy of some species is quite difficult to assess.

Importantly, all of these new estimates seem to post-date traditional estimates for the origins of these groups that rely mostly on simple occurrence dates of the fossils, and don't account for their evolutionary relationships.

This is important for evolutionary studies as it means that we can now more accurately assess the times of important steps in the global tree of life, and apply these to our large-scale understanding of the macroevolution of life on Earth.

Reference

Lloyd GT, Bapst DW, Friedman M, Davis KE. 2016 Probabilistic divergence time estimation without branch lengths: dating the origins of dinosaurs, avian flight and crown birds. Biol. Lett. 12: 20160609. http://dx.doi.org/10.1098/rsbl.2016.0609.

Bigger theropods rocked flashier head gear

Dinosaurs come in all shapes and sizes, and were the weird wonderful show-offs of the Mesozoic world. From massive, plated body armour to elaborate frilly head shields and rock solid bone-heads, they sported just about every sort of flashy fashion possible at the time.

There is a large ongoing discussion between researchers as to why these sorts of 'ornaments' evolved – was it to differentiate between species, for sexual selection, for communicating between individuals, for fighting or defence, or for something else entirely?

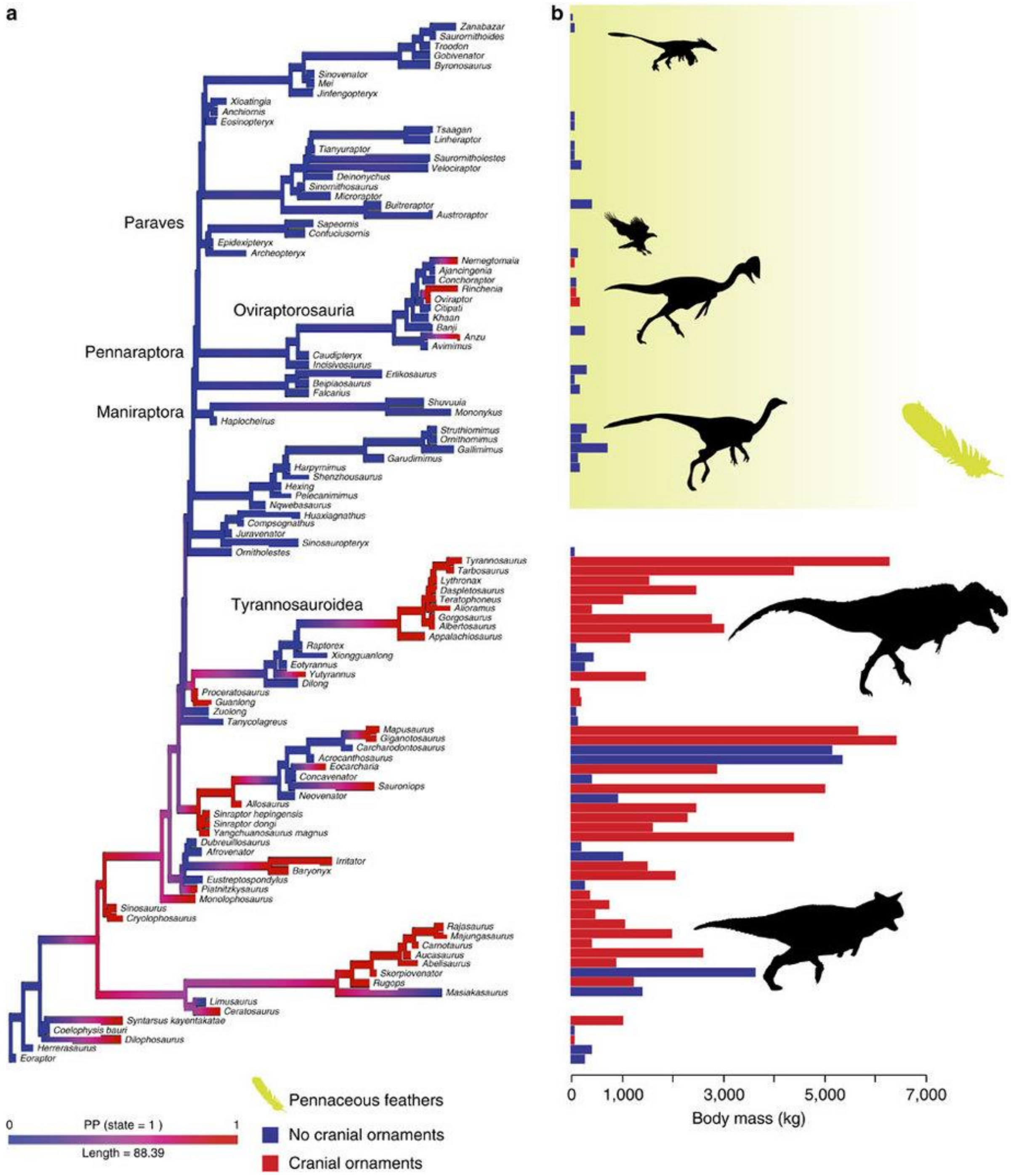
One of the problems here for extinct dinosaurs is that we can't actually go back in time (yet) and see exactly how these animals used their ostentatious ornaments. This is a bit of an issue if we want to learn more about how dinosaurs functioned not just as animals, but in a social context.

Allosaurus flashed these cute crests above its eyes, but what were they for? (Source: Wikimedia).

New research by Terry Gates and colleagues has shown that in theropod dinosaurs, the evolution of the weirdness of their head gear, mostly bony horns and crests, is closely tied to the progressive development of gigantism – larger body size.

This evolutionary trend towards gigantism occurred an order of magnitude faster in more flamboyant theropods than those who remained unadorned. Not only this, but it seems that in many different lineages, if you wanted to grow to over 1,000kg then this was dependent on the previous evolutionary acquisition of ornamentation. No crown, no entry into the big leagues for theropods, it seems. This is actually the first time such an evolutionary threshold has been found in any amniote group (those which lay eggs), making theropods even weirder than they were before!

Interestingly though, evidence for this trend is at its strongest in what we consider to be ‘basal’ theropods, those which are more towards the base of the theropod family tree.



From Gates et al. (2016).

Maniraptorans, the more ‘advanced’ group that includes all modern birds and some of their closer theropod cousins including *Velociraptor*, generally lack these bony structures. This is unusual, as they achieved a whole range of body sizes, from whopping beasts as tall as a double decker bus, right down to chicken-sized cuties.

However, some species did evolve weird ornaments too. Almost all of the largest of these belong to a group called oviraptorosaurs, once thought to be sneaky egg (ovi) thieves (raptor), but now considered more to be just a bizarre evolutionary offshoot closely related to birds. Why this is remains a mystery for now, but it certainly raises intriguing questions about the sociology of this group.

The reason for this apparent body size related distinction might be due to the evolution of pennaceous feathers in maniraptorans – those which are structurally designed for flight like we see in most modern birds. Now this is where it gets really cool. What this suggests is that these theropods had a sort of evolutionary trade-off, where they shifted visual communication structures away from simple bony elements to the more elaborate and colourful patterns that you get with feather displays. What’s more attractive – a rhino or a peacock? (OK, subjective I know, but you get the point...)

It also suggests that different theropod groups evolved in highly distinct ways. Numerous recent studies have shown that in the maniraptoran lineage, there was a sustained and accelerated evolutionary trend towards decreasing body size that was probably ecologically driven by the ability to fly. This is distinct from other larger-bodied theropod groups, where it seems social or sexual factors were more at play in driving evolutionary trends in body size.

This study is a really nice piece in helping to understand dinosaurs in a more social context, and helps to breathe a new life into how we see them as living, interacting organisms.

Reference

Gates, Terry A., Chris Organ, and Lindsay E. Zanno. “Bony cranial ornamentation linked to rapid evolution of gigantic theropod dinosaurs.” *Nature Communications* **7** (2016): 12931. https://doi.org/10.1038/ncomms12931.

The Brazilian Titan

Sometimes the greatest dinosaur discoveries are just lying waiting to be found in a museum cupboard.

Titanosaurs were some of the most enormous animals to have ever strode the Earth, moving in enormous herds and thundering across the land, devouring any forests in their path. They reached a near-global distribution during their time, even reaching Antarctica and Australia, and recent discoveries have revealed an amazing species diversity for the group.

In South America, titanosaurs truly reached their zenith in both size and biodiversity. Nonetheless, new species keep becoming known to science through numerous discoveries, both old and new! Recently, yet another new species has been named based on series of fossilised vertebra after being locked away for more than 60 years in a museum basement.

The fossils were actually originally discovered back in 1953 by Brazilian palaeontologist Llewllyn Ivor Price, but remained hidden in storage at the Museum of Earth Sciences in Rio de Janeiro due to the lack of proper tools or finances to study it further.

The new species is named *Austroposeidon magnificus*, and comes from a place in São Paulo State of southeast Brazil called the Paraná Basin. It hails from right near the end of the Cretaceous, when the truly gigantic dinosaurs were roaming the lands, just before many went extinct. The name, *Austroposeidon*, comes from “Austro” meaning southern, and refers to Poseidon, the Greek god for causing earthquakes, as the beast would have shaken the very ground it walked on!

The Director of Earth Science Museum Diogenes de Almeida Campos shows the biggest piece of fossil of the *Austroposeidon magnificus* dinosaur's neck (source).

Austroposeidon would have been a pretty magnificent sight to behold, coming in at around 25 metres (about 82 feet) in length when fully grown, placing it way up in the heavyweight category. That's about the same as two buses back to front, and makes it the largest known dinosaur from Brazil! So far...

Kamila Bandeira and colleagues were able to even use 3D CT scanning to show that, similarly to other titanosaurs, the vertebral bones were pneumatised – possessing numerous internal air pockets. These would have considerably lightened the enormous skeleton, much as we see in modern birds. The researchers went back to the original place of discovery to try and find more of the animal, but unfortunately the area has been urbanised now, rendering finding the final resting place nigh impossible.

Austroposeidon wouldn't have been alone in its adventures. Other sauropods, albeit much smaller sized ones, are known from the same rocks, including *Brasilotitan* and *Gondwanatitan*. Similar to other regions were multiple giant herbivores co-existed, it is likely that these animals had certain very specific feeding styles in order to efficiently maximise the use of limited vegetation resources. The latter two might have fed on plants closer to the ground, while *Austroposeidon* towered above them, gracefully grazing from the treetops.

The deserts of South America are revealing new dinosaur species to us at an astonishing rate, and the future of discovery there is truly exciting!

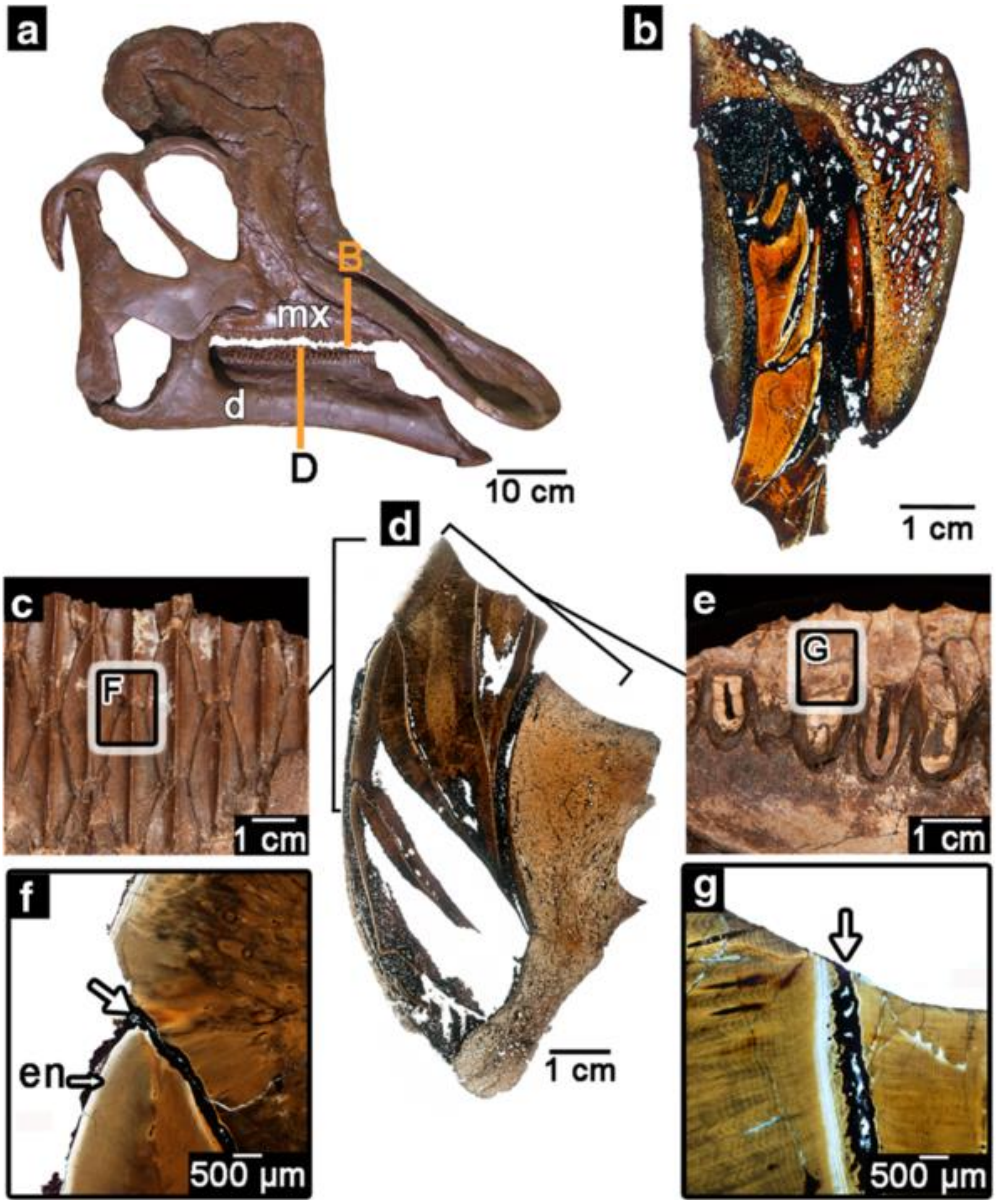
Reference

Bandeira, K.L., Simbras, F.M., Machado, E.B., de Almeida Campos, D., Oliveira, G.R. and Kellner, A.W., 2016. A New Giant Titanosauria (Dinosauria: Sauropoda) from the Late Cretaceous Bauru Group, Brazil. *PLOS ONE*, 11(10), p.e0163373. https://doi.org/10.1371/journal.pone.0163373.

All the better to chew you with, my dear

Hadrosaurs were the ‘duck billed’ cows of the Cretaceous. They got this reputation firstly for their unusual ‘beaked’ mouths, and secondly for their apparent ability to chew food with amazing efficiency, often depicted grazing like cattle.

Hadrosaurs had teeth arranged into what are called dental batteries – rows of stacked teeth designed for crushing and grinding tough, fibrous plant matter to increase its digestibility. These tooth batteries could contain up to 300 individual teeth in each part of the jaw!

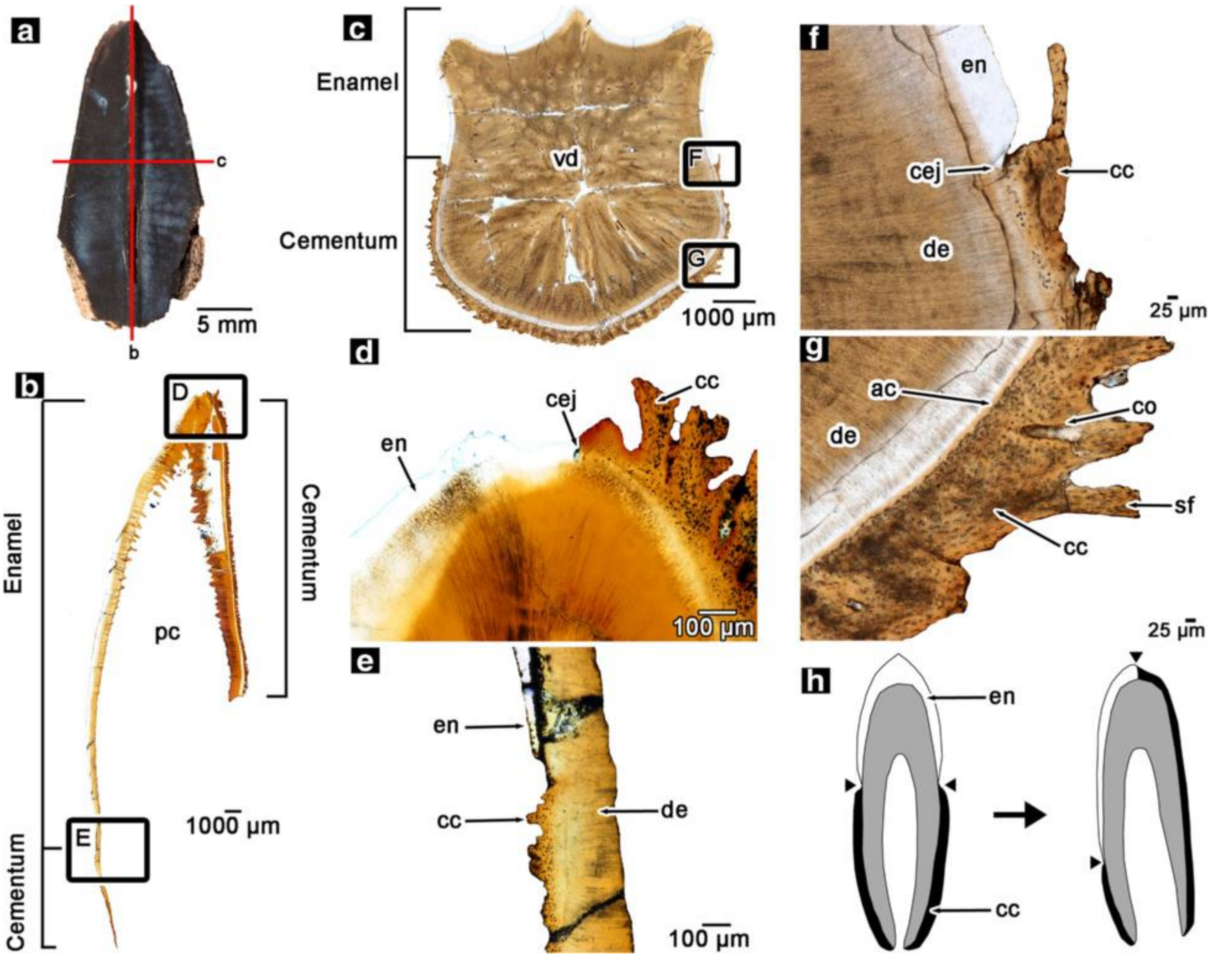


The dental battery of hadrosaurs. (a) *Corythosaurus*, (b) cross section through cheek dental battery, (c) lower jaw battery, (d) thin section of lower jaw battery, (e) chewing surface of battery, (f and g) close-ups of intersection between teeth.

Despite not being as 'media sexy' as giant sauropods or ferocious theropods, these dental batteries are the most complex tooth forms ever developed in the whole history of vertebrate evolution. And that's pretty damn awesome.

What is a little odd though is that despite wide interest in these amazing teeth, very little is known about their evolutionary origins. Which is even odder because dinosaur researchers are usually really good at obsessing over little things like this.

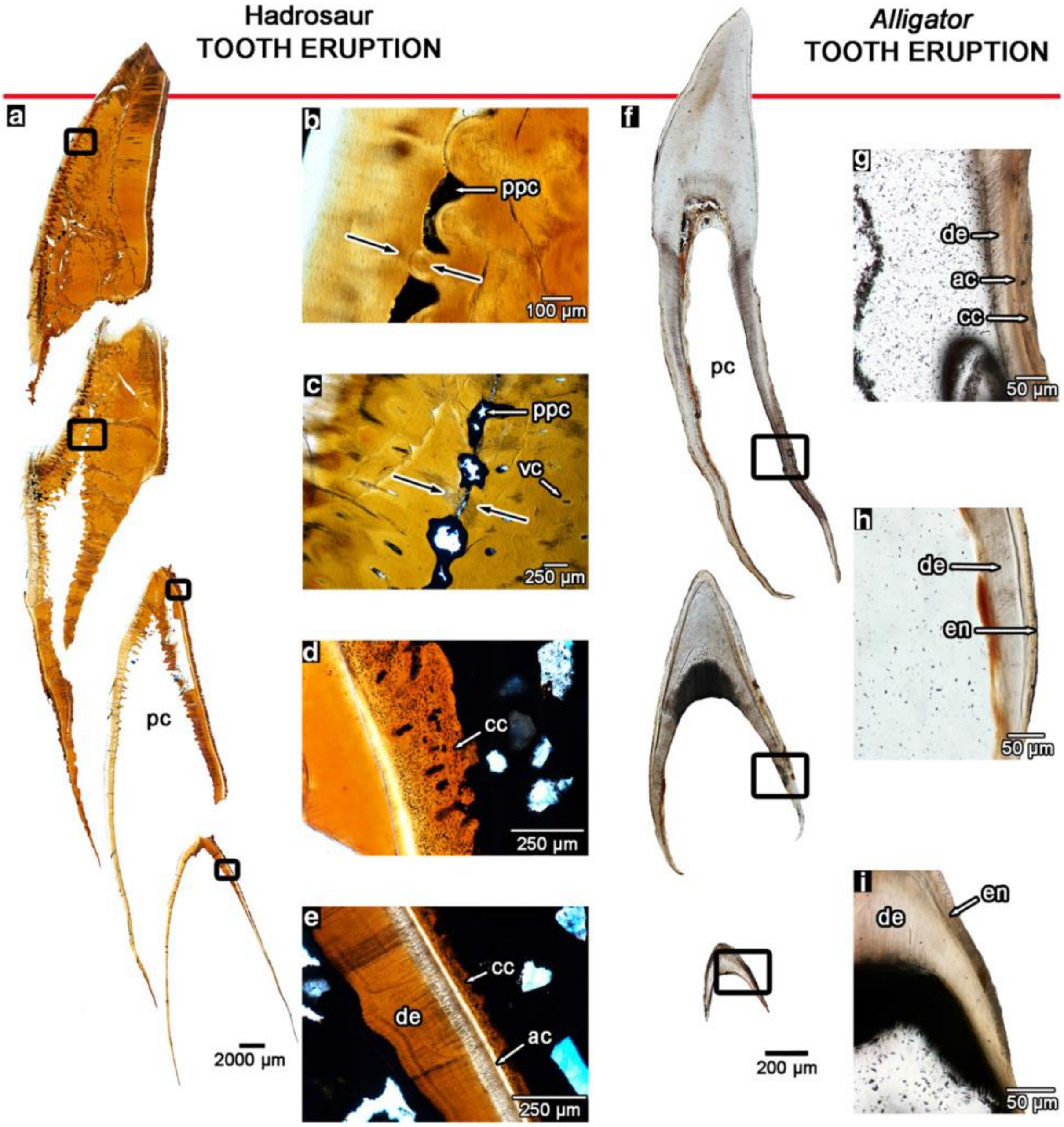
Research by [Aaron LeBlanc and colleagues] looked at the development of the different tissues making up hadrosaur teeth through individual growth series to see just how these complex tooth batteries formed.



Histology of hadrosaurid teeth showing different cross-sections.

They did this by slicing up the teeth of hadrosaurs into really thin slices called thin sections. These are thin enough that you can look in great detail at the three-dimensional microstructure of the bone under a microscope, and see the different and exquisite tissue types and textures.

What the team discovered is that the dental batteries formed through a combination of being able to stop the process of normal tooth replacement and then also allowing the root of the teeth to form part of the grinding surface – also known as the occlusal surface (because it's the surface with which the tooth sets 'occlude').

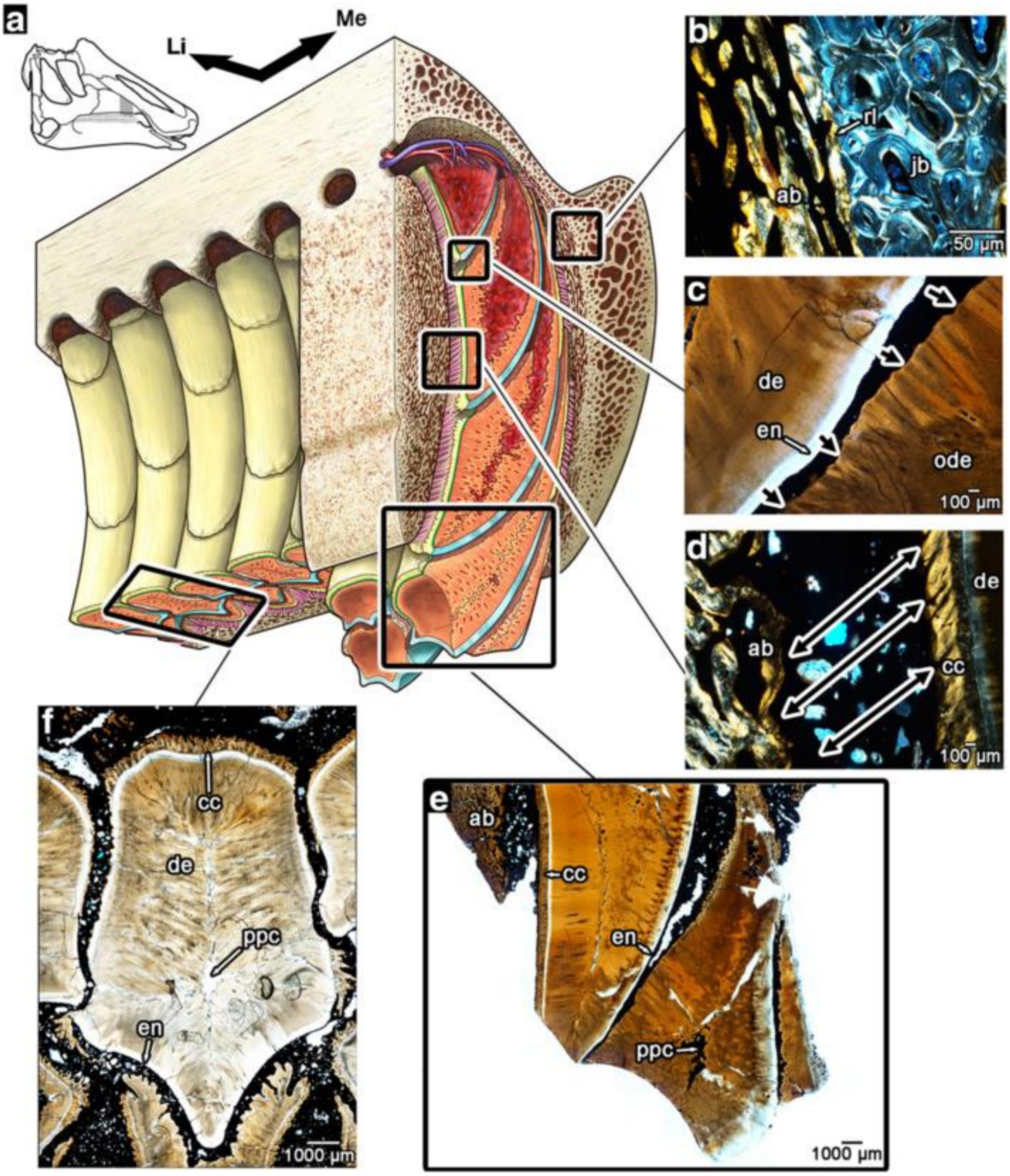


Comparisons of tooth development in hadrosaurids and modern *Alligator*.

This is unusual as usually in other amniotes (egg-laying animals), the enamel forms a complete covering crown over the core of the tooth (you can feel this right now with your tongue). But in hadrosaurs, the enamel shifts to one side, and the tissue that makes up the core, called cementum, forms the other side of the tooth.

This tooth form exists not just in the adult hadrosaurs, but also in teeny embryonic specimens and those preserved as hatchlings. What this means is that even at the earliest stages in development, both the enamel and the cementum start forming at the same time as opposed to one after the other.

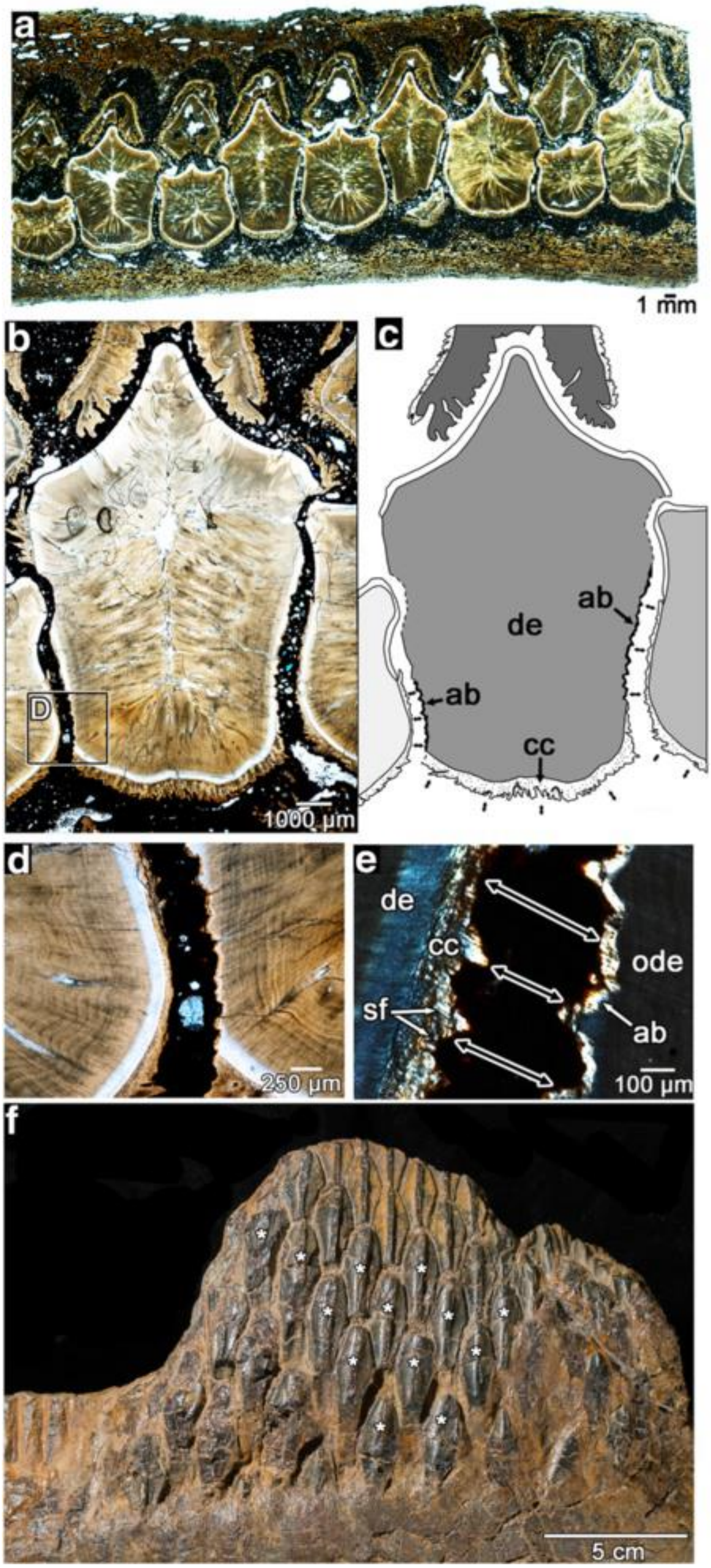
Because hadrosaurs also did not shed their teeth, like most other vertebrates, this means that they retained multiple ‘generations’ of teeth in stacked positions on top of each other. What seems to happen here is that instead of teeth being pushed to the side as new ones emerge, older teeth are resorped quite a bit, which leads to a tight and solid interlocking structure.



Internal anatomy of a hadrosaur tooth battery.

The result of this is a highly complicated and integrated ‘matrix’ of different bits of tooth, including living replacement and dead grinding teeth, all connected by a flexible network of ligaments.

Rather than a single, solid block then, it is better to view hadrosaur dental batteries as more similar to scales on medieval armour or shark skin – here, each single element is strong and rigid, but the material connecting them is flexible and makes interactions between groups of teeth more efficient. This complexity is undoubtedly one of the reasons for the evolutionary success of hadrosaurs, and while they might not look as spectacular as other groups of dinosaurs, they were certainly no less impressive!



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5 cm

Tooth-to-tooth attachment within the hadrosaur dental battery

Reference

LeBlanc *et al*. (2016) Ontogeny reveals function and evolution of the hadrosaurid dinosaur dental battery, *BMC Evolutionary Biology*. 16:152, https://doi.org/10.1186/s12862-016-0721-1.

Brain anatomy convergence between crocodylians and their epic carnivorous cousins, the phytosaurs

If I ask you to think of a large, extinct carnivorous reptile, what do you think of? I'm gonna guess that pretty much all of you went straight for a *T. rex*, or if you're a bit weird (or vegetarian), maybe a *Stegosaurus*.

But if you think back in time of when the dinosaurs were around, and especially when they were just getting kick-started, there were so many other bizarre and spectacular groups of animals around.

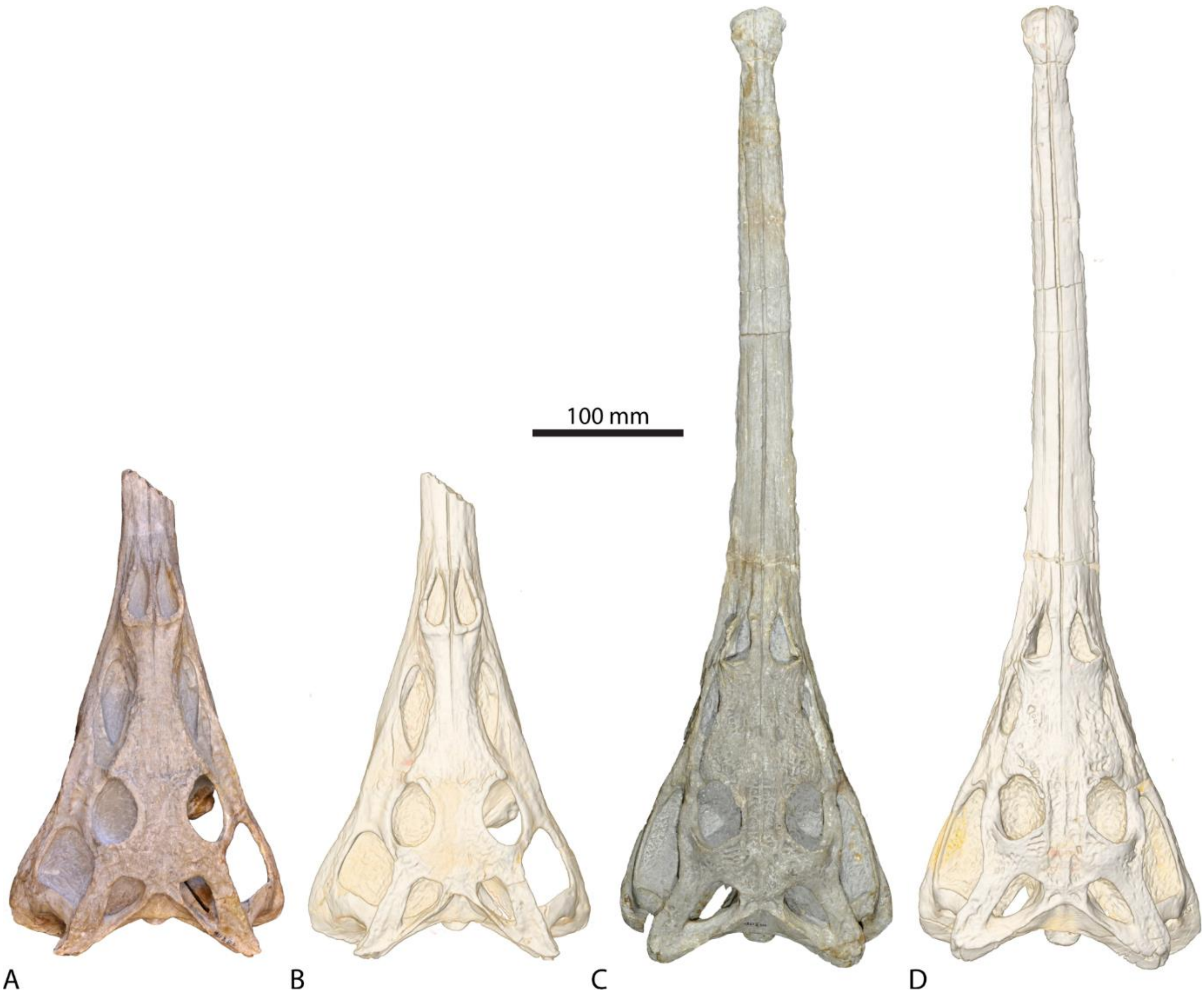
Let's go back to the Late Triassic, around 230 to 200 million years ago. Earth was pretty different to how it was now – you wouldn't recognise any of the modern groups we know so well like birds, mammals, and amphibians. The continents were in disguise too, collaborating to form the giant supercontinent Pangaea, which sat over the equator ready to rupture at any second (slash million years or so…)

One of these groups were called phytosaurs, and are hideously under-appreciated beasts. They were a group of large carnivores, closely related to the earliest dinosaurs and crocodiles. It has often been pointed out that they even look suspiciously similar to some modern crocodylians, such as gharials, as both share elongated, tooth-filled snouts. This snout form is known as a 'longirostrine' morphology.

But beyond this superficial similarity, we actually know very little about crocodylians and phytosaurs.

Research by Stefan Lautenschlager and Richard Butler aimed to change this by investigating the resemblance between phytosaurs and crocodylians in terms of the structure of their brain cases, research that has only recently become possible due to the wider application of CT scanning technology.

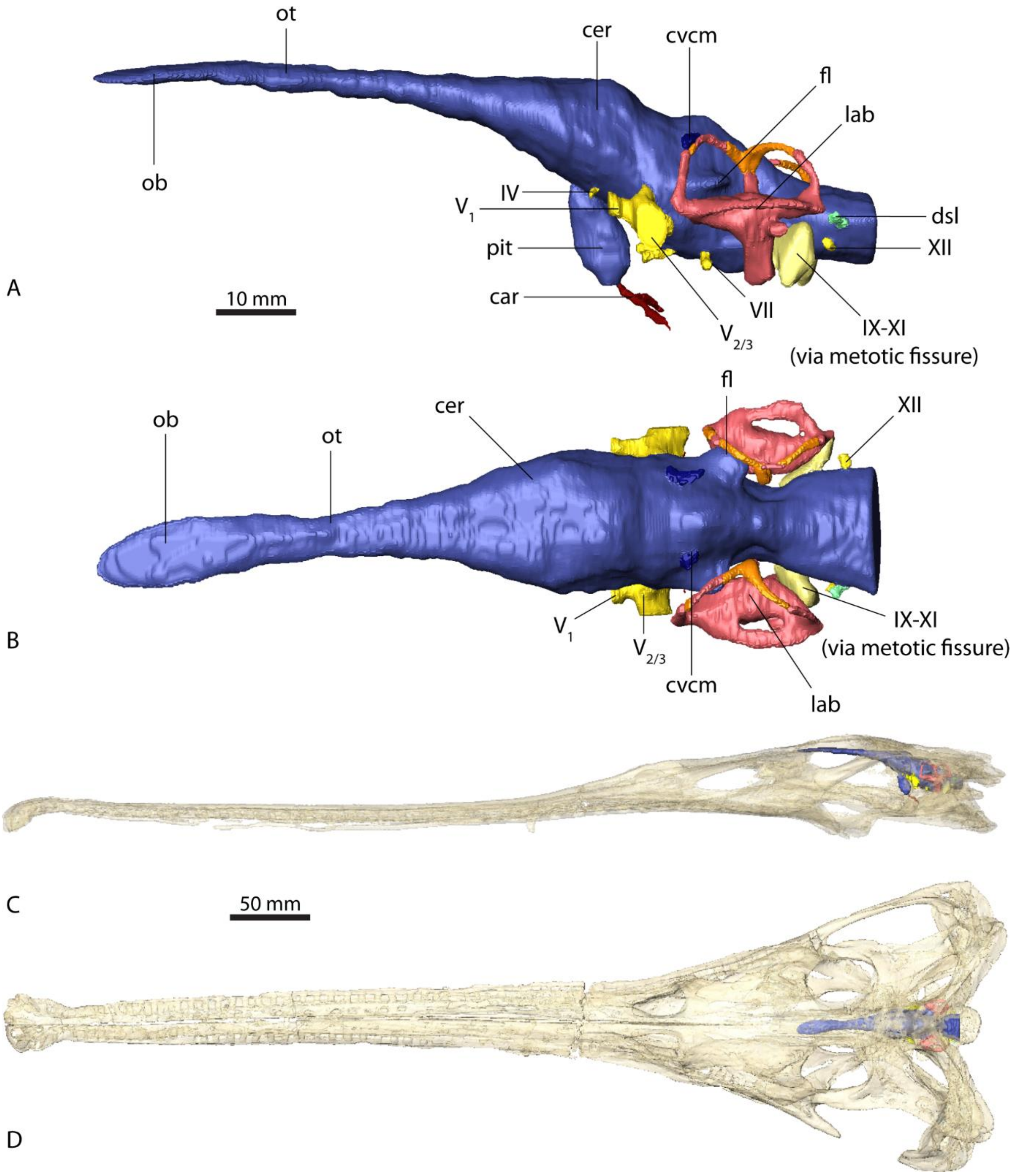
This method allows us to scan the fragile skulls of fossils, and reconstruct them as digital 3D images. From here, we can explore and compare their anatomy in details that was not possible beforehand, and opens up a whole new realm of research possibilities for palaeontologists.



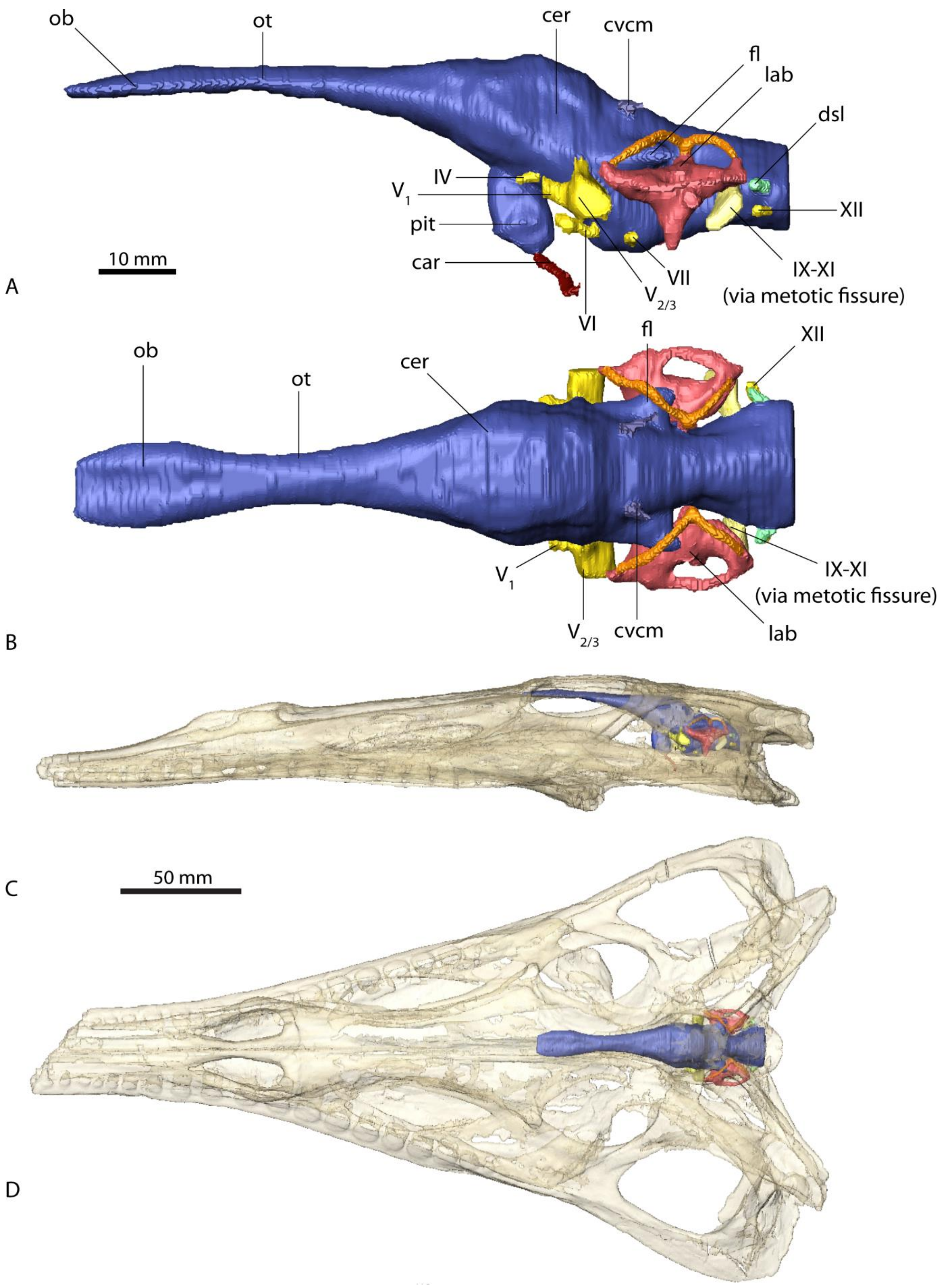
Parasuchus (left) and *Elbrachosuchus* (right) – physical specimens and digital representations!

What they found is that phytosaurs have a very unusual and near-unique endocranial anatomy (the endocranium is the basal part of the skull that surrounds the brain). They have a really elongate olfactory tract, which means that they probably had super-reptilian senses of smell. The general structure of the brain architecture was also arranged as a series of longitudinal segments, a very distinct feature for phytosaurs.

Rather neatly though, it seems that modern crocodilians and their ancestors, collectively known as Crocodyliformes, share this general endocranial morphology. Modern crocodylians, including *Crocodylus* and *Alligator* are similar, as are other longirostrine and now extinct species including *Pholidosaurus* and *Cricosaurus*. Like phytosaurs, these extinct species would have spent all or most of their time out to sea.



Endocranial anatomy of *Ebrachosuchus neukami*.



Endocranial anatomy of *Parasuchus angustifrons*.

Differences between the endocranial structures in phytosaurs can likely be explained by differences in their sensory evolution, related to adaptations to different modes of life and behaviours. For example, we might expect that phytosaurs that spend more time in water have greater sensory adaptations towards detecting movement of prey in lakes and rivers.

We're only just beginning to understand the ecology and evolution of phytosaurs, and this study provides an exciting new step. By comparing them with crocodylians, we gain an additional dimension by being able to look at how similar living, breathing relatives behave. This is so important for developing our collective understanding and vision of phytosaurs not as fossils, but as animals that were once real and alive.

Reference

Lautenschlager, S. & Butler, R. J. (2016) Neural and endocranial anatomy of Triassic phytosaurian reptiles and convergence with fossil and modern crocodylians, *PeerJ*, https://doi.org/10.7717/peerj.2251.

How did wombat noses evolve?

One of the great questions in life. Clearly, this had been plaguing Alana Sharp, a postdoctoral researcher from Australia, so much that she had to go out and research it for herself!

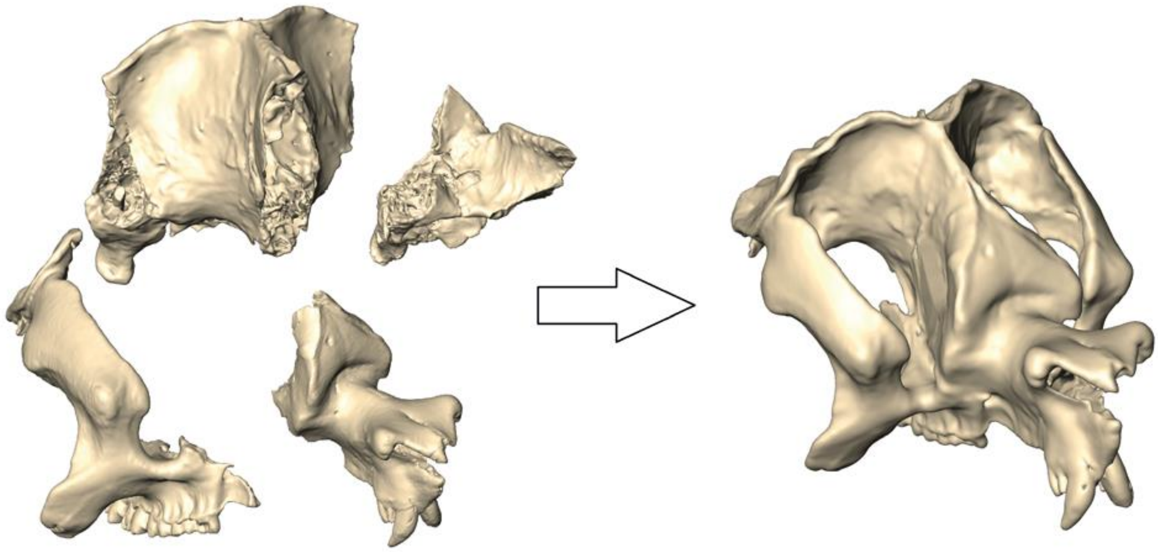
In part of a memoir series published by the Victoria Museum, Alana carefully analysed the skulls of fossil and living wombats to see how their sinuses and brains evolved through time.

Sinuses are part of the skull that form as cavities due to resorption and deposition of bone. This happens due to the different stresses that impose upon the skull as it develops during growth.

Wombat! So cuddly... (Source).

Some marsupial species are known to have pretty large sinuses. Even extinct animals, such as *Diprotodon*, the largest marsupial ever discovered, had massive sinuses that extended all the way through the skull and over the brain towards the back. The evolutionary context for this has remained a mystery though, until now.

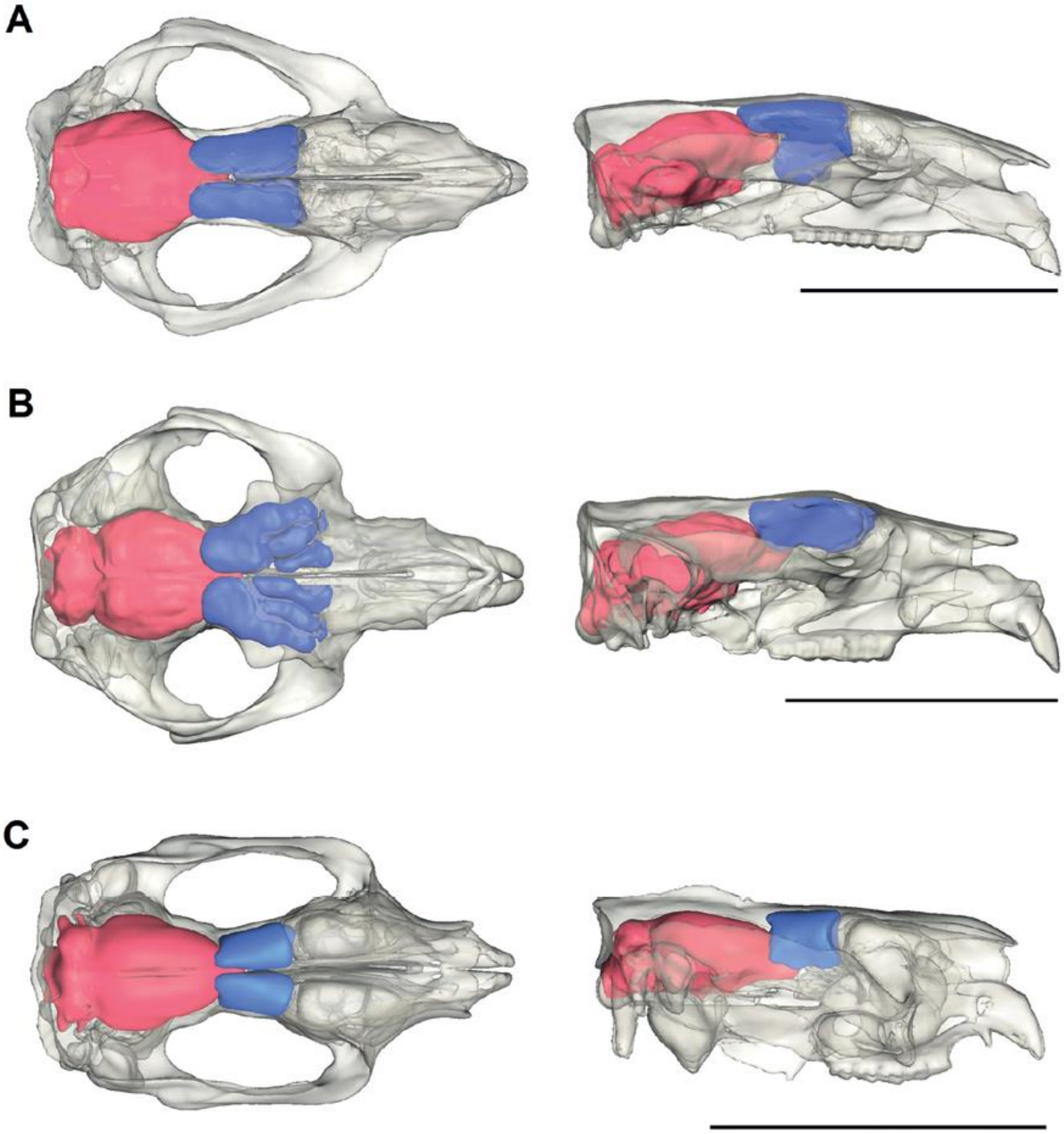
Using CT scanning, a 3D digital imaging technique originally designed for medical purposes, Alana was able to investigate the interior sinus anatomy of a range of wombats and their close relatives. Wombats form a group with their ancestors known as vombatiforms, which kinda sounds a bit like a rubbish German EDM band. All vombatiforms are browsing herbivores that arose during the Cenozoic period (66 million years ago to now), and includes the modern koala and wombat.



Three-dimensional digital reconstruction of the cranium of *Zygomaturus trilobus*, an extinct giant marsupial from Australia during the Pleistocene (Sharp, 2016).

Alana wanted to know what the relationship between body size, brain size, and sinus size was in vombatiforms. For example, as they got bigger through evolution, did their brains decrease in size while their sinuses increased? So, better sense of smell, less brain power to figure out what it is they were smelling. A classic example of an evolutionary trade-off.

What she found was that in the larger, extinct vombatiforms, the sinuses seemed to almost surround the inner brain, but in the smaller, living species, the sinuses were much smaller. As well as this, the size of the sinuses positively scales with the volume of the whole cranium. Because of this, the size of the brain negatively scales with increasing cranial size, meaning that larger-headed species have bigger sinuses but smaller brains in general.



Three-dimensional reconstructions of *Vombatus ursinus* (coarse-haired wombat) (A), *Lasiorhinus latifrons* (hairy-nosed wombats) (B) and *Phascolarctos cinereus* (koala) (C) showing the extent of the sinuses in blue and brain endocast in red.

The reasons for larger marsupials, including these vombatiforms, having smaller brains could be due to any number of reasons, including the brain being an expensive machine to run metabolically, or environmental conditions relating to seasonality. It might be then that smaller brains are necessary in order to compensate for higher energy demands due to having a large body, something known as the Expensive Brain Hypothesis.

Cranking up the size of the sinuses also increases the area available for attachment of the muscles responsible for chewing, which compensates for the decrease in external surface area of the braincase due to brain shrinkage.

Alana thinks there is much more room for growth in this area though. For example, how do individuals within a species vary in their sinuses? What about other marsupials, such as kangaroos and other macropods – do they follow similar patterns? Do we see variations between the sexes at all?

Hopefully all will be revealed in time as we learn more and more about the weird and wonderful wombats!

Reference

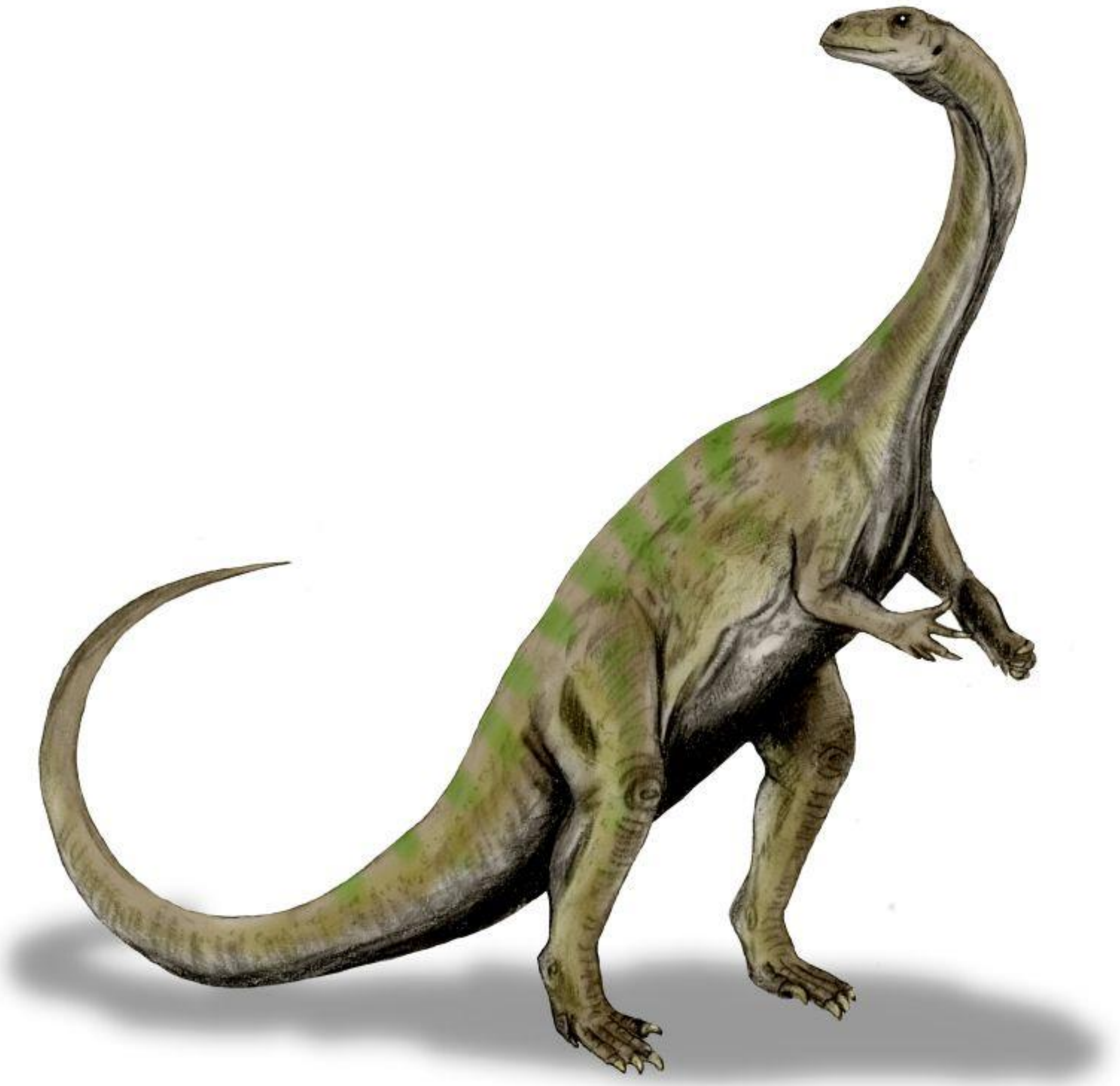
Sharp, A.C. 2016. A quantitative comparative analysis of the size of the frontoparietal sinuses and brain in vombatiform marsupials. Memoirs of Museum Victoria 74: 331–342. https://doi.org/10.24199/j.mmv.2016.74.23.

A busy year for a little dinosaur

This is a guest post by Matt Baron, a PhD student at the University of Cambridge, UK.

Take a walk around the Free State of South Africa, or, if you fancy it, Lesotho (le-sOO-tOO), and you might just come across some genuine dinosaur fossils. Trudge around the exposed layers of red/purple rock that make up the upper Elliot Formation and, luck permitting, among the odd bits of stone and rubble that you may kick along the way, bits of claw and arm and foot and tooth of long gone animals might become apparent to you.

Most likely, if you're in the right sort of place, the fossil material will represent the remains of a particular long-necked herbivore (sauropodomorph), *Massospondylus*. This herbivore, which lived around 200-180 million years ago, would have been an all too frequent sight on the plains of Early Jurassic southern Africa and, along with a number of other closely related animals, it certainly dominated during its time. This early dominance of sauropodomorphs is reflected by their relatively high occurrence frequency in the fossil record.



Massospondylus, by Nobu Tamura (CC BY 3.0).

However, albeit far, far less common, there is another herbivorous dinosaur that can be found in the rocks of the upper Elliot, one that is only distantly related to *Massospondylus* and its kin: *Lesothosaurus diagnosticus*. Whilst only small (estimated to be around 1-2 meters in length), and relatively rare, this little dinosaur actually has a great deal to say when it comes to the question of early dinosaur evolution. In fact, without knowledge of

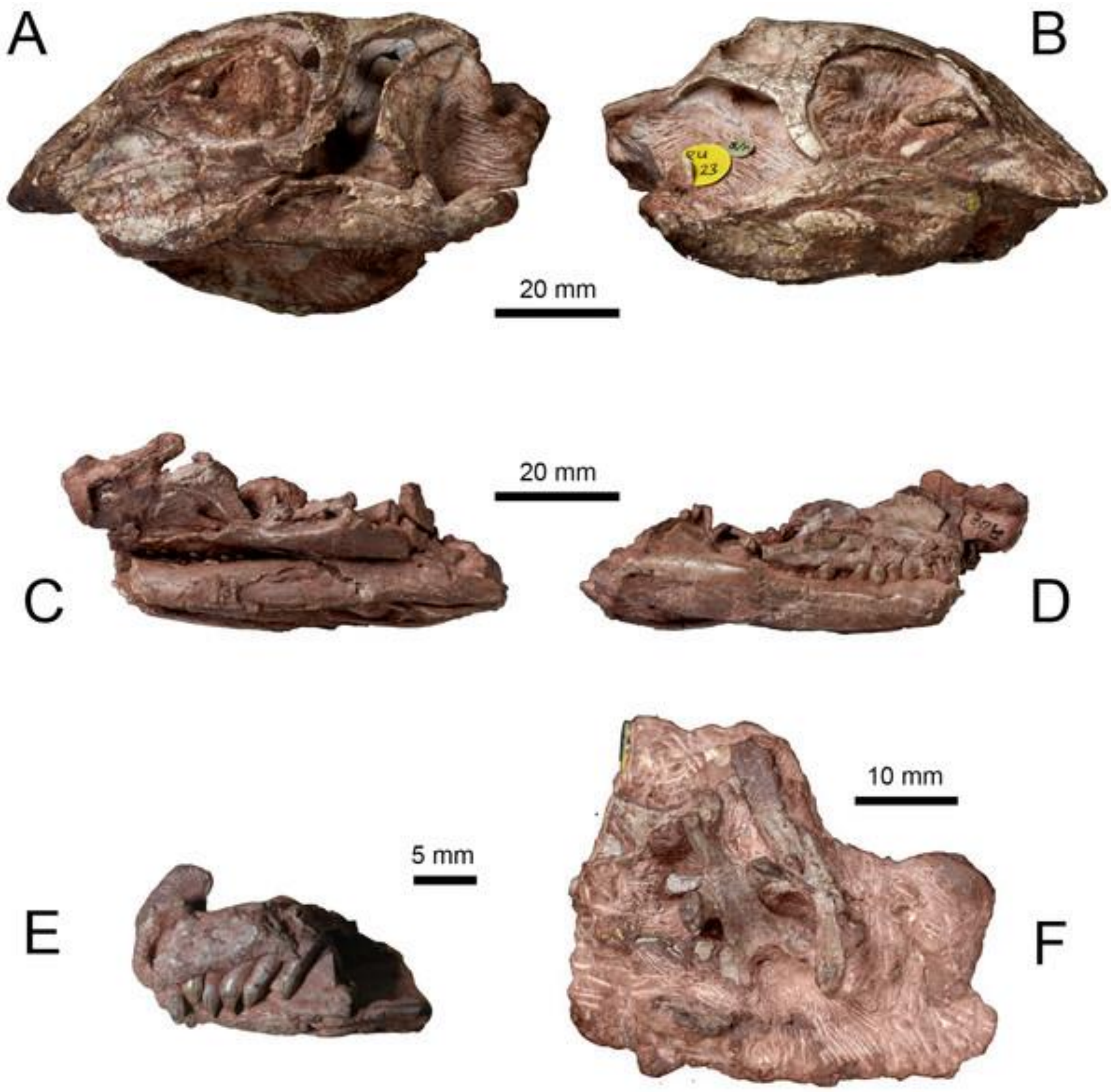
Lesothosaurus, palaeontologists would be faced with a number of awkward questions. That being said, the presence of *Lesothosaurus* in the upper Elliot Formation also raises a number of new questions, ones which are only starting to be answered now. And this is where we begin…

At the close of 2015, the first of 3 successive new papers on *Lesothosaurus diagnosticus* were published. This paper, by Porro, Witmer and Barrett, examined the known skull material of *L. diagnosticus*, using the modern imaging technique of CT scanning. This research revealed a number of new details of the skulls of these animals, allowing for a much more complete description of this particular part of the body. This new information was then used to refer a couple of additional specimens to the species, increasing the data that we have for it. This paper can be found here (OA via PeerJ).

Lesothosaurus reconstruction, by Jack Wood (CC BY-SA 4.0).

Only a few months after Porro *et al*.'s work, a second paper on *Lesothosaurus diagnosticus* was published. This paper dealt with a number of newly discovered specimens that the authors also considered to belong to *L. diagnosticus*. In this work, Barrett, Butler, Yates, Baron and Choiniere provided detailed description of new skull material and new post cranial elements that were collected near the town of Fouriesburg, South Africa. This new material provided further information on *L. diagnosticus*, particularly regarding how we can diagnose it and distinguish it from other species. Critically, the new finds showed that the size range of *L. diagnosticus* was greater than had been previously supposed, and this has some implications for another species, which I will deal with shortly. Further to this, the fact that the material was found to belong to a number of individuals, all of whom were buried together at once, was suggested by the authors to be possible evidence for group-living behaviour. While group-living had been previously floated as an idea for how such early animals would have lived, the finds of this paper constituted the first real evidence for such a hypothesis. This international collaborative effort, provided some key information for the developing arguments surrounding this little dinosaur and where it might fit into the wider picture of dinosaur evolution. This paper can be found here (OA).

Last, but by no means least, was a paper covering the post-cranial anatomy of *Lesothosaurus diagnosticus* by Baron, Norman and Barrett, filling in the remaining bits of anatomy from Porro *et al.*'s study and completing the Barrett-authored triumvirate of the subject. In this paper, the phylogenetic position and the ontogenetic profile of *L. diagnosticus* was examined, and the status of another upper Elliot taxon, *Stormbergia dangershoeki,* was re-evaluated. The bulk of this research related to the details of the anatomy of *L. diagnosticus* with every bone of every known species described, and with most elements of the post-cranium figured. This study added an additional set of anatomical characters to the list of diagnostic features (apomoprhies) for the species, reviving a few old ones as well. As with the second study, the size range of *Lesothosaurus* was shown to be great, with some specimens showing that this taxon actually got much bigger than previously thought. Additionally, the small anatomical differences recorded among the specimens was shown for the first time to be most likely related to the maturity of the individuals (ontogenetic) and a picture of the growth of *Lesothosaurus* was proposed.



Syntype skull of *Lesothosaurus* (source).

One of the interesting things about *Lesothosaurus diagnosticus* is that a number of elements of its anatomy appear very primitive for a dinosaur. For example, the hole in its pelvis (acetabulum) is partially closed by a medial wall, unlike most members of Dinosauria. However, despite its primitive anatomy, *Lesothosaurus* nests within Ornithischia (one of the 2 major groups within Dinosauria). As one of only a few well-known early ornithischians, we must turn to *Lesothosaurus diagnosticus* to for key information on the early evolution of this group. Much like its other early ornithischian cousins such as *Heterodontosaurus*, *Lesothosaurus* was a small and bipedal animal, probably capable of running at decent speeds, and that this seems likely to be the condition for the earliest dinosaurs and dinosaur ancestors as well. The step-wise transformation from this condition through to the very large, armoured ornithischians of the later Jurassic (and the monstrously huge duck-billed animals and tank-like lumbering herbivores of the Cretaceous) seems to find an early landmark in *Lesothosaurus*. In fact, with regard to armour, it has even been proposed that *L. diagnosticus*, with its combination of derived and primitive features, may in fact represent the earliest known member of the group that would later produce *Stegosaurus* and *Ankylosaurus*. Alternatively, *L. diagnosticus* may represent the earliest known member of the group that would eventually produce the three-horned icon *Triceratops* and the giant duck-billed, great-crested herbivores like *Parasaurolophus*. In their study, Baron *et al.* find the latter to be the case. Not that I have a bias or anything, but this seems very sensible to me.

The other major point of Baron *et al.* was the sinking of another Early Jurassic taxon, *Stormbergia dangershoeki*. This genus and species were proposed for the largest known 'fabrosaurs' (a vague term for a number of Early Jurassic ornithischians), but has since been hotly contested. Baron *et al.* demonstrated, as part of the broader ontogenetic study of *Lesothosaurus diagnosticus*, that *Stormbergia dangershoeki* was simply an adult form of *Lesothosaurus* and therefore not a valid taxon. This paper can be found here.

So, all in all, it's been a very busy year for little *Lesothosaurus*. One thing that has been striking about the progress of it all, for me at least, is how much of a collaborative effort it takes for such research to be successful. Counting the 3 aforementioned papers only, 8 authors from institutions on 4 different continents contributed to the ongoing discussions and investigations, and specimens housed in collections all over the world had to be visited and studied to make all of this happen. Fieldwork in the upper Elliot formation was also conducted by a number of these authors, including work done as part of an international collaborative effort between teams from the UK and South Africa. As one of the lucky few who got to go on both (2014 and 2015) excursions into the Free State, I got to witness first-hand the incredible thrill of new discovery. With any luck, the hard work of the teams that went out on each trip will provide us with heaps more information, on a whole range of animals, which will help further the field of palaeontology and our understanding of past worlds. The process of finding and exploring new sites, digging and moving material, prepping it into a condition that allows for detailed study and then doing the studying itself, is one that so many people dream of as a kid (and adult) and I feel very privileged to be a part of it. However, such work can only be done when a large number of people work together to make it so. If nothing else can be taken from the case of *Lesothosaurus*, at least this little dinosaur shows us just how important it is for research scientists to band together, for the good of the field, and produce work which furthers science in a way that solo efforts seldom do. Without meaning to sound cheesy… just as *Lesothosaurus* has been revealed by these studies to have been a group-living animal, so too have us scientists, and that is perhaps the most significant point of it all.

Tracking Australia's dinosaur past

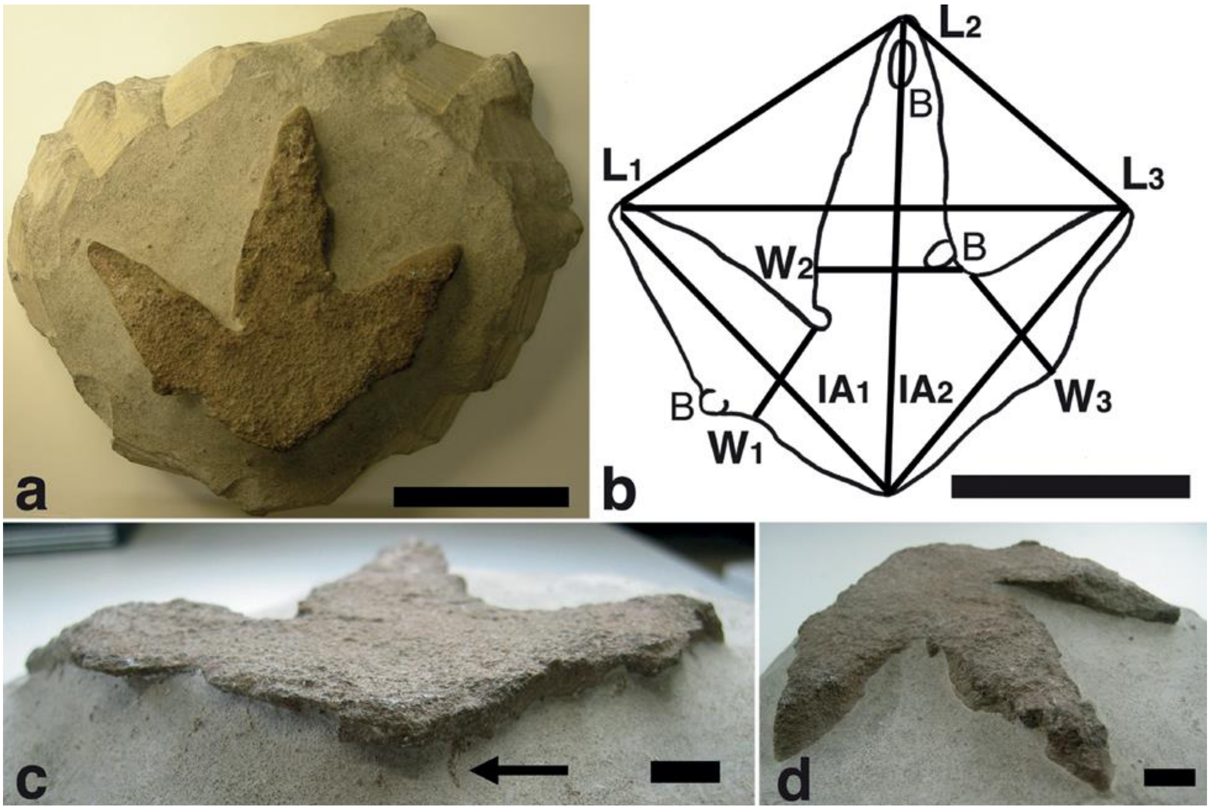
The Australian outback. Known for a few, very specific things. Kangaroos. Sand. Lots of animals that want to kill you. More sand. Paul Hogan. And dinosaurs!

Some of the very best dinosaur fossils we know come from Victoria, one of the major regions of Australia. They come from around 100 million years ago, when Australia was more of a polar rainforest, something we know from examining the rocks from this time. The first dinosaur fossils from here were discovered back in 1903, one of the finger bones from a theropod.

Now dinosaur bones are interesting for a multitude of reasons. But what they tell us in reality about the living, breathing animal it once was is very little: they tell us more about its death. There is a whole other style or type of fossil that we call trace fossils. Trace fossils are records of the behaviour of animals, including remains like burrows, trackways, or tooth marks. These tell us about how animals interacted, and most importantly what they were like when they were still alive.

It was not until 1980 when the first dinosaur trace fossils were discovered in Victoria. Found in the aptly named Knowledge Creek, this opened up the path to explore the behaviour and life of the dinosaurs that once roamed the outback. Since then, a whole range of discoveries have been made, mostly the trackways of different polar dinosaurs, but also possible burrows (yes, some dinosaurs used to burrow!)

Recently, a wonderful Memoir series from the Museum Victoria was published in honour of the eminent palaeontologist, Thomas H. Rich, and contains a wealth of great information about the palaeontology of Australia. Among this, Tony Martin, one of the world's top ichnologists (trace fossil expert, not fish expert), wrote a great account of the dinosaur trace fossils of Australia.



One of the footprints from Knowledge Creek (Martin, 2016).

By examining the shape and structure of the trackways from Victoria, Tony was able to use his keen eye and expertise to work out that some belonged to an ornithopod dinosaur. This deduction was based on their size and shape, and proximity to where we know other ornithopod fossils have been found. Ornithopod translates as 'bird foot', and their trackways are quite similar to those of theropod dinosaurs, which have also had their trackways found in the region.

The only ornithopods that are known from this time in Australia based on skeletal remains are small, fast-running ones known broadly as hypsilophodontids, such as *Laellynasaura*. These little bipeds are often depicted as caring creatures, or meeting their disastrous end at the claws of a larger theropod dinosaur.

We know from the rocks in which the trackways are preserved in that it used to represent the floodplains of an ancient seashore. It's nice to think back 100 million years to think that little dinosaurs pitter-pattered around the rivers, possibly dancing along with the ripples. I mean, that's the great thing about trace fossils – they let us use our imaginations to recreate the beauty of lost worlds in our minds. And that's pretty awesome.

Reference

Anthony J. Martin (2016) A close look at Victoria's first known dinosaur tracks, *Memoirs of Museum Victoria*, **74**, 63-71. https://doi.org/10.24199/j.mmv.2016.74.06.

Birds of a fibula

Over the last 20 years, there has grown insurmountable evidence that birds are the direct modern descendants of dinosaurs. Eagles are dinosaurs. Pigeons are dinosaurs, annoyingly. Even penguins are weird, swimming dinosaurs.

The data supporting this comes from a whole range of scientific domains, from the discovery of thousands of feathered dinosaurs in the fossil record to chemical and biological analysis of these fossils at a molecular level. As science progresses in terms of technical capability, what we can glean from the fossil record increases too, and we learn more about the link between dinosaurs and birds.

A hugely advancing research field at the moment is in embryonics and genetics. What does this have to do with dinosaurs, you might ask (don't even think about mentioning Jurassic Park...) Well, it's a good point. We don't have any dinosaur DNA, and we have very few fossilised embryos. But wait! If modern birds are dinosaurs, then that means we actually have a lot of dinosaur DNA and their embryos! This means we can start asking a whole range of new questions about the evolution and origins of birds from dinosaurs.

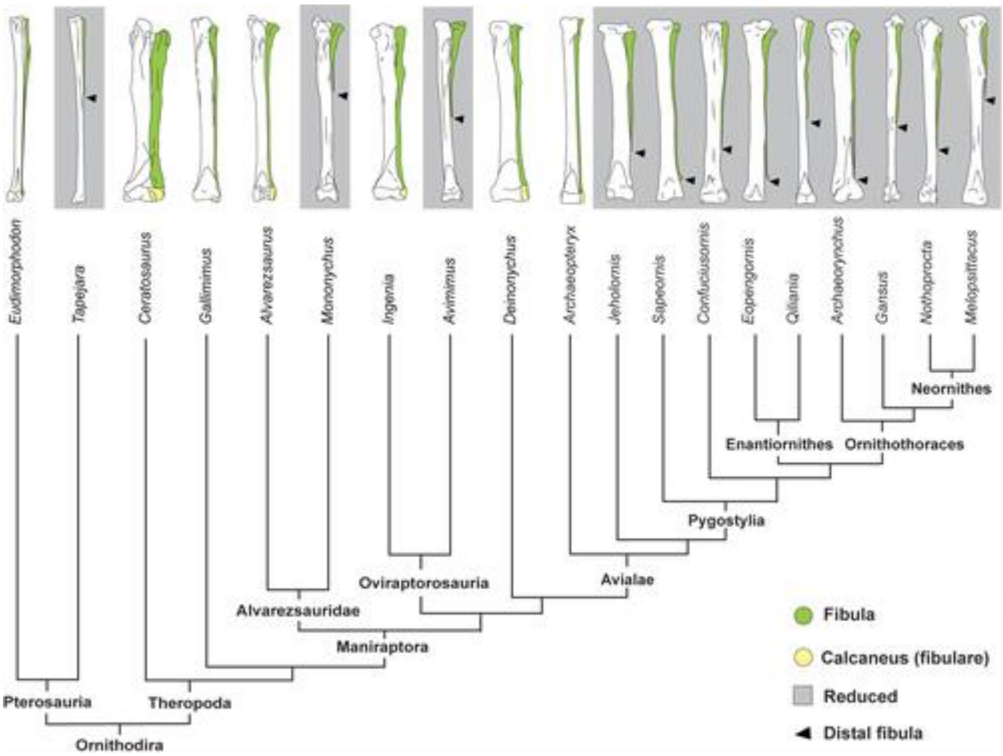
Recently, an international team of researchers took on the task at looking at developmental links between dinosaurs and modern birds. There is an old and quite controversial saying that 'ontogeny recapitulates phylogeny', which means that the growth or development of an individual can be a reflection of the evolution that has occurred along its lineage. Wouldn't it be cool if we could see that in birds and their dinosaur ancestors?

By looking at the development of the fibula (one of the lower leg bones) of chicken embryos, the team discovered that the far end of the fibula expresses a gene known as Indian Hedgehog (great name!) during development. This gene plays an important role in the replacement of cartilage with bone, a process known as ossification.

The Indian Hedgehog gene works as part of a feedback system with another gene, not so nicely named as Parathyroid hormone-related protein (PTHrP), which acts to delay bone growth and also inhibits the further production of Indian Hedgehog. What this means is that if PTHrP is activated within cartilage, it leads to decreased growth of the bone where it is activated.

This feedback system seems to be related to a reduction in the size of the fibula, from an earlier embryonic stage in which both the fibula and tibia start out at similar lengths to each other. This is really neat, because if you look at fully grown birds, they have a much smaller fibula, shaped like a splint, compared to the tibia (the other lower leg bone).

Almost all birds from the Mesozoic era also have a fibula that is much shorter than the tibia, and does not even touch the ankle bones any more. In some early birds, including the now extinct Enantiornithes, the fibula was still almost as long as the tibia. The story the fossil record tells us is one of the formation of an early splinter-shaped fibula, followed by the independent and convergent acquisition of the reduction of this bone in several distantly related early bird groups, including the one that led to modern birds.



Evolution of the fibula across the theropod dinosaur tree.

This means that dinosaurs and early birds shared the same or similar pattern of fibula development, reflected in their evolutionary relationships and through time.

The reason why this happens though remains a bit of a mystery. Modern birds of different sizes and ecologies all show evidence of this fibula reduction. This suggests that it is what is called a 'non-adaptive' process, as it is highly unlikely that such a feature would play a part in such different roles.

We're only just beginning to unlock the molecular links between dinosaurs and birds, and this represents a really neat glimpse into the future of this research field. Stay tuned!

Reference

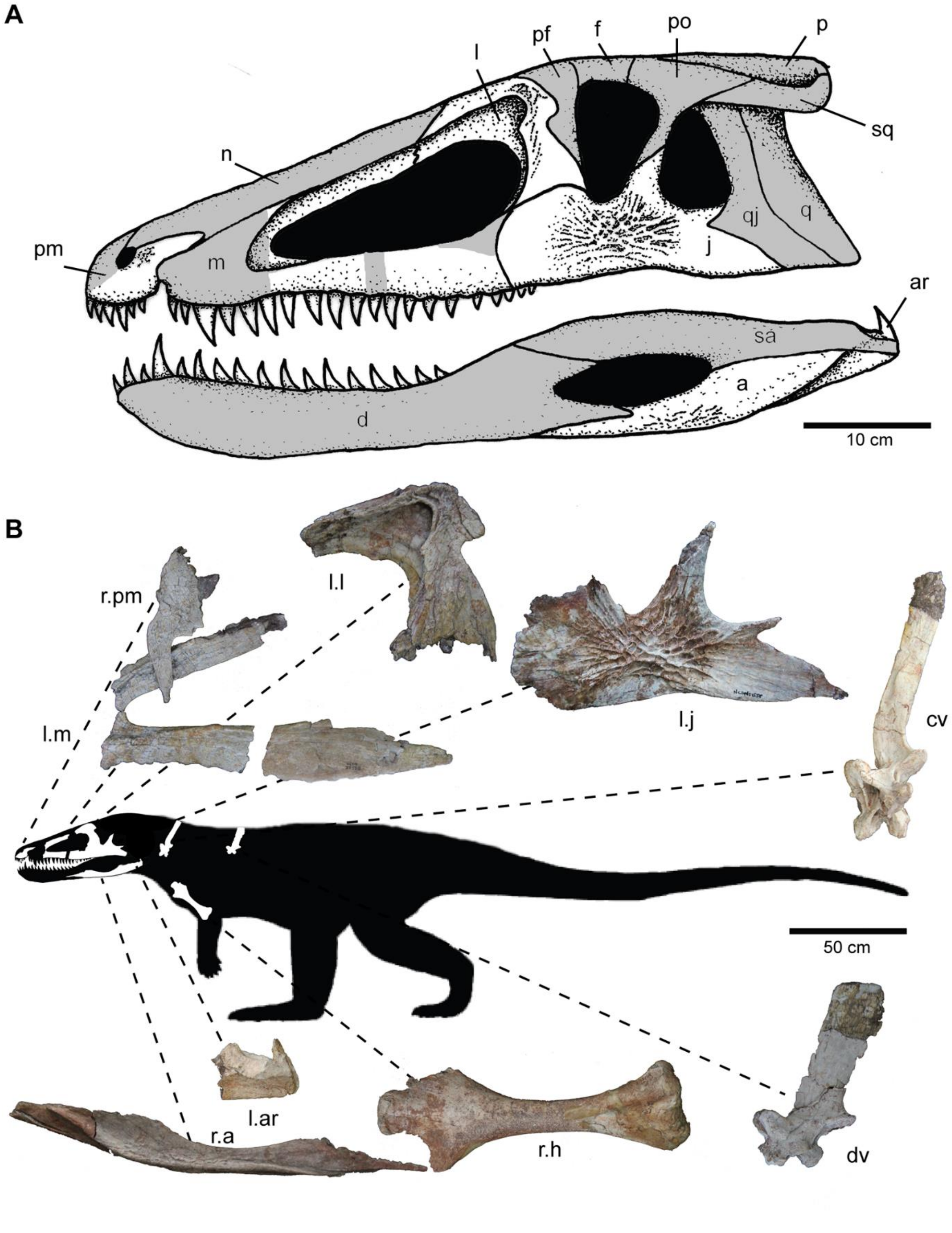
Botelho, J. F., Smith-Paredes, D., Soto-Acuña, S., O'Connor, J., Palma, V., & Vargas, A. O. (2016). Molecular development of fibular reduction in birds and its evolution from dinosaurs. *Evolution*. https://doi.org/10.1111/evo.12882.

The first crocodile ancestors

Did you know that birds and crocodiles are practically cousins? Around 230 million years ago, you wouldn't have been able to tell the difference between the two different lineages. This is because birds and crocodilians (which includes alligators, caiman, and gharials) are part of a much larger group called Archosauria, or ruling lizards, which means they share a common ancestor far back in time. When they split from each other, they formed two major evolutionary pathways: the bird-line archosaurs, which also includes all dinosaurs, and the crocodile-line archosaurs, which includes crocodilians and their ancestors, the crocodylomorphs.

Back at around the time of this split, during a time known as the Late Triassic, the world was much more different than it is today. Small crocodylomorphs prowled the land, along with the earliest dinosaurs. There were a host of other bizarre reptiles, such as the predatory rauisuchids, which might be closely related to the first crocodylomorphs, and small, fox-like sphenosuchians.

One of these was an animal known as *Carnufex*. Not only is that an awesome name, but it was also an impressive beasty to withhold, coming in at around 3 metres in length. It had serrated teeth for tearing apart its prey, and a long, slender body for rapid movement. Importantly, it is from around the time when this dinosaur-crocodile split occurred, and therefore should hold important clues to the evolutionary history of these groups.

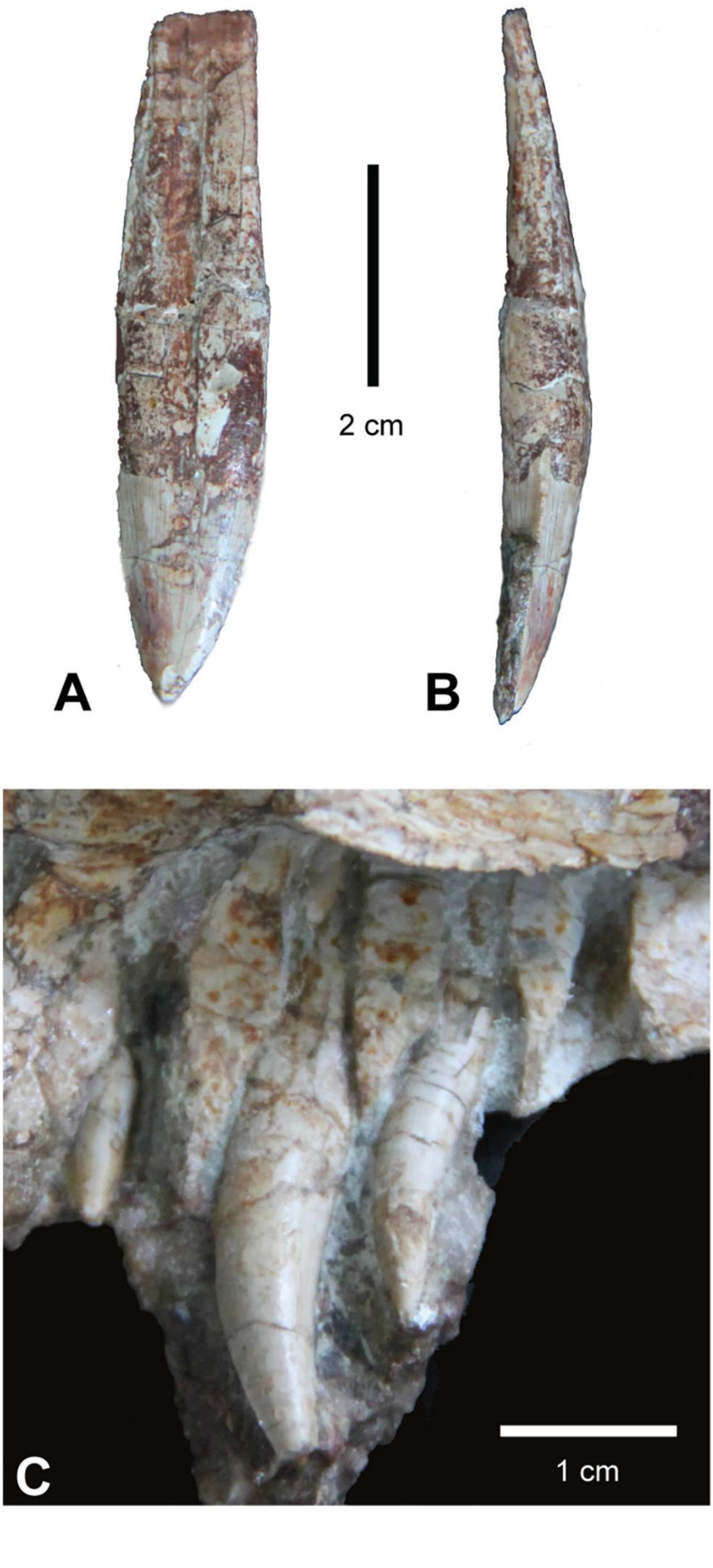


Skeletal reconstruction of *Carnufex*.

Susan Drymala and Lindsay Zanno from North Carolina recognised the importance of *Carnufex* in helping to solve the dinosaur-crocodile divergence issue, and set out to conduct an impressive anatomical assessment of the well-preserved fossils. The fossils belonging to

Carnufex also come from North Carolina, and were first discovered in 2003. They consist mostly of skull material, which is important for determining diagnostic relationships in archosaurs, and several bits of the spine and limbs.

By analysing the anatomy of *Carnufex* along with a large range of other similar animals, they were able to work out its evolutionary relationships. What they found is that, quite like many early diverging species, *Carnufex* had a mosaic of features, some more crocodilian, some more dinosaurian.


2 cm
A
B
1 cm
C

The teeth of *Carnufex*, perfect for piercing and slicing flesh.

What this implies is that *Carnufex* is actually one of the earliest diverging crocodylomorphs, and therefore was highly important in determining the early fate of this ancient group. It was closely related to another crocodylomorph called *Redondavenator*, which was also fairly hefty in size.

Life reconstruction of *Carnufex carolinensis*. Image credit: Jorge Gonzales.

This is important for several reasons. *Carnufex* was no tiddly croc, but a pretty large and fearsome predator. Other crocodylomorphs around at this time were usually small, nimble hunters, quite different from *Carnufex*. What this means is that the very first crocodylomorphs, such as *Carnufex*, were much larger than we previously thought, and developed their smaller body size later on, something which we can trace based on their evolutionary relationships. This also means that evolution of a smaller body size was something that occurred subsequent to the acquisition of features defining crocodylomorphs, rather than before.

In the Late Triassic, this means that *Carnufex* would have been one of the top predators roaming the plains of North America. This is quite exceptional, as other crocodylomorphs at the time were by no means top tier predators, with this role usually taken on by other now extinct archosaurs. Shortly after (geologically speaking...) *Carnufex*, this top predator tier was taken by theropod dinosaurs, which went on to dominate for around 150 million years.

What is clear is that *Carnufex* was a key stage in crocodylomorph evolution, and may have been critical in helping them survive the end-Triassic mass extinction, which took out almost all other archosaur groups around at the time.

Reference

Drymala SM, Zanno LE (2016) Osteology of *Carnufex carolinensis* (Archosauria: Psuedosuchia) from the Pekin Formation of North Carolina and Its Implications for Early Crocodylomorph Evolution. *PLoS ONE* 11(6): e0157528. https://doi.org/10.1371/journal.pone.0157528.

Beaked birds champions of the last mass extinction

A new study shows that teeth are not too good for you if you're a dinosaur trying to not go extinct.

Around 66 million years ago, a time known as the end-Cretaceous, there was a massive extinction of life, with around 75% of all known species dying off. Perhaps most well-known at this time is the extinction of the non-bird line dinosaurs.

We've known about this extinction for decades now. But in spite of this, the causes, timing, and ecology of it still remain fairly elusive and highly debated. This is quite important for figuring out what triggered the origins of modern birds, as their radiation has been thought to be closely related to the extinction of their close dinosaurian cousins.

New research on maniraptoran dinosaurs, the group that includes *Velociraptor* and modern birds, shows that having a beak conferred a survival advantage by providing birds the ability to eat seeds. When animals around you are dying off in droves because meteor strike, this would have come in pretty handy by being able to exploit dwindling food resources.

Take cover! Image credit: Danielle Dufault.

Teeth are particularly handy for studies like this, as not only are they relatively frequent in the fossil record, but they also reveal to us much about the ecology of dinosaurs at this time, such as what they ate.

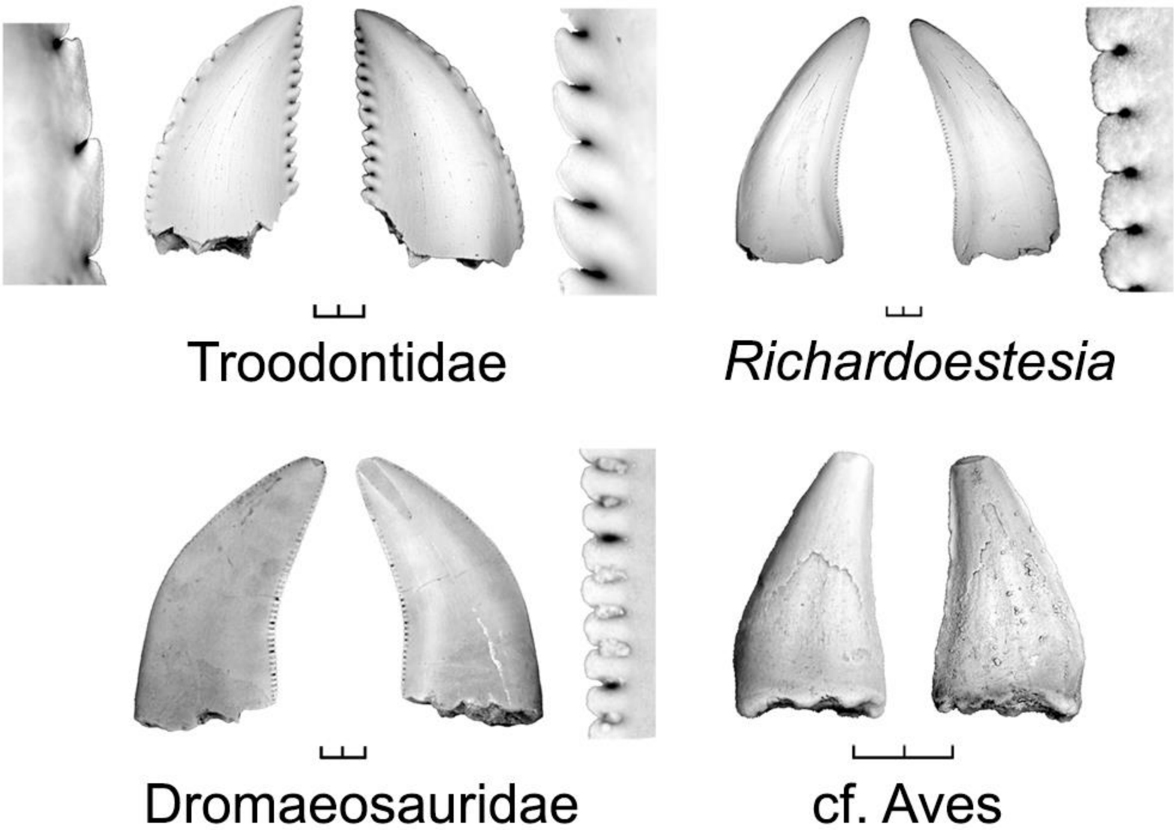
One way to measure ecology quantitatively is through something called disparity. This is a measure of the diversity of different types of anatomy, which can be related to specific functions. A simple measure of disparity might be the curvature of the tooth, or the distance from the root to the crown.

The team analysed more than 3100 of these teeth from different dinosaur groups to see how disparity changed through time coming up to the end-Cretaceous extinction boundary. What they found is that up until the extinction, disparity remained pretty high in theropod dinosaur groups such as dromaeosaurs and troodontids, including birds. This is what we might think of then as 'ecosystem stability', with consistency in the variation of maniraptorans throughout this time.

"We've used the teeth of these bird-like dinosaurs to show that these dinosaurs were a consistent and stable part of the ecosystem leading up to the end of the Cretaceous," explained lead author of the study Derek Larson, assistant curator at the Philip J. Currie Dinosaur Museum and PhD candidate at the University of Toronto.

What this means is that the extinction was fairly instantaneous, and not drawn out over a long period of time. Therefore, it is more likely that aspects relating to this such as diet were more important, and in particular the evolution of the beak in birds.

In particular, one striking difference between small maniraptorans and early birds at this time is the presence of a keratin-sheathed beak in the latter group. In dinosaurs, the acquisition of a beak was a key characteristic in their survival and subsequent evolution. Even today, there are more than 10,000 species of bird, highlighting the success this evolutionary innovation gave to them.



Different types of maniraptoran teeth around at the end of the Cretaceous. Photo credit: Don Brinkman.

Larson explained, “By analysing the known diets of modern birds, we can see many groups that probably survived the extinction could have survived by eating seeds, probably one of the few plentiful resources that were available in the climatic upheaval in the aftermath of the asteroid impact. Those dinosaurs without a beak and without the right teeth to access those resources, would have been relegated to extinction.”

This story based on fossils actually fits in quite nicely with what studies of the DNA of modern birds tells us. Using modelling approaches, we can tell that early birds around this time where granivorous, that is they ate seeds either entirely or as part of a mixed diet.

This is really important, as it shows that as food webs collapsed due to the end-Cretaceous meteor strike, being able to survive of seeds might have been critical in the survival of modern birds. This is similar to what we observe during forest fires, with some birds the first to recolonise damaged areas due to the abundance of left-over seeds.

So, I guess the real question now is, what if *T. rex* had a beak...?

Reference

Larson, D.W., Brown, C.M., and Evans, D.C. 2016. Dental disparity and ecological stability in bird-like dinosaurs prior to the end-Cretaceous mass extinction. *Current Biology* **26**, 1–9. http://dx.doi.org/10.1016/j.cub.2016.03.039.

Identifying the gender of a *T. rex*

In living animals, it's pretty easy to tell if one is a male or a female. You look at their, er, dangly bits, or lack of them, observe their mating behaviour, and also see how they give birth.

In the fossil record, it is extremely rare to find examples of this sort of thing preserved through the ravages of time. There are spectacular and hilarious cases of fossils preserved *in flagrante*, but these are very much rare exceptions.

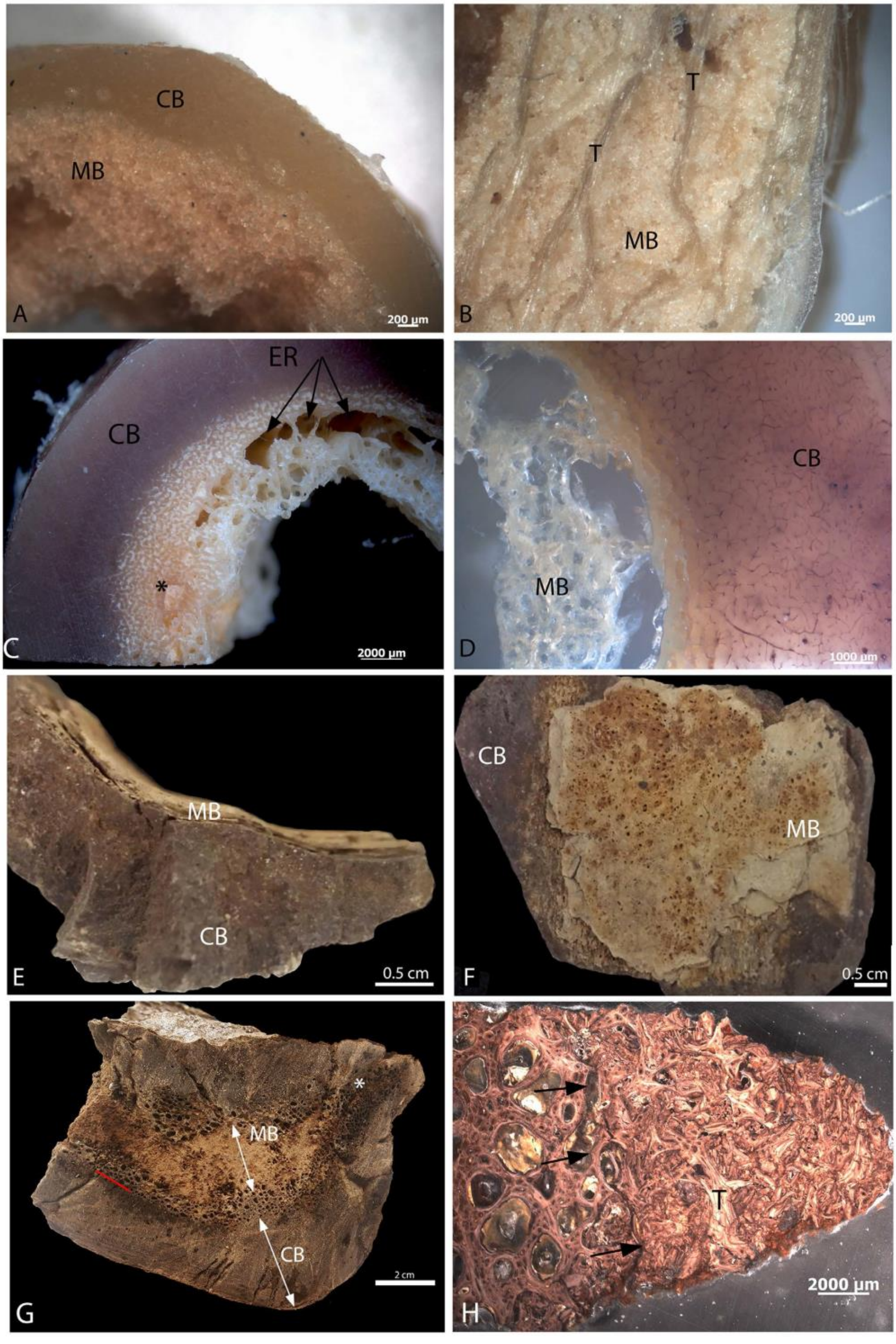
Trying to figure out if a fossil represents a male or female animal is quite important. It can tell us quite a bit about their ecology, differences between the sexes, and about their behaviour.

Thankfully, the fossil record does leave behind some clues to help us decipher sex differences. One of these is the presence of medullary bone. This is a tissue that is present in all living birds (except songbirds) that are reproductively active, so is a great way of identifying which ones are females.

The purpose of medullary bone is to serve as a reserve calcium source for egg production. It can be easily mobilised from within an animal and transferred to the developing egg, and is therefore highly gender-specific for sexually mature females*.

Medullary bone is stored in the long bones of birds. That is their arms and legs, pretty much. As we know that birds are descended from dinosaurs, that means if we find medullary bone in dinosaurs, we can infer that they're a female!

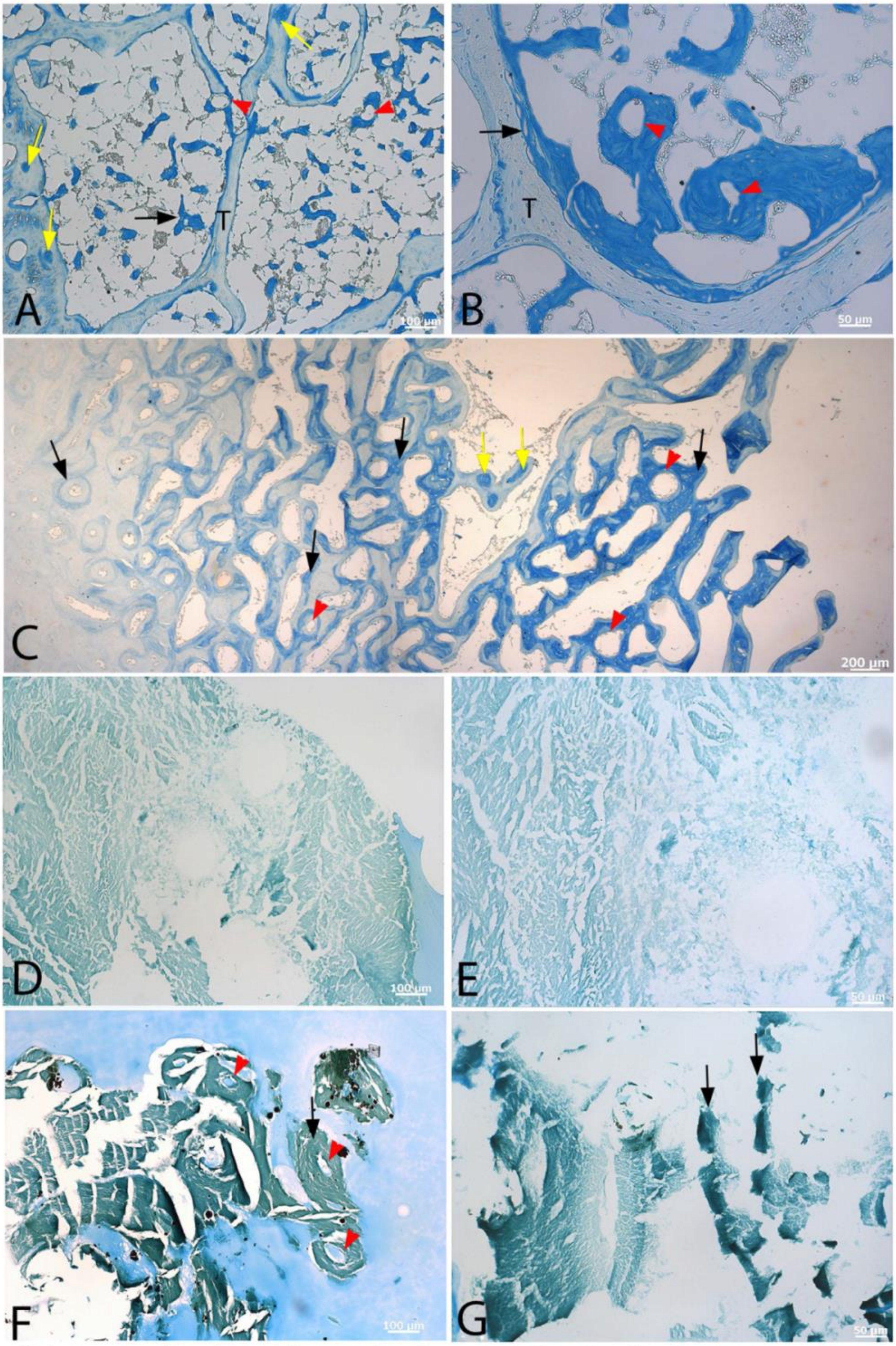
And what better animal to test this on than *Tyrannosaurus rex*! A team of researchers, led by Mary Schweitzer, set out to find using a cool set of chemical and histological (microstructural) tests. One of the great things about medullary bone is that it's made of calcite, which preserves nicely in the fossil record, so makes it relatively easy to examine and use for sexual identification. As opposed to, say, a penis, which would rot away relatively quickly and leave no traceable mark. Note that if anyone ever finds one for a *T. rex*, it's either a fake, or you're financially set for life.



How to spot the differences between medullary bone and cortical bone in hens (top), ostriches (middle top) and *T. rex* (bottom 4 panels).

What the research team found is that medullary bone is definitely present in at least one specimen of *T. rex*, but is distinct in the texture, density, structure, and morphology from extant dinosaurs (so birds). The tissue was also distinct from that of cortical bone, another typical type of tissue found in dinosaurs (and other vertebrates).

They confirmed these microstructural observations using a type of chemical staining, which highlights the chemical differences known to exist between medullary bone and cortical bone. The stain reacted with the medullary bone in *T. rex* and [once] living dinosaurs by reacting with a chemical called glycosaminoglycan keratin sulphate (say it ten times fast), a chemical not found in cortical bone.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Histochemical stains for hens (top), ostrich (middle top), and *T. rex* (bottom four panels) under different magnifications.

What they found was that the bone lit up in specific areas when applied. This confirms the presence of medullary bone in *T. rex*, which indicates that it was definitely a female! In this case, the specimen analysed comes from the Museum of the Rockies in Montana, so you can bet they'll be pleased with the results!

This research is a great contribution to that of Mary Schweitzer and her colleagues, who continue to astound us with their discoveries of chemical remains in dinosaurs, as well as those of soft tissues. They help to show us that the fossil record isn't all just dust and bones, and depending on the questions we ask of it and the techniques we apply, we can keep learning more and more about dinosaurs and their kin in ever more exquisite detail.

So, how do you identify the sex of a *T. rex*? Super awesome advanced science, and a lot of hard work, that's how!

*Apparently it can be induced in males through extreme dosing of oestrogen, but that's another story…

Reference

Schweitzer, M. H., Zheng, W., Zanno, L., Werning, S., & Sugiyama, T. (2016). Chemistry supports the identification of gender-specific reproductive tissue in Tyrannosaurus rex. *Scientific reports*, *6*. https://doi.org/10.1038/srep23099.

Tiny dwarf crocodiles roamed Brazil 120 million years ago

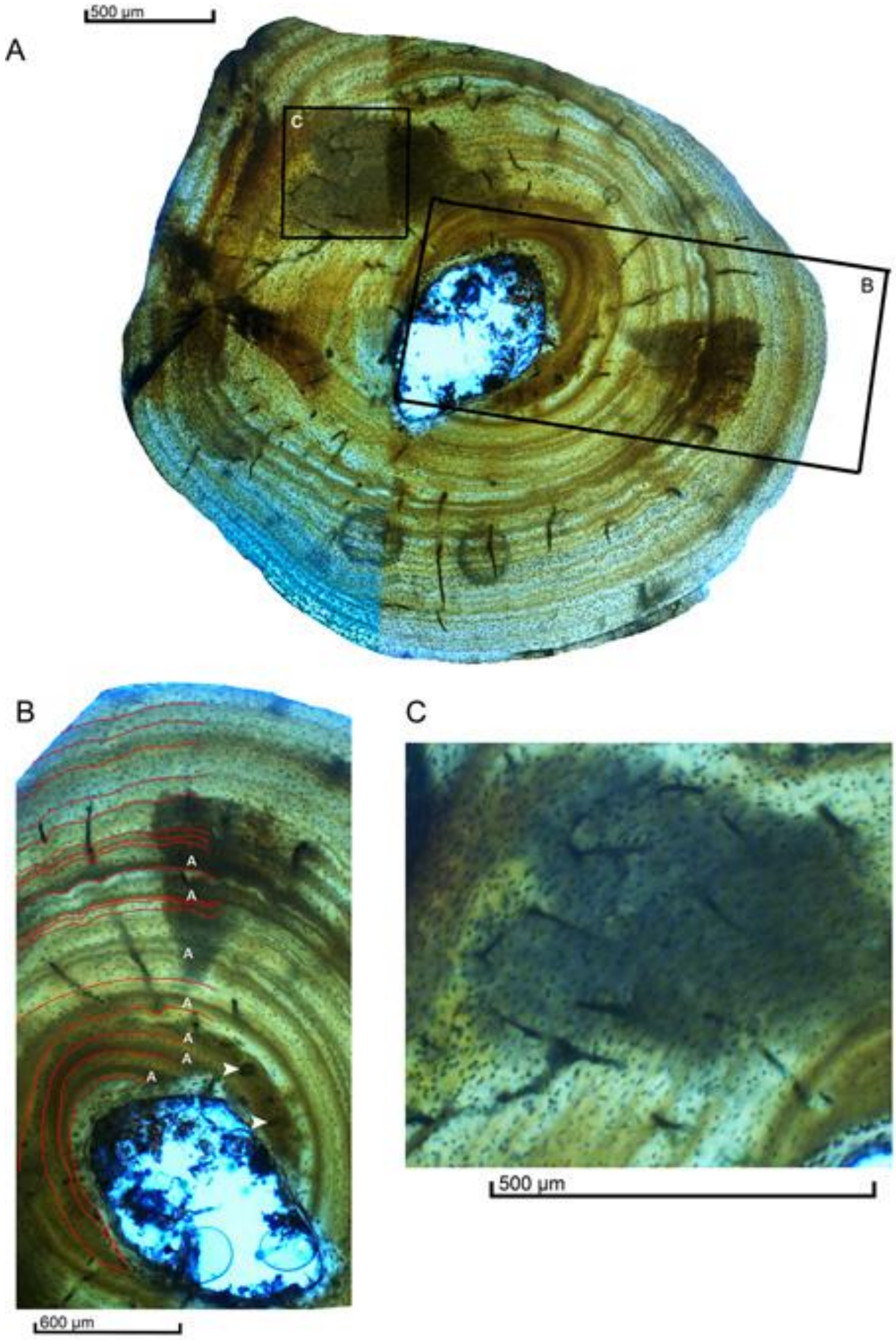
What is a 'dwarf'? Popular images conjured are those of small, marching, bearded miners, or perhaps more recently impish and alcoholic pseudo-politicians from Westeros.

In palaeontology, or even biology, a ‘dwarf’ is a very specific, and peculiar, thing. Just because something is small, it does not mean it is a dwarf. It could just be well, small, or it could be younger specimen or animal. In modern animals, this is pretty obvious to see, as we can track the life histories of individual animals and tell when something is small because it is small, or small because it is young.

A ‘dwarfed’ organism is one which has undergone a size reduction from a larger ancestor, due to factors such as resource availability. It has to happen over generational time, not the life of an individual. Tiny island elephants are one fascinating example of what we call insular dwarfism.

This is pretty difficult to see in the fossil record though. Fossils are frozen in time at the point of death. If they kept growing, that would be kind of weird. Fortunately for us, they preserve their growth stages in their bones. So how do you tell if fossils are small because they are small, or because they are young, or because they are something else, like a dwarf?

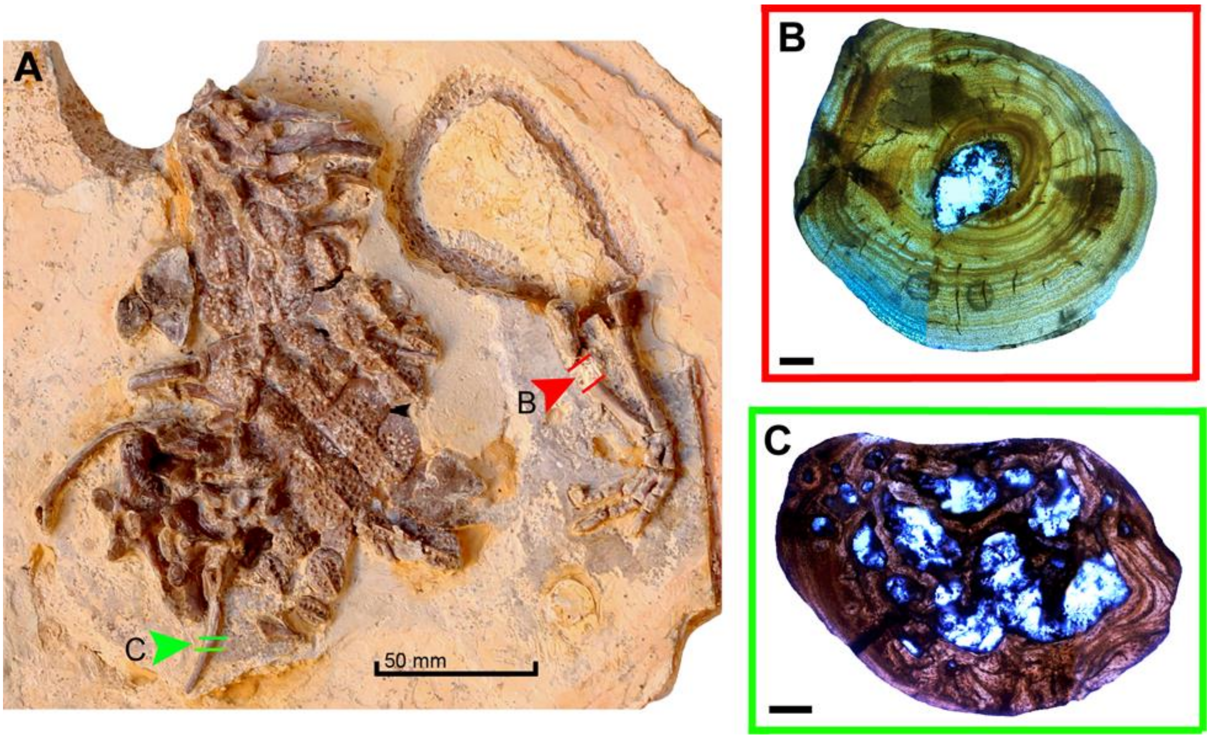
Well, individual fossils also preserve their growth history in their bones. I don’t want to say just like a tree, but yeah, it’s pretty much just like a tree. If you slice open the bones of oh say for example a fossil crocodilian (crocodiles, alligators, caiman and gharials and false gharials), you see tiny growth lines inside the cross-section.



The ulna of *Susisuchus*. Analysing the cross section is called ‘osteohistology’.

These are called ‘lines of arrested growth’, or LAGs. Their form is influenced by the physiology, growth rate, and age of an animal, which is reflected in their microstructural properties. So, combining crystallography with palaeontology, you can learn some pretty neat stuff about even extinct animals! LAGs indicate times of pause in growth in animals, and in crocodiles usually indicate a cyclic growth period.

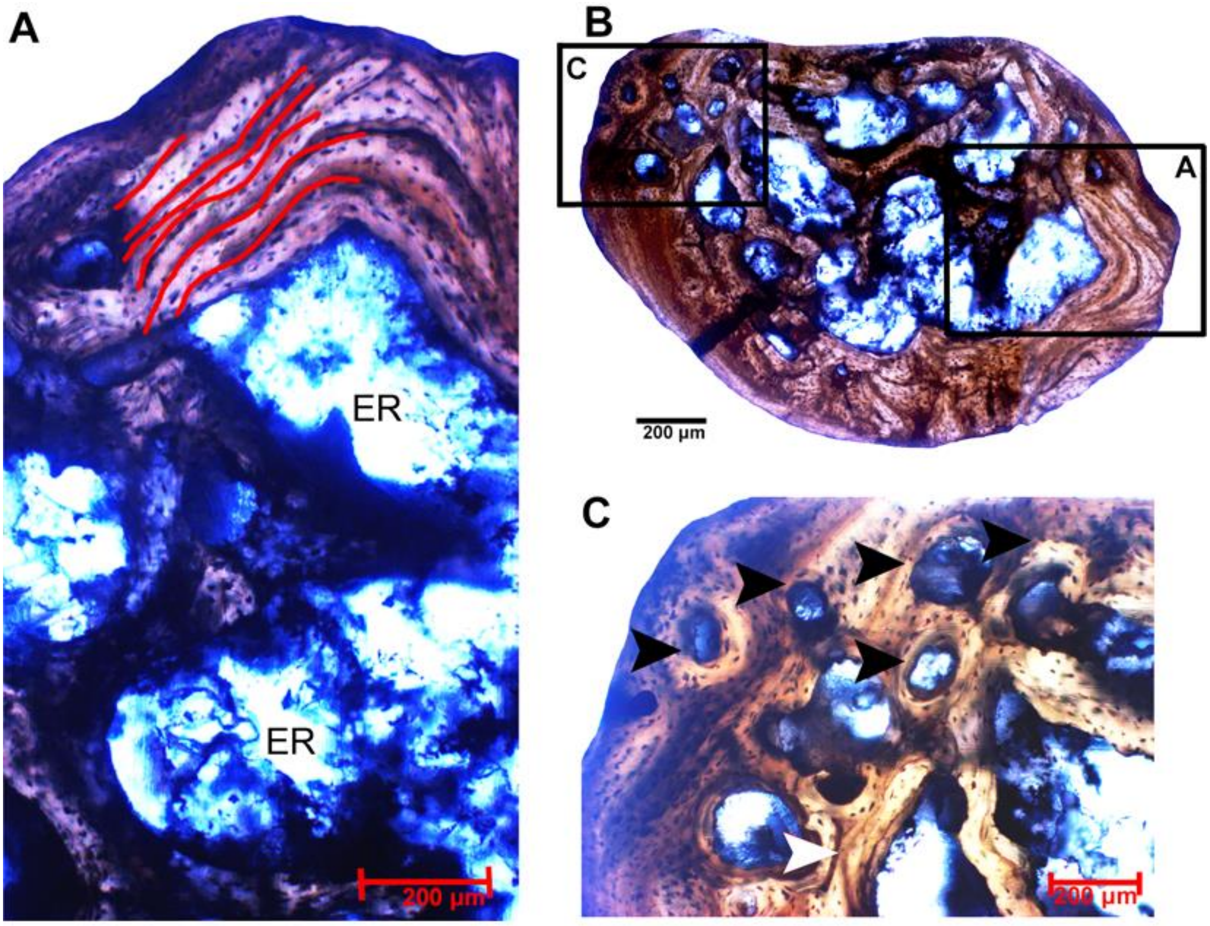
A new study from an international team of experts led by Juliana Sayão decided to see if they could work out whether a cool little crocodilian ancestor called *Susisuchus* was a dwarfed croc, or just a small, immature specimen. To do this, they obtained cross-sections of the rib and the ulna (lower arm bone, use your imagination for how) of a specimen of *Susisuchus* and checked it out under a microscope.



Sampled bones of *Susisuchus* with respective thin sections.

The forearm of *Susisuchus* had 17 of these LAGs in the ulna, which suggests it was pretty old, at least a sub-adult, but way past sexual maturity. Goodness only knows what a moody teenager crocodile looks like... But this means we know at least that the croc was 17 years old when it died. If anyone feels like throwing a very late crocodilian birthday party, now is the time.

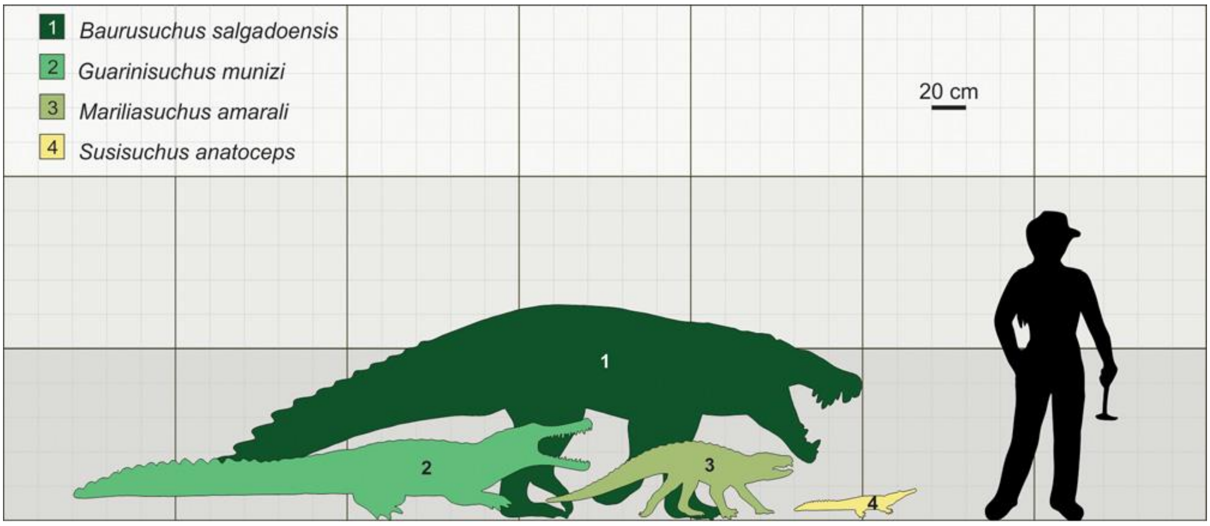
These lines of arrested growth are arranged in a very specific parallel-fibered way, which we can use to deduce the rate of growth and bone deposition of the animal. Sherlock himself would be proud! In this case, parallel fibers indicate that the bone was deposited relatively slowly, implying a slow rate of growth.



Histological characteristics of the rib of *Susisuchus*. Pretty colours due to cross-polarised light.

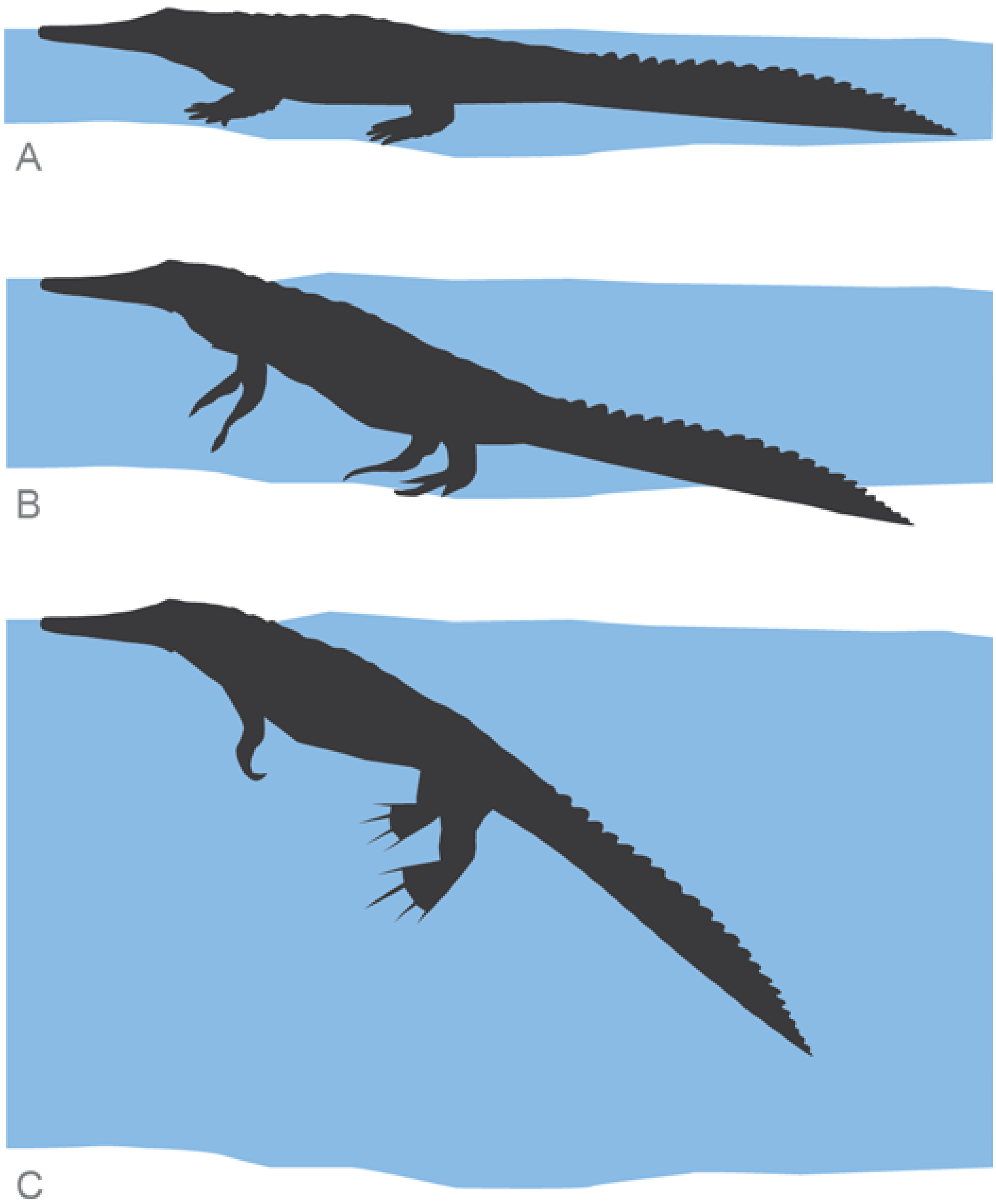
Based on this, and contrary to previous assertions, this means that *Susisuchus* was a pretty small critter, even when fully mature. It just grew slowly, for some reason, perhaps due to some physiological factor, or due to ecological relationships with other animals around at the time.

Importantly, *Susisuchus* possesses what we might think of as a combination of 'primitive' and 'advanced' anatomical features. If *Susisuchus* is indeed a dwarfed taxon, we might expect it to retain more of these 'primitive' features despite being relatively advanced. This discovery might help to figure out where *Susisuchus* should be placed in the crocodilian tree of life, as this combination of characters can lead to some confusion when assessing it alongside other crocs. Recently, *Susisuchus* was moved from a position very close to the origin of modern crocodiles to a more basal position, outside of the clade known as Eusuchia, which includes all modern crocodylians. But this might just be due to mis-interpretation of some of its features. Only further analysis and time will tell!



Susisuchus in comparison to other Brazilian Cretaceous crocs. Soon to be very dead human for scale.

Susisuchus was actually a fairly ordinary croc as far as these Mesozoic weirdos go. It probably lived a fairly sedate semi-aquatic lifestyle, perhaps as an ambush predator. The relatively dense bone which *Susisuchus* possesses is probably indicative of the lineage returning to the waters after being fully developed for life on land. Spongy tissues within the bone which the researchers also identified in cross section show that *Susisuchus* was actually probably fairly buoyant in spite of this, and could probably control its movement with little paddles, just like we see in some modern crocodiles.



Schematic representation of resting postures of *Susisuchus anatoceps* based on extant crocodylomorphs.

What's really cool is that we can compare *Susisuchus* to some living crocodilians! *Osteolaemus* is considered to be a dwarf crocodile, with several species known from Africa. Similar to its extinct counterparts, it's also super cute, but perhaps most importantly by comparing species we can learn more about the growth of crocodiles and the evolution of dwarfism.

Reference

Sayão JM, Bantim RAM, Andrade RCLP, Lima FJ, Saraiva AAF, Figueiredo RG, et al. (2016) Paleohistology of *Susisuchus anatoceps* (Crocodylomorpha, Neosuchia): Comments on Growth Strategies and Lifestyle. PLoS ONE 11(5): e0155297. https://doi.org/10.1371/journal.pone.0155297.

The evolution of giants

Sauropod dinosaurs are some of the most notoriously recognisable animals. With their whiplash tails, and long searching necks, they are the biggest terrestrial vertebrates ever to walk the Earth.

One factor that has received much attention from a range of scientific disciplines is the evolution of gigantism: how and why did sauropods get so damn big? Many sauropods were up to an order of magnitude than the biggest mammals, and they had a distinct body plan to accompany and accommodate this, with stocky, columnar limbs and a tank-like torso.

The sauropod *Apatosaurus louisae*, Carnegie Museum. Credit: Tadek Kurpaski (CC BY 2.0, source).

Size matters

But what does 'big' mean? And how do you measure 'big' in fossil species?

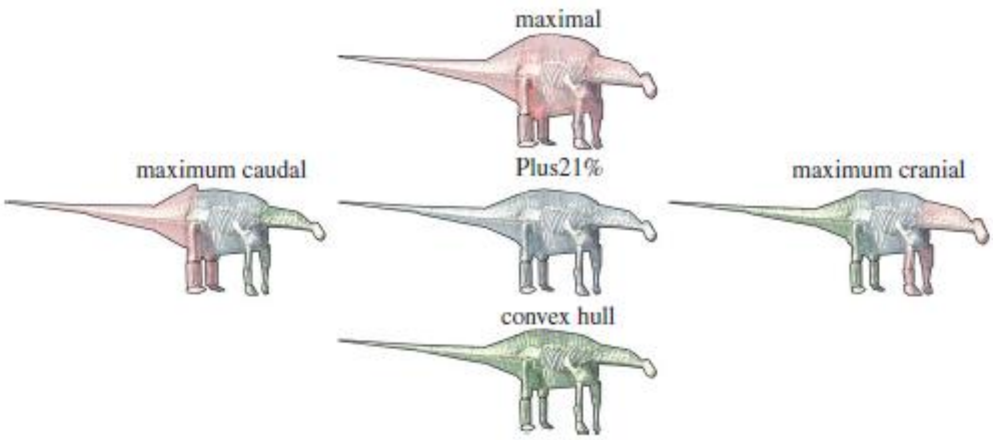
Size is a multi-dimensional factor. For example, what is bigger, a 3-meter-long snake, or a 3-metre-tall giraffe? They are both equally 'big' in one dimension, and 'bigger' than the other based on it. What about a one tonne elephant – is that bigger than a 3-metre-tall giraffe or a 3-metre-long snake?

Size takes on different dimensions, and is important for a number of reasons. Size confers a survival advantage on an animal, for example – the bigger you are, the less risk you're at from predation. Unless your predators grow equally in size too, in which case you get predator-prey escalation in a sort of arms race. Similarly, small size can often be a good thing too – imagine a 15-metre-long sauropod trying to fly!

So *big* is complicated, and when we're talking about sauropods, 'big' or 'gigantic' can refer to their enormous height, length, or body mass. If the fossil record were kind, we would be able to calculate these things easily. But as readers of this blog will know, the fossil record is rarely kind, and often cruel.

We often only have scraps of dinosaur, a bone here or there, perhaps a few articulated skull elements or a limb. Very rarely do we get a complete dinosaur which we can accurately estimate size from. So how do we accurately estimate the size of sauropods, and place this into an evolutionary context?

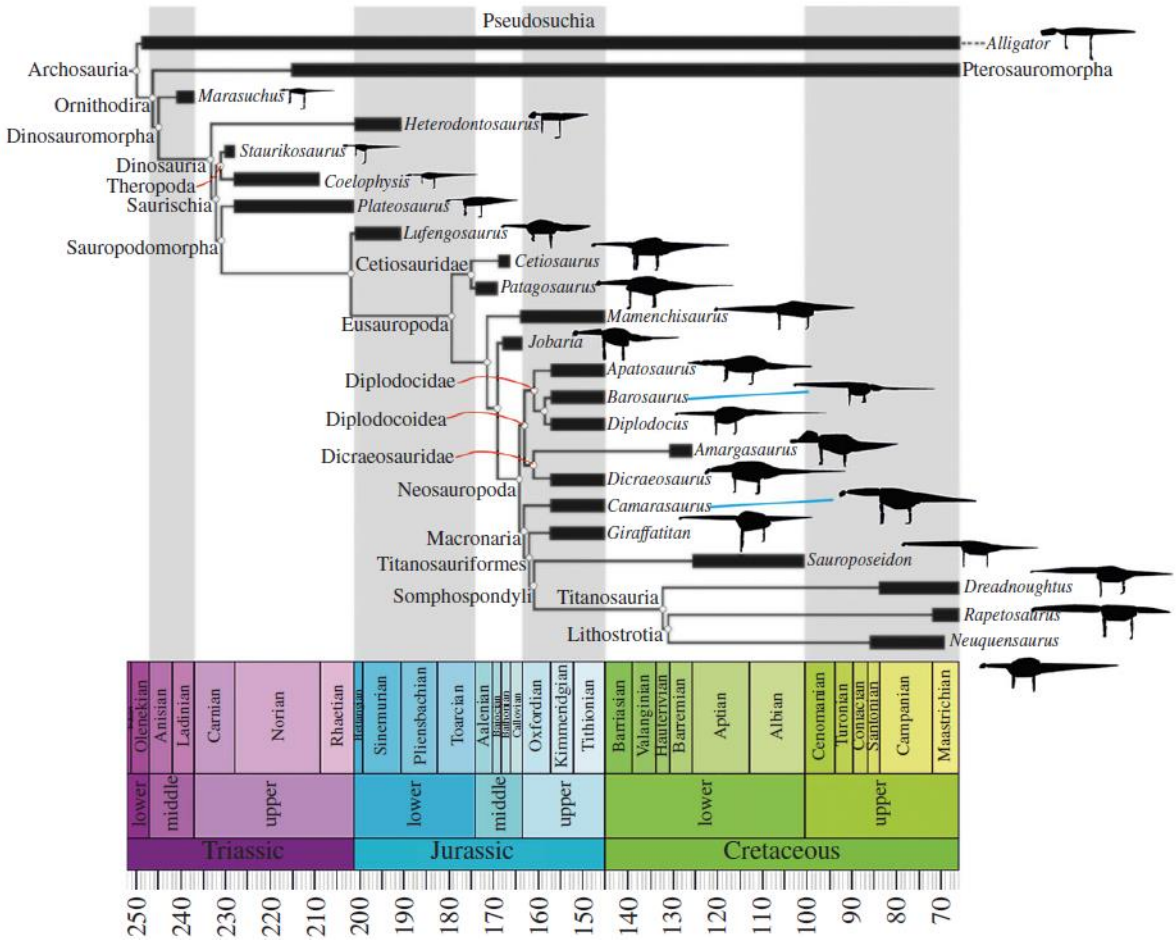
Karl Bates from the University of Liverpool (UK) and an international team of colleagues set out to answer these questions using what are informally known as 'kick ass' methods.



Estimating the sizes of sauropods – which one is best?! Bates et al. (2016).

Previously, size has been estimated in extinct dinosaurs by using proxies, such as the length of the femur or the total length of the body. From this, we generally know that sauropods evolved from smaller, bipedal animals into the quadrupedal titans we perhaps know best. Previous studies have estimated the mass just of one or two exceptional sauropod species, which doesn't tell us much about evolutionary trends, and is more about understanding evolutionary limits, or sometimes even just something for a bit of media grabby attention. Bates and the team sampled sauropod species from across their evolutionary tree, totalling 17 species in all.

Not only did they have a much wider temporal and phylogenetic coverage than all previous studies, but they also used really cool methods based on automated computational volumetric to estimate their body sizes.



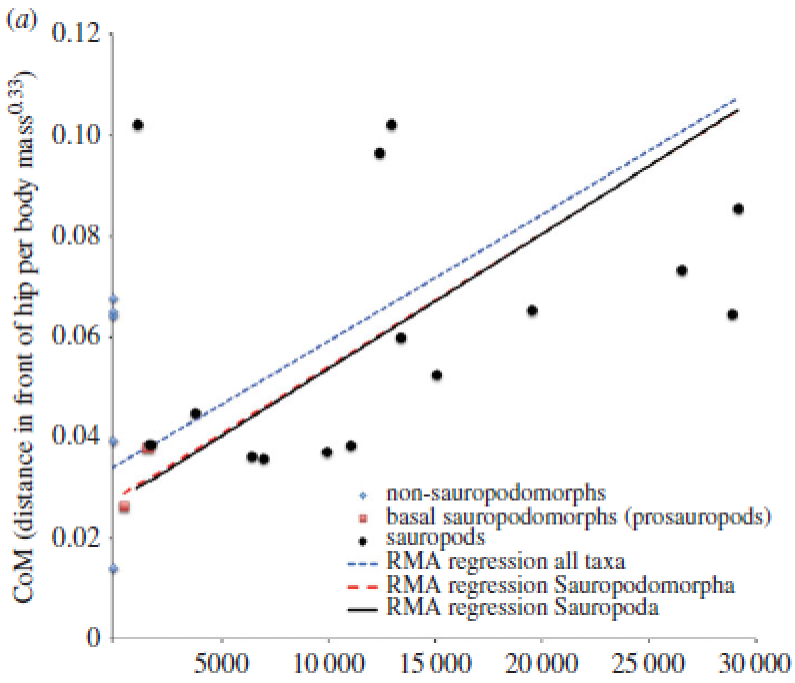
The evolutionary relationships of all sampled sauropods. Bates et al. (2016).

Fire the "laser" ...

They used a long-range laser scanning technique and digital photogrammetry to create computer models of entire sauropod skeletons. To reconstruct the fleshy parts of each animal, a convex hull approach was used which fits three-dimensional polygons around different sections of the skeleton to digitally represent the volume of each animal. This provides a baseline minimal body size estimate, and the team played with this to test the sensitivity of results by increasing the volume of the convex hulls to represent different body proportions. As such, estimates of body size contain large error bars, which is needed for calculations like this in which there is a lot of potential uncertainty.

What the team found is perhaps intuitive, but cool nonetheless. It seems that all major changes in body size within sauropods and their ancestors (sauropodomorphs) are related to major macroevolutionary events in the history of the group.

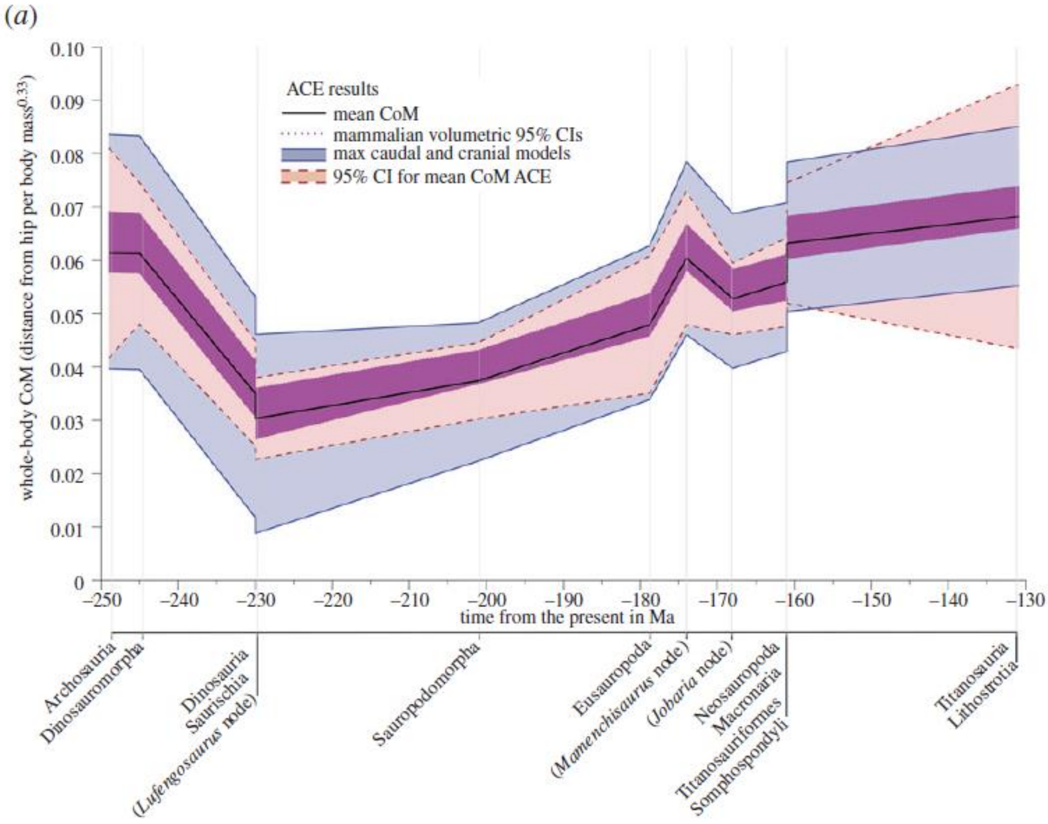
In the Middle Triassic (245-230 million years ago), when dinosaurs were just getting going, there is evidence for shift in the centre of mass of saurischian dinosaurs (early theropods and sauropodomorphs). This tail-wards shift in centre of mass seems to be associated with the evolution of bipedalism in these early dinosaurs.



The relationship between centre of mass and body mass for sauropods. Bates et al. (2016). The lines represent reduced major axis regressions.

However, this change was reversed by the Late Triassic, as sauropods became more graviportal and took to four legs to support their increasing body sizes during the Early to Middle Jurassic. This constraint to using four limbs to walk is called 'obligate quadrupedalism'.

Later on in their evolution during the Late Jurassic (around 161 million years ago), this reversal becomes more prominent as the centre of mass moved more towards the skull, particularly striking in the titanosauriforms – the sauropod group that included the largest species of all (in case you didn't get that from the name..)



How has the centre of mass of sauropods changed through time? Bates et al. (2016).

Centre of mass shifts towards the front end of the animal are each associated with lengthening of the neck, a trait that was probably one of the most important factors in the evolution of gigantism in sauropods. A longer neck gives an animal a greater 'feeding envelope' and it becomes more efficient in gathering food. Additionally, it means you can reach food that other smaller herbivores are incapable of. And trees thought they were so smart...

These shifts are also related to changes in locomotory habit and environmental distributions in titanosaurs. For example, some sauropods had what is called a 'narrow gauge' stance while others had a 'wide gauge', which relates to the relative distances between pairs of legs beneath the torso. Wider gauge trackways are those in which the legs are planted further away from the midline of the animal. The evolution of this 'wide gauge' stance is coincident in time with the evolution of a more cranial-positioned centre of mass, and development of a greater neck length.

Also, it seems that some subgroups of sauropods preferred to inhabit coastal environments, while others dwelled more inland in freshwater habitats like lakes and rivers. Whether this environmental differentiation had a role to play in the evolution of sauropods remains to be seen.

What we do know now though is that estimating the size of dinosaurs is complicated! But researchers are making great strides to measure this, while understanding the limits of what current technology can tell us. By doing so, they're slowly unlocking the constraints placed on the evolution of life, and that's pretty awesome.

Reference

Karl T. Bates, Philip D. Mannion, Peter L. Falkingham, Stephen L. Brusatte, John R. Hutchinson, Alejandro Otero, William I. Sellers, Corwin Sullivan, Kent A. Stevens, Vivian Allen (2016) Temporal and phylogenetic evolution of the sauropod dinosaur body plan, *Royal Society Open Science*, https://doi.org/10.1098/rsos.150636.

The lost history of Australia's penguins

Penguins are amazing creatures. They belong to a group called Sphenisciformes, and are one of the few flightless groups of bird. They are beautifully adapted to life in the water, where they spend around half of their lives playing and hunting.

The first penguins are known from around the time the non-avian dinosaurs went extinct, 66 million years ago at the Cretaceous-Paleogene boundary. The first fossils are known from around Antarctica and New Zealand, which were much closer to each other at the time, and have since drifted apart since their tectonic life turned plutonic.

These days, southern Australasia and Antarctica are isolated from each other and around 4000 kilometres apart. This plate reconfiguration has had a distinct impact on penguin evolution in the southern hemisphere, due to its impact on possible dispersal pathways and species isolation.

These days, there is just a single species of penguin living in Australia, the little penguin, *Eudyptula minor*. And yes, they are totally as cute as the name suggests! But time travel back millions of years, and you have a very different story!

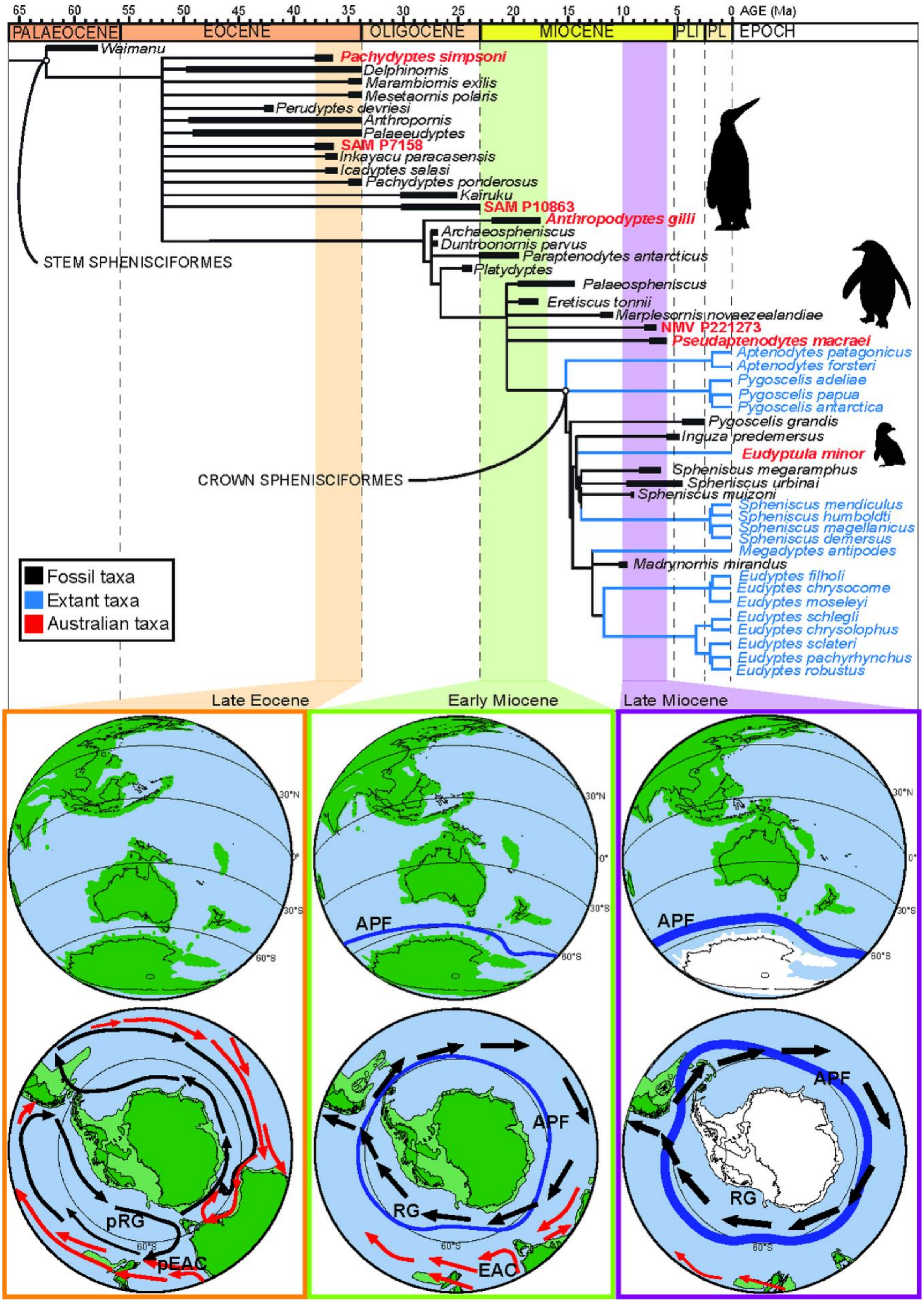
Humeri (upper arm bones) of the little penguin vs the Emperor penguin vs giant penguins (from left to right). Credit: Travis Park.

Travis Park, who also recently discovered that 26 million year old whales could echolocate, investigated the evolutionary history of penguins in Australia based on some poorly known fossil remains as part of his undergraduate research. The fossils were collected back in 2006, and come from marine rocks in Portland, Australia, and are around 7.2-7.9 million years old –

a period known as the late Miocene. This research is important, as pre-Quaternary fossils of penguins from Australia are relatively rare, and therefore represents a major gap in our knowledge of penguin evolution and biogeography.

“The past 20 years has seen a renaissance in our understanding of penguin evolution,” explains Park, “However, Australian fossil penguins have, until now, been left out of this global picture and no-one has known where they fit into the story. Our paper is the first attempt at putting the missing piece of this puzzle in place.”

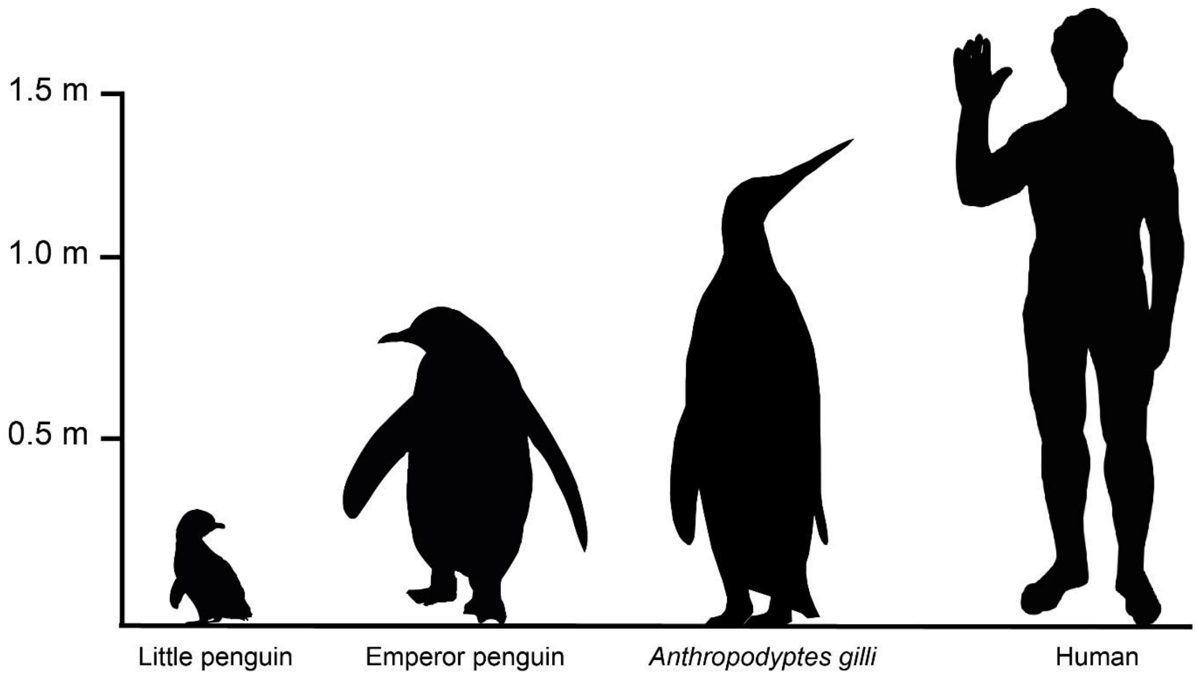
To assess the evolutionary history of penguins, they conducted a phylogenetic analysis using the new specimens and a previously published dataset on fossil and living penguins. By combining resulting evolutionary trees with geographic information, it becomes possible to make biogeographical inferences about the group, such as when and where species dispersed from one continent to another.



The evolutionary relationships of penguins mapped onto geography! Note the distribution of Australian species/specimens throughout the tree. (Park et al., 2016)

What Travis and his colleagues found is that the fossil penguins are distantly related from the little penguins still cooped in Australia, and overall Australian penguins are quite dispersed throughout the tree. What this means is that instead of a single lineage persisting in Australia, as looking at just the modern penguins would suggest, there have actually been multiple lineages colonising the Australian shores through geological history. This overall pattern is the same as what we see when looking at penguin colonisation in South Africa too, despite a fairly different geological history.

Travis also found an interesting clue about the geographical pattern of extinction in penguins. Around 23 million years ago, the giant penguins went extinct almost across the globe, but not in Australia, where the species *Anthropodyptes gilli* hung on beak and claw for another 3-7 million years. When this happens, surviving populations are described as persisting in a 'refugium' until their ultimate extinction, where some combination of ecological factors different from other regions promotes their evolutionary longevity.



Relative penguin sizes compared to oblivious waving guy.

Overall, the new information from fossil penguins in Australia ties in to several key events in their evolutionary history. In the late Eocene, there was the widespread dispersal of archaic penguins across the southern hemisphere. These ancient penguins went extinct at the Oligocene-Miocene boundary, and appear to have been replaced by smaller-bodied species in the early Miocene. Following this, all crown-group penguins dispersed again throughout the southern continents. However, in Australia, archaic giant penguins, and other earlier species, persisted much later than everywhere else until the early Miocene, and crown group penguins don't arrive on the scene until later.

Teeny! Sizing up the giant and little penguins. Credit: Travis Park.

Bringing this back to geology (everything always comes back to the rocks...), the reason for this multiple colonisation and penguin longevity seems to be due to the drifting of Australia away from the Antarctic plate. This actually started 100 million years ago, back in the Cretaceous, as part of a late stage rifting phase and continuous break-up of the super-continent, Pangaea.

This means that slowly but surely, the seaway between Antarctica and Australia has got wider and wider over millions of years. The poor penguins in Antarctica would have found it increasingly difficult to move to Australia, and vice versa, effectively creating two isolated sets of populations on either continent.

The penguins did catch a break though. Around 10-15 million years ago, oceanic circulation patterns shifted and opened up a dispersal pathway through the strengthening of the Antarctic Circumpolar Current for penguins to re-colonise Australia. They would have been able to use this current to paddle from South America or South Africa across the Indian and Southern Oceans towards Australia.

In spite of this, it seems that modern penguins, the little penguins, didn't appear to have reached Australia until the last million years or so. Were they just late to the party? And why does penguin evolution in Australia seem so different to that in the other southern continents?

As Dr Erich Fitzgerald, Museum Victoria's Senior Curator of Vertebrate Palaeontology and study co-author explains: "What happened to penguins in this part of the world during global warming 15 million years ago, and then when the Earth cooled dramatically about 3 million years ago, are chapters of the penguin story we want to know more about. Australian fossils may be the key to understanding these millions of 'missing years'."

Only by using fossils to connect the dots can palaeontologists begin deciphering the evolutionary history of penguins down under.

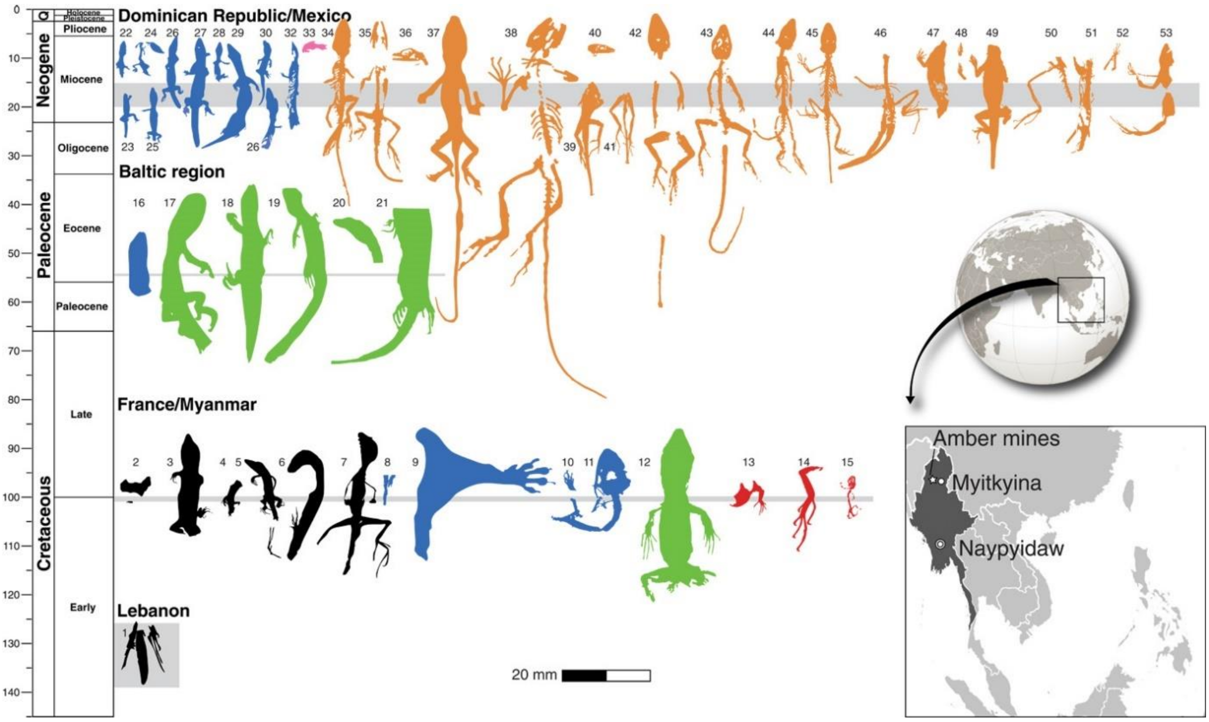
Reference

Park, T., Fitzgerald, E. M., Gallagher, S. J., Tomkins, E., & Allan, T. (2016). New Miocene fossils and the history of penguins in Australia. *PloS one*, *11*(4). https://doi.org/10.1371/journal.pone.0153915.

100-million-year-old lizards entombed in amber reveal stability of tropical ecosystems

When talking about amber fossils, there is usually one image that springs to mind: that perfectly preserved mosquito sitting on John Hammond's cane in Jurassic Park, entombed there for millions of years.

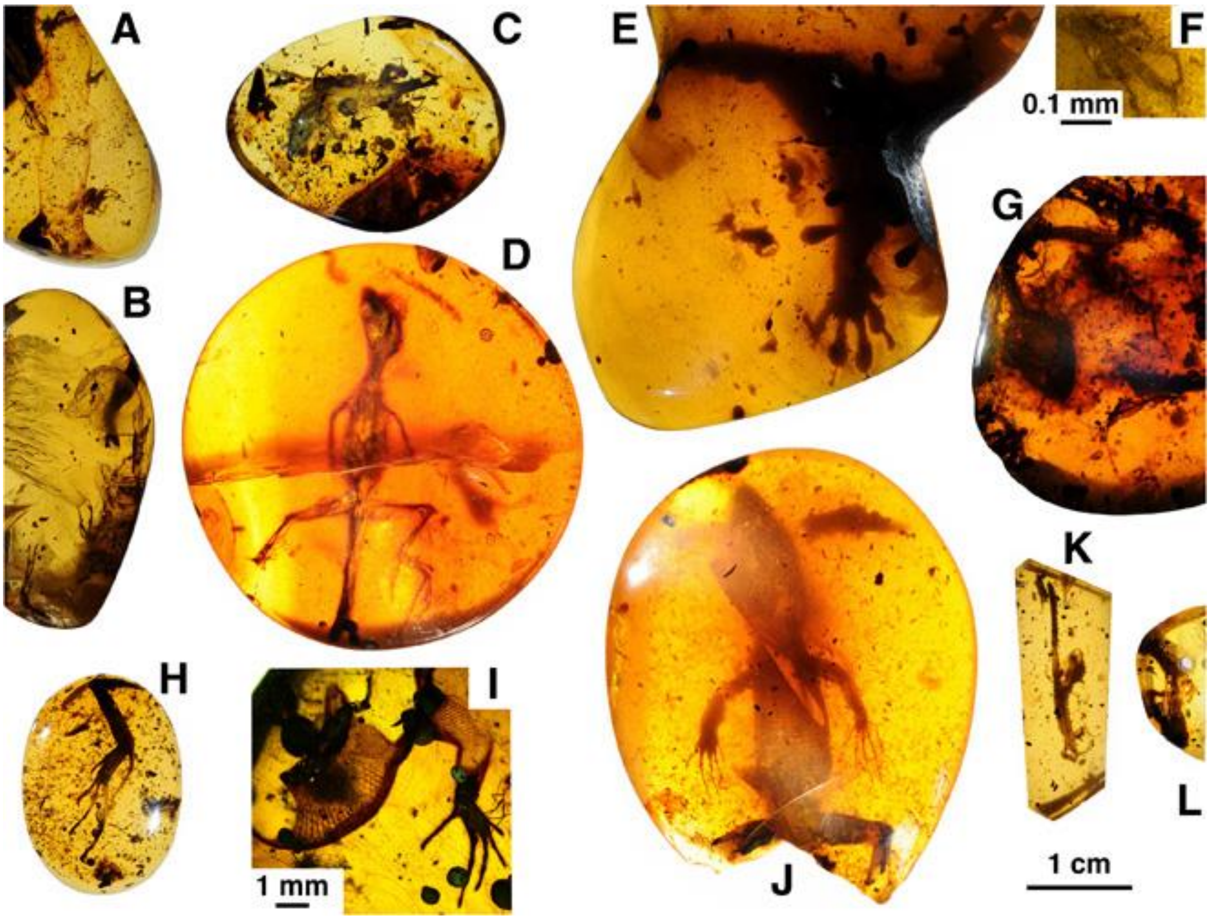
Amber is fossilised tree resin. Because of the way it forms, it is usually constrained in size and not more than a few inches in diameter. So there's not much chance it will ever capture a dinosaur (although feathers have been found preserved in amber!). But what it does capture is a unique part of ecosystems that is not usually preserved to us: that of tree dwelling organisms.



Squamates in amber from the four known localities. Colour key: Black, stem Squamata; blue, stem Gekkota; green, Lacertoidea; red, Acrodonta; orange, Pleurodonta. (Daza *et al*., 2016).

And it preserves them exquisitely too. This is really important, as often smaller animals that are more delicate are less likely to be preserved – they simply cannot withstand the fossilisation process as much as a chunkier animal, like a dinosaur or mammal, is able to.

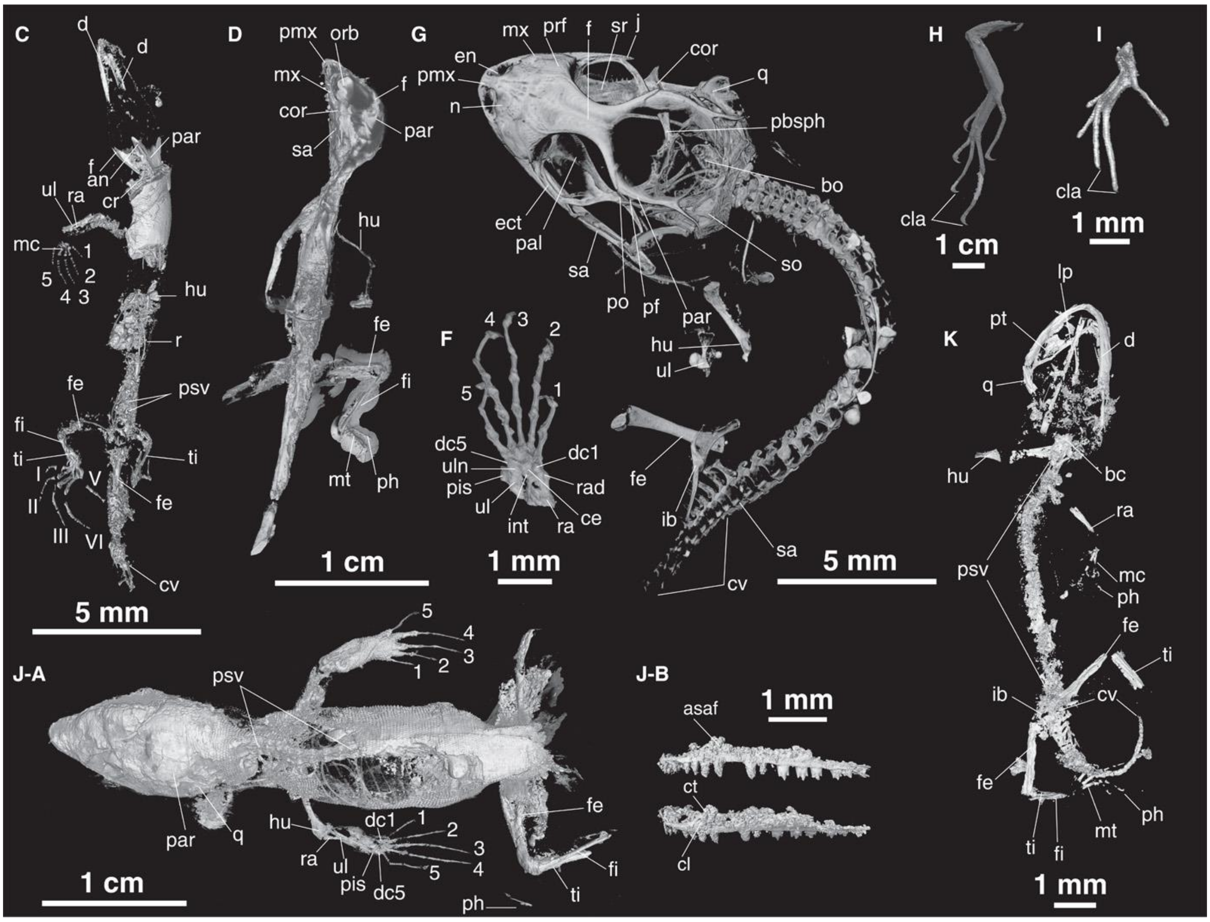
So, amber can give us an occasional glimpse into a new dimension for ancient ecosystems. New discoveries now from the Cretaceous of Kachin Province, northern Myanmar, radiometrically dated to around 99 million years old, provide evidence for the oldest lizard fossils preserved in amber we know of. Amber from here is called burmite, and reveals a huge diversity of early flowering plants, scorpions, roaches, termites, ants, and a whole range of other creepy crawlies.



Lizards preserved in mid-Cretaceous Burmese amber. (Daza et al., 2016).

They also preserve them in astounding detail, with soft tissues still intact over millions of generations. If you look at the fossils, entombed in space and time, you'd think they could have formed like that only yesterday. Certainly, I've seen fresh roadkill that doesn't look as good as these fossils!

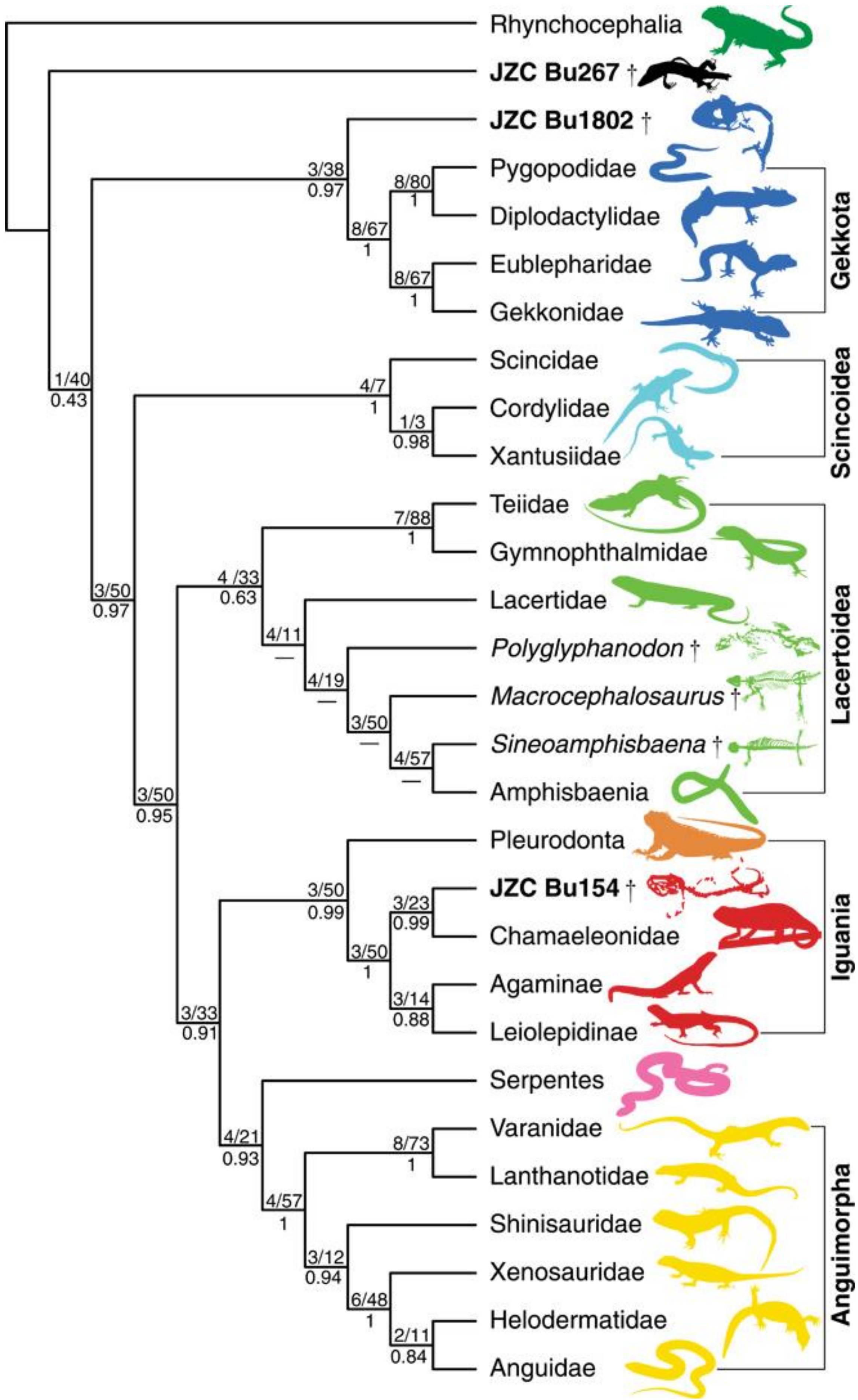
The newly discovered lizard fossils contain representatives of five major groups of lizards, which is quite a bit more than the fossil record usually divulges for these fragile animals. This is the most diverse lizard fauna ever discovered in amber, and makes quite the shining spectacle.



High-resolution x-ray computed tomography images of mid-Cretaceous lizards in Burmese amber. (Daza *et al*., 2016).

Perhaps most importantly, the high degree of preservation reveals stunning details about their soft tissues, which means they can be more easily related to modern lizards. This makes them very valuable, as it means we can calibrate with more certainty when modern groups arose, and what their ancestral forms would have looked like.

Different fossils were recovered by phylogenetic analysis to represent a variety of early squamates, gekkos, and chameleons. Squamata is the group that includes all modern lizards and snakes, some 9900 species, so is a pretty hefty and diverse group. Gekkota is less diverse, comprising around 1650 living species of gecko and pygopod. Only around 200 species of chamaeleonoid are around today, but anyone who’s ever met one of these will know their rarity just makes them even cooler! Other fossils represent groups such as Agaminae, known from the old-world tropics, and Lacertidae, which includes new and old-world representatives.


Rhynchocephalia
JZC Bu267 †
JZC Bu1802 †
Pygopodidae
Diplodactylidae
Eublepharidae
Gekkonidae
Gekkota
Scincidae
Cordylidae
Xantusiidae
Scincoidea
Teiidae
Gymnophthalmidae
Lacertidae
Polyglyphanodon †
Macrocephalosaurus †
Sineoamphisbaena †
Amphisbaenia
Lacertoidea
Pleurodonta
JZC Bu154 †
Chamaeleonidae
Agaminae
Leiolepidinae
Iguania
Serpentes
Varanidae
Lanthanotidae
Shinisauridae
Xenosauridae
Helodermatidae
Anguidae
Anguimorpha
1/40
0.43
3/38
0.97
8/80
1
8/67
1
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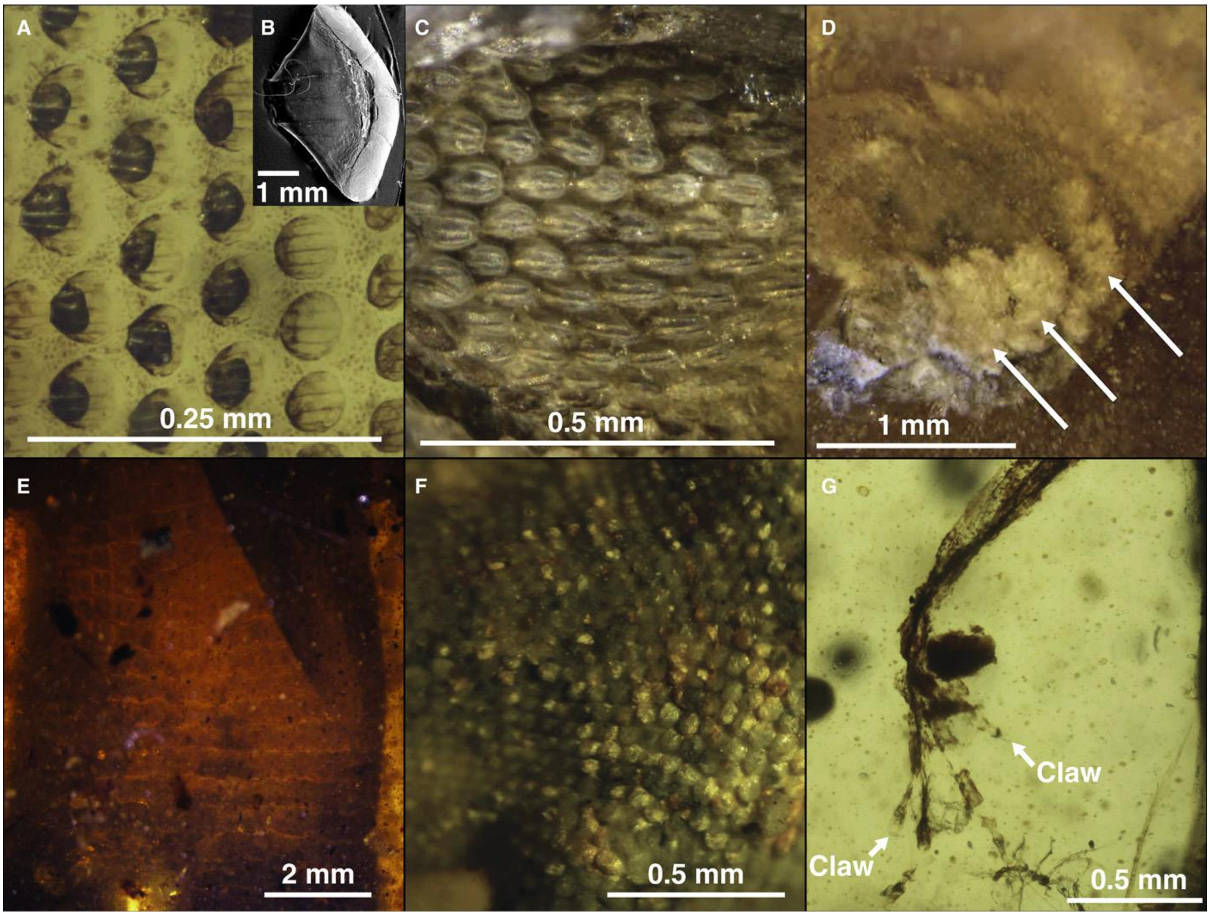
4/21
0.93
8/73
1
4/57
1
3/12
0.94
6/48
1
2/11
0.84

Results from phylogenetic analysis, showing where the new fossil specimens fall out. (Daza *et al*., 2016).

All of these groups are often found in tropical areas, which don't leave their traces too well in the fossil record. As such, discovery of a 100-million-year-old tropical herp fauna is pretty awesome! Small size and a bad environment for fossilisation means that we know relatively little about fossil lizards. This is a shame, because small size might actually be one of the things responsible for their great evolutionary success!

The detail they preserve is amazing. Some even preserve the little adhesive toe pads for climbing trees we see in modern species. The chamaeleonid has facial features characteristic of their weird projectile tongue feeding strategy, indicating that these key evolutionary characteristics were in place early on in their evolution during the Cretaceous.



Photomicrographs of the integument of mid-Cretaceous lizards in Burmese amber. (Daza *et al*., 2016).

The presence of these groups in Myanmar at this time tells us more about their evolutionary success too. Many of them still have living representatives in Myanmar, which suggests that not only have those lineages been there for around 100 million years, but survived the great extinction 66 million years ago, when groups such as the non-avian dinosaurs went kaput. So, lizards > dinosaurs.

This also suggests that tropical assemblages are pretty stable, if they can survive relatively intact for 10s of millions of years. Such a find supports the idea of the tropics being a 'museum' of biodiversity. Good job humans aren't totally destroying millions of years of evolutionary heritage or anything then.

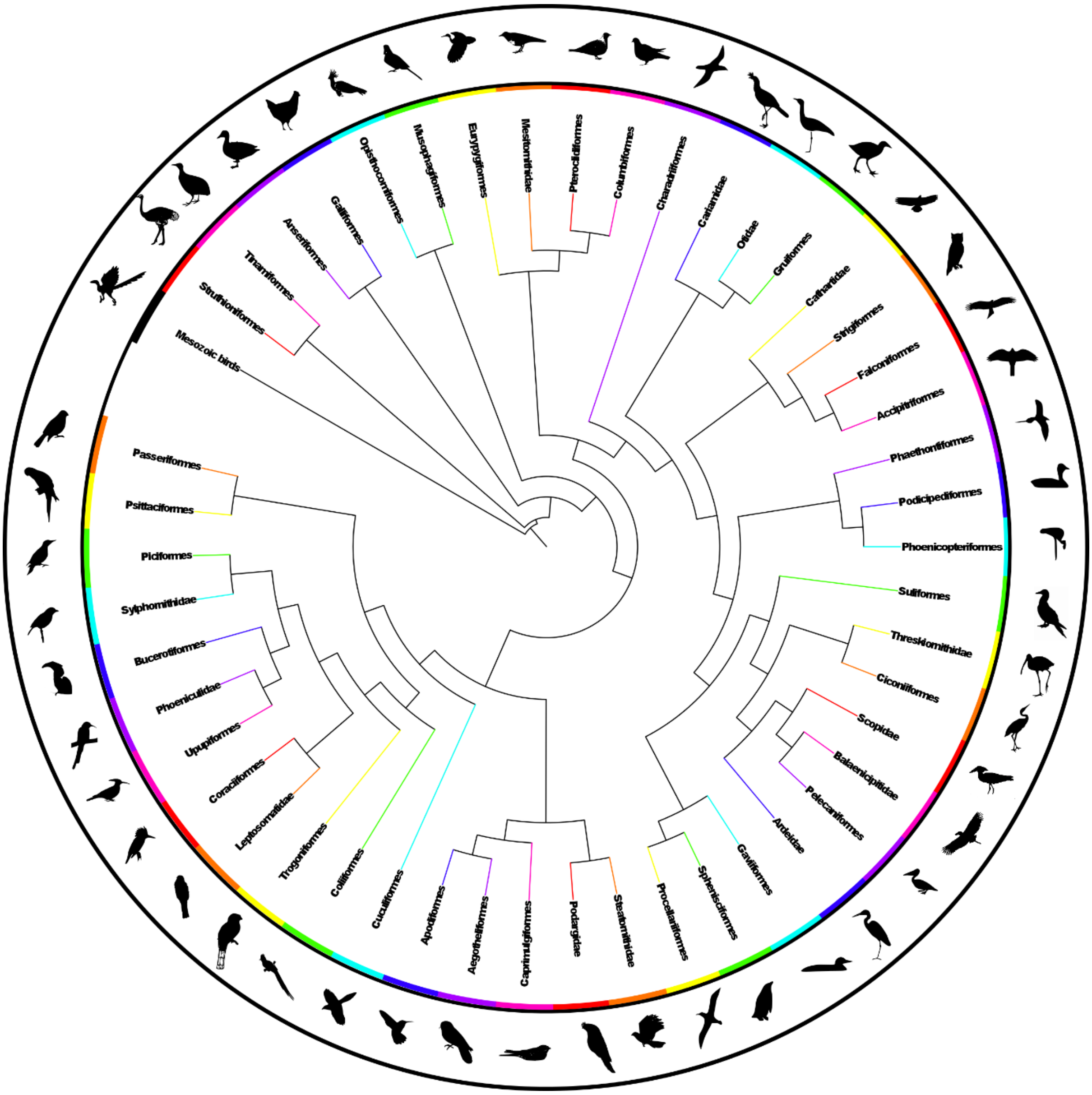
Reference

Daza *et al*. (2016) Mid-Cretaceous amber fossils illuminate the past diversity of tropical lizards. Science Advances, 2: e1501080. https://doi.org/10.1126/sciadv.1501080.

How many dinosaurs were there?

There are more than 10,000 species of bird living on Earth today. If you recognise that birds are living dinosaurs, which overwhelming evidence indicates that they are, then this makes them more diverse than their living mammalian counterparts. So, if you take the number of species to mean anything, this means we're still in the reign of the dinosaurs! These days they're just mostly a bit smaller and fluffier than their Mesozoic ancestors.

But one massive question still remains for Palaeontologists and Neontologists: Why are there so many bird species around today, when we have relatively so few dinosaurs in the fossil record? This disparity is even more extreme when you consider that while non-avian dinosaurs were around for about 170 million years, there were only ever about 800 or so species of dinosaur, based on current records. The actual number fluctuates through time, as new species are discovered, and others are shown to be invalid through research broadly known as 'taxonomy'.



So many birdies! (Source).

Recently, Jostein Starfelt and Lee Hsiang Liow of the University of Oslo made a major step forward in answering one of the key questions related to this: Just how many dinosaur species were there in reality?

Most previous studies of dinosaur diversity have only looked at relative diversity, which assess proportional changes from one time to another. But how do you actually estimate the real total number of dinosaurs through time?

How do Palaeontologists read the fossil record?

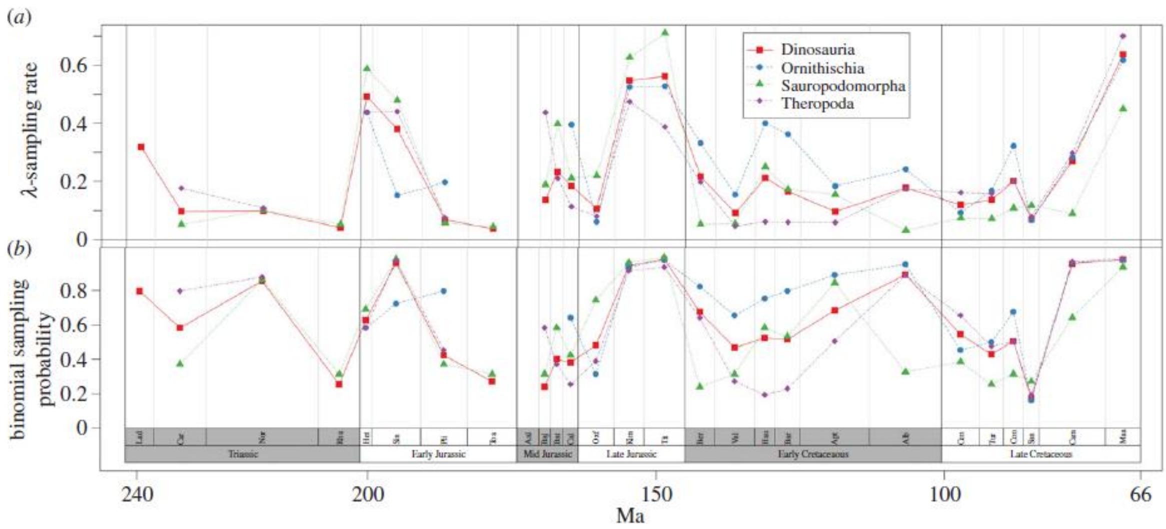
One of the major problems in calculating diversity is that the fossil record is a poor representation of the biological part of ecosystems. Animals are preserved differently due to differences in their anatomy. Also, not all animals have the same chance of becoming fossils, based on where they happen to find their final resting place.

Furthermore, the geological record is preserved differently through space and time, due to where seas and rivers were to deposit sediment, and due to processes of mountain building and erosion.

Once you get past these two hurdles, humans have then sampled this record differently through time, for example by collecting only from rocks where they know there is a high probability of finding new fossils, also known as the 'bonanza effect'.

Dinosaurs be TRiPSin'...

All of this variation is broadly known as *sampling bias*. While many methods have been developed to account for these biases in different ways, Starrfelt and Liow developed a brand new one called TRiPS, which stands for True Richness estimated using a Poisson Sampling Model. This accounts for variation in the sampling of the dinosaur record by estimating both the bias and the overall diversity (richness) based on variation in the number of times each dinosaur species occurs at different points in time. For example, if we know lots of specimens of a particular dinosaur species, we can infer that it has a relatively high preservation potential and collection probability. The authors used this to investigate the dynamics of dinosaur diversity through time, and to assess possible extinction events in their history.

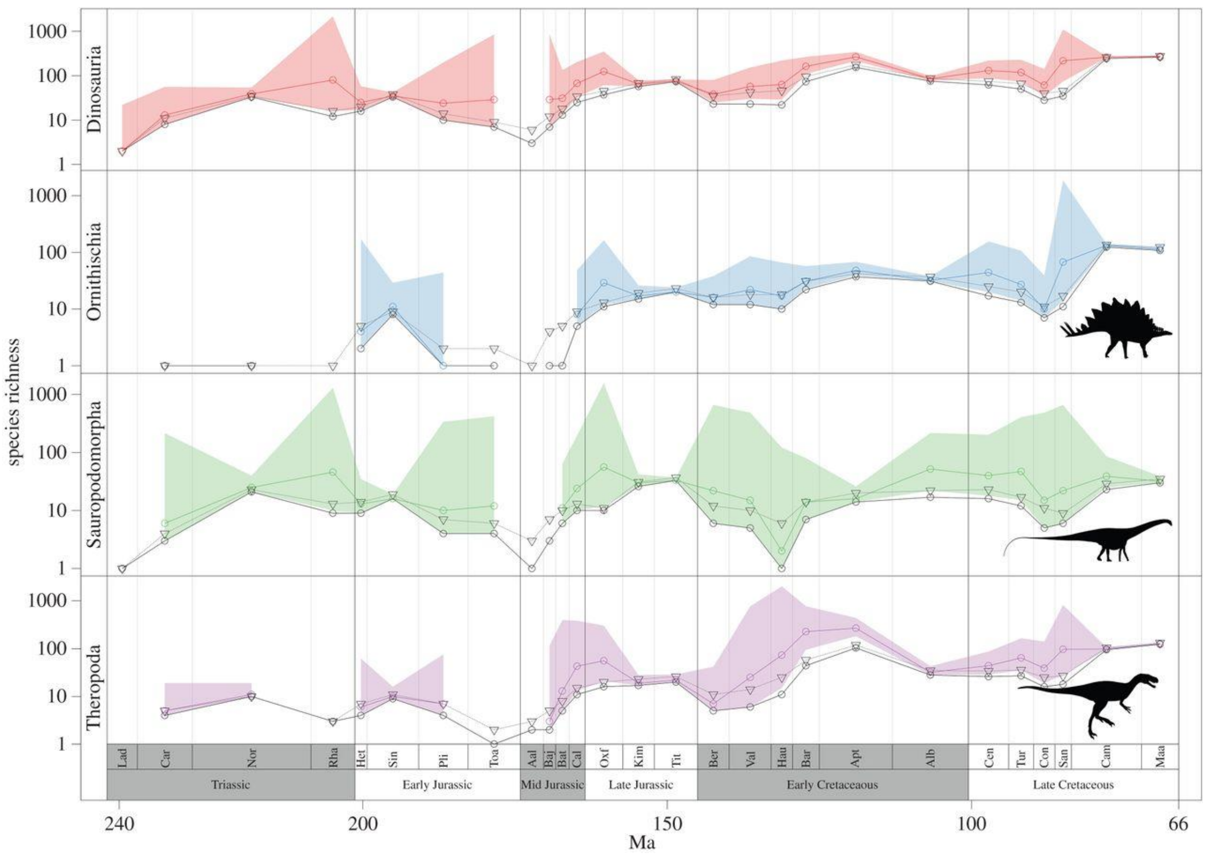


How has the sampling of the dinosaur fossil record changed through time? Starrfelt and Liow (2016).

Using this new method, applied to the whole known dinosaur record through the whole of the Mesozoic (Triassic to the end of the Cretaceous), they estimated that 1543-2468 species existed altogether around the globe. While the authors acknowledge that this is a crude estimate, it is largely convergent on previous calculations too.

Importantly, this number is much higher than what is currently known from the fossil record. If you break this down into the three major dinosaur groups, a slightly different pattern emerges. Theropods, the mostly carnivorous group leading to modern birds, had almost twice as many species (1115) than either the long-necked sauropods (513) or bird-hipped ornithischians (508).

Steve Brusatte of the University of Edinburgh is sceptical though: “I would take these numbers with an ocean full of salt”, he said. “There are over 10,000 species of birds – living dinosaurs – around today. So, saying there were only a few thousand dinosaur species that lived during 150+ million years of the Mesozoic doesn’t pass the sniff test. That’s not the fault of the authors. They’ve employed advanced statistical methods that take the data as far as it can go. The problem is the data. The fossil record is horrifically biased. Only a tiny fraction of all living things will ever be preserved as fossils. So, what we find is a very biased sample of all dinosaurs that ever lived, and no amount of statistical finagling can get around that simple unfortunate truth.”



Dinosaur species' diversity through time, with confidence intervals. Starrfelt and Liow (2016).

Jostein Starrfelt also thinks that there is more work to be done in this domain: "Our estimate of total dinosaur richness of approximately 2000 species was done attempting to combine the sampling probabilities from all stages of the Mesozoic and should be interpreted with caution, and my gut feeling is that the total number of dinosaur species for the whole Mesozoic is higher than our total estimate suggests."

The future of dinosaur hunting

So, what does all of this mean for dinosaur hunters? Well, it suggests that there are still hundreds more to be found out there! So, get your hiking boots out and go track some dinosaurs!

Brusatte said "There are huge swaths of the planet and huge stretches of the Mesozoic that have yielded few or no dinosaur fossils. The Middle Jurassic and mid Cretaceous are notoriously poorly sampled, as are Antarctica, Australia, and much of Africa. It's only been over the last few decades that we've come to appreciate the bounty of Chinese dinosaurs, and they keep coming at a furious pace. We still have a lot to find." Indeed, Starrfelt agreed that their method could be used to "get a better picture of which continents are under-sampled and for which periods (and could thus deserve some more human effort)."

It also hints that there might be something fundamentally different about the evolutionary biology of bird-line dinosaurs, and non-avian dinosaurs. Many studies are beginning to unravel the origins and diversification of modern birds, but these will only truly shed light if they are considered in the wider context of dinosaur diversity through time.

Starrfelt also hinted at his future plans with this line of research. "As with most scientific endeavours I wouldn't say that TRiPS has solved the major problems of using the fossil record as a source of information about the dynamics of clades; but that it might be a good start. The approach lends itself easily to being extended; in the future we might be able to include information about the 'human effort' part of fossil bias by interpreting the sampling rate as the product of a fossilization rate and a 'discovery probability', for instance. We're also in the process of putting TRiPS in a Bayesian framework." How exciting!

Only by being able to estimate diversity with greater accuracy through space and time can we begin to understand the forces that have shaped the evolutionary history of animals.

As always, Brian Switek has also written an excellent post on this study.

Reference

Starrfelt, J., Liow, L. H. (2016) How many dinosaur species were there? Fossil bias and true richness estimated using a Poisson sampling model. *Philosophical Transactions of the Royal Society Series B: Biological Sciences*. https://doi.org/10.1098/rstb.2015.0219. The data and code are all available via Dryad.

Multiple fathers for reintroduced endangered Orinoco crocodile egg clutches

The Orinoco crocodile, *Crocodylus intermedius*, is one of the most threatened crocodile species in the world. There are now just a few wild populations remaining in Venezuela and Colombia. Excessive hunting until the 1960s and egg collecting for their local consumption decimated their numbers, and now new conservation efforts are aiming to revive their dwindling population numbers.

One such effort involved the reintroduction of one population by an international team of researchers led by Natalia Rossi Lafferriere from Columbia University, and can be found at the La Ramera lagoon at the El Frío Biological Station, Venezuela. I can't imagine a better job than rearing endangered crocodile eggs for the purpose of reintroducing them into the wild when they were ready!

Location of the El Frío Biological Station (EFBS), and three additional localities where last remaining populations of Crocodylus intermedius are found in Venezuela. (Lafferriere et al., 2016).

But how do you work out if reintroducing endangered species like this is a successful venture or not?

To test this, the team sampled 20 egg clutches (335 hatchling micro-crocodiles) for incubation in their laboratories, and were able to conduct genetic analysis on them in order to test to see who their fathers were. This is important as you can get a measure of genetic diversity within populations, which is a vital factor in whether or not populations have the capacity to survive. It's probably also important to do this via genomic analysis rather than observation for what I'd think were obvious reasons.

Orinoco crocodiles chilling in Villacicencio, Colombia CC BY-SA 3.0 (Source).

What did they find?

Perhaps unexpectedly for humans, but quite expected for wild animals, the research team discovered that half of the egg clutches were actually fathered by more than one male! Of the 14 fathers inferred from genetic analysis, they found that only 6 contributed to a whipping 90% of the total offspring. Even more bizarrely, 3 of these 6 males fathered more than 70% of the total number of offspring. Full points for productivity to those chaps!

The evolution of females mating with multiple mating is known as polyandry, and can be achieved either through mating with multiple individuals during the same reproductive season, or actually storing sperm in the reproductive tract for later fertilisation.

This activity has rarely been observed in captive population of crocodiles, but has been documented in the wild for American alligators and the spectacled caiman, suggesting that multiple mating systems might be widespread in crocodilians and an important factor in their survival. These beasties and their ancestors have been around since a time around the origin of dinosaurs, after all!

These new results reveal the first evidence for multiple paternity in a reintroduced Orinoco crocodile population, and therefore supports the success of reintroduction efforts for this species.

Why is this important?

More than half of the living species of crocodilian are endangered, thanks to threats to habitat change, human disruption, and ongoing environmental changes. By gaining an insight into their reproductive behaviour, we can learn more about how to reintroduce these animals into the wild into sustainable populations.

In this case, multiple paternity might be important part of mating systems for increasing the overall genetic diversity in populations, as well as the total size of populations. These factors are often critical in maintaining flexibility and diversity in populations, and they play an important role in survivability at a population level, something that is becoming increasingly crucial for these endangered animals.

Other benefits of this can include sharing resources with mothers to ensure greater offspring survival, and greater selection of ‘higher quality’ mates, which is important for that well-known concept of survival of the fittest. Darwin would be proud!

Successful reproduction is a vital and necessary first step in the recovery of the Orinoco crocodile. This is an excellent example of a successful reintroduction effort of a critically endangered species, and hopefully a sign that we can reverse the effects that led to their endangerment before it’s too late.

Continued conservation action will be important to mitigate ongoing threats to the Orinoco crocodile. This includes banning poaching, protecting their habitats, and will require a combined effort from governmental conservation authorities in order to create sustainable initiatives.

All is well that ends well too, and all crocodiles were released back into the wild as juveniles. Life, er, finds a way!

Reference

Rossi Lafferriere NA, Antelo R, Alda F, Mårtensson D, Hailer F, Castroviejo-Fisher S, *et al*. (2016) Multiple Paternity in a Reintroduced Population of the Orinoco Crocodile (*Crocodylus intermedius*) at the El Frío Biological Station, Venezuela. *PLOS ONE* **11**(3): e0150245. https://doi.org/10.1371/journal.pone.0150245.

190 million years of tetrapod biodiversity

Tetrapod is the name given to any vertebrate animal with four (*tetra*) legs (*pod*). There are more than 30,000 living species of tetrapod known today, and this includes many of the animals we are familiar with like mammals, crocodiles, snakes, and birds. The question of how they reached this level of diversity is still very much open, and we know that by peering back into pre-history with the fossil record the number of tetrapod species has not remained constant through time.

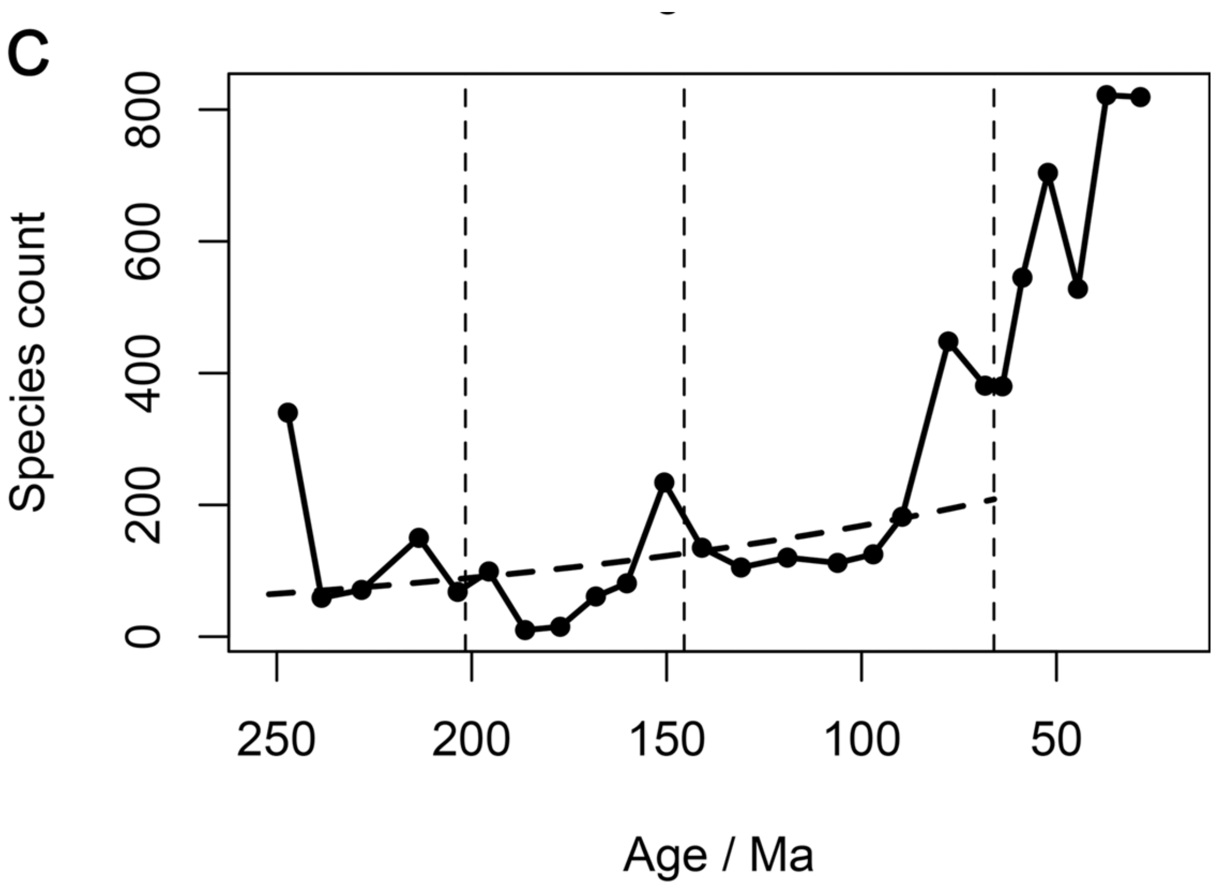
The history of tetrapod life is punctuated by episodes of mass extinction, huge reorganisations of life both in terms of ecology and the relative dominance of different groups. With extinction comes radiation, the origin of new groups to fill the vacant environments and ecologies left as species die out. This natural variation in the fluctuating number of species through time is inconsistent through time, and unlocking what drives such patterns remains one of the long standing, but well-investigated, realms of palaeontological research.

The importance of why we research such things might not be immediately clear, but there are two main reasons that come to mind:

1. Understanding the evolution of life on this planet is a totally awesome thing to study;
2. By learning about past patterns and processes in the history of life, we might better understand how to stop destroying it so much in the future.

Recently, we have been able to provide some answers to the questions of how diverse through time has life been, based on the building of large fossil occurrence databases and new methods of analysing them. One such development has been the Paleobiology Database, a professional crowd-sourced archive of fossil history, where the context of fossils is provided in both space and time, and largely based on the published record of fossil discoveries.

Unfortunately, simply counting the number of species preserved through time as fossils is not a good way of measuring biodiversity: we can't simply say we have n species found in this time period, and therefore diversity was n. The reasons for this are due to differences in how the fossil record is preserved through time, and presented to us as collectors and researchers. For example, what do you do if you have a lot of fossiliferous rock in one time period, but very little in another, and does an absence of fossil-bearing rock imply low diversity or something else? Or how do you compare samples if you have 100 fossil occurrences representing 20 species in one time bin, but 150 occurrences representing 50 species in another? This is the fundamental problem with the evenness of sampling, which is sometimes called 'sampling bias', and has plagued palaeontologists since the day someone was kind enough to point it out.



Raw count of species diversity through time. The dashed lines represent major period boundaries. (Benson et al., 2016).

However, this problem, as with all of those in science, is not completely intractable! Thankfully, there exist a whole suite of methods to counter this issue of sampling variation. One of the more recently implemented of these is one called Shareholder Quorum Subsampling (SQS) developed by John Alroy, the statistical sensei of palaeontology. It has a horrific name, yes, but SQS is essentially a method that weights how diverse one species is (the shareholder) based on its frequency of occurrence. Using this, and a calculation taken from ecology of how evenly sampled your overall sample is, you can then count through repeated random trials (subsampling) until a pre-defined threshold (the quorum; you see where this is going now...) applied to all samples is met. If that doesn't make sense, don't worry about it – it took me years to understand and implement this method, and that was only with the help of John himself (who, incidentally, is an author on the paper this post is all about!)

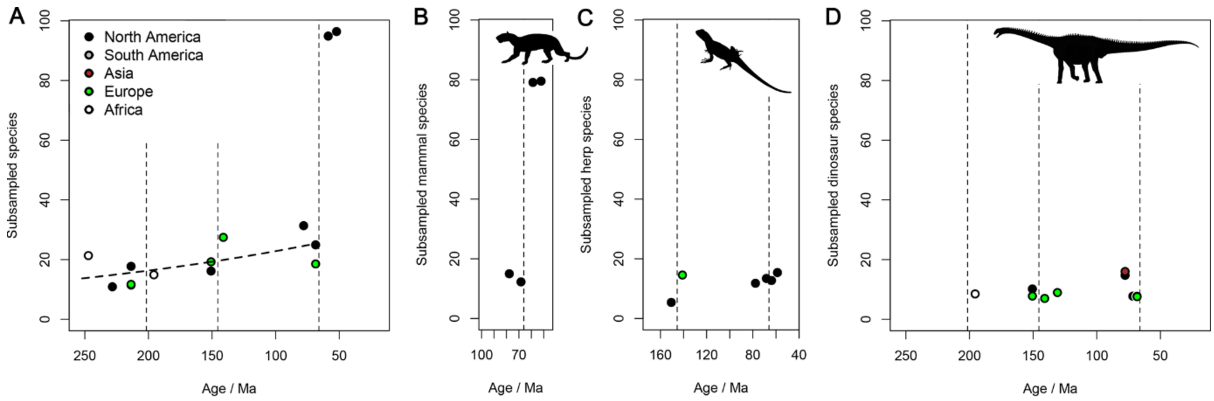
By applying SQS with our development of large fossil occurrence datasets, voila, we are able to gain renewed insight into the diversity of life through history in a way that accounts for the inherent biases of the fossil record!

And that's just what a new study in PLOS Biology set out to do. Led by Roger Benson of the University of Oxford, an international team of researchers applied SQS to one of the largest tetrapod fossil occurrence databases ever assembled (if not the largest!), comprising more than 27,000 individual fossil occurrences! This represented almost 5000 fossil species, and the data were restricted to just those fossils that dwelled on land – so this excludes groups like ichthyosaurs and plesiosaurs, for example. They also excluded flying tetrapods, so birds, bats and mammals, as these are known to have very different preservational histories in the fossil record. For palaeontology though, this is definitely 'big data'.

The team restricted their analyses to just the Mesozoic to early Paleogene, a time span of around 190 million years (a fairly long time, even by geological standards!). If you think about it, that's 5000 species over about 190 million years, which compared to 30,000 around today is pretty weird even in itself.

But anyway, armed with this hefty dataset, it becomes possible to group them by the time at which they occur in the fossil record, and use SQS to assess how their diversity changes through time. Simples?

What did they find? Well, perhaps a quite unexpected result. They found that tetrapod diversity actually remained fairly constant and stable throughout most of this time period. This was in spite of the fact that we have new groups originating and diversifying, such as mammals, amphibians, and dinosaurs, while other groups go extinct or massively reduce in numbers. In all, species diversity of non-flying mammals increased less than double, which suggests that there is some suppressing or limiting factor that controls long term diversification in tetrapods.



Total subsampled palaeocontinential diversity (A), and individually for mammals (B), herps (C; non-mammalian, non-dinosaurian tetrapods), and dinosaurs (D).

Interestingly, the extent of sampling bias detected varied substantially on a regional level, based on approximate palaeocontinental reconstructions (the world was a very different place 100 million years ago!) What this means is that global diversity counts, when applying techniques like SQS, are poor reflectors of what is happening to diversity at a regional level through time.

The team also found an anomaly at the end-Cretaceous mass extinction, with a four-fold expansion of species diversity following the extinction, suggesting that this extinction was highly important in paving the way for the origins of modern biodiversity. This result does not seem to be due to the aforementioned geographical biases, and instead appears to be almost entirely due to an explosive radiation of mammals subsequent to the extinction event. This led to an almost total restructuring of pre-extinction terrestrial ecosystems, and ultimately led to what is commonly referred to as 'the rise of the mammals'. Sorry dinosaurs!

However, Benson and colleagues to advise caution in interpreting this as a genuine evolutionary phenomenon. This is because mammalian species are much more easily identifiable based on the remains of teeth, and therefore part of this apparent increase in diversity after the extinction event might simply be due to changes in how vertebrate discovery and taxonomy works.

Overall, the results obtained in the study show that tetrapod diversity throughout the Mesozoic less than doubled when sampling issues are accounted for. This in turn implies a very low, near-zero rate of diversification through time. Such a discovery is highly at odds with previous analyses which either accounted for sampling issues in different ways or ignored them entirely, which suggested that tetrapod diversity actually was unconstrained and rapidly increased on land throughout the Mesozoic.

The reasons for why this pattern exists though are more complicated. It is difficult to tell whether it is due to the achievement of a diversity equilibrium, where extinction rates and rates of diversification balance each other out, a phenomenon often referred to as 'diversity dependence', or perhaps simply due to overall stability in environments throughout the Mesozoic. The result of both of these hypotheses would be static diversity through time. Alternatively, it could be something a little more exciting, where we have a scenario in which diversifications are largely unconstrained, but regulated by more frequent episodes of extinction or dramatic reductions in diversification rates. So, in short, it's a bit of a mess and quite difficult to tell.

This is already a rather long post, and could go on forever about the cool results obtained in the Benson et al. study. So, I'll end with a couple of key points:

- The fossil record is our gateway to understanding the patterns and processes regulating past diversity, and remains key to understanding the origins and future of modern biodiversity;
- Mesozoic tetrapod faunas appear to have been relatively stable when regional sampling biases are accounted for, and document very low diversification rates;
- Palaeontology has never been more relevant in helping us to understand the evolution of life, and we're making huge leaps forward in terms of data and methods to realise this.

Reference

Benson, R. B., Butler, R. J., Alroy, J., Mannion, P. D., Carrano, M. T., & Lloyd, G. T. (2016). Near-stasis in the long-term diversification of Mesozoic tetrapods. *PLoS biology*, *14*(1). https://doi.org/10.1371/journal.pbio.1002359.

The evolution of tyrannosaurs

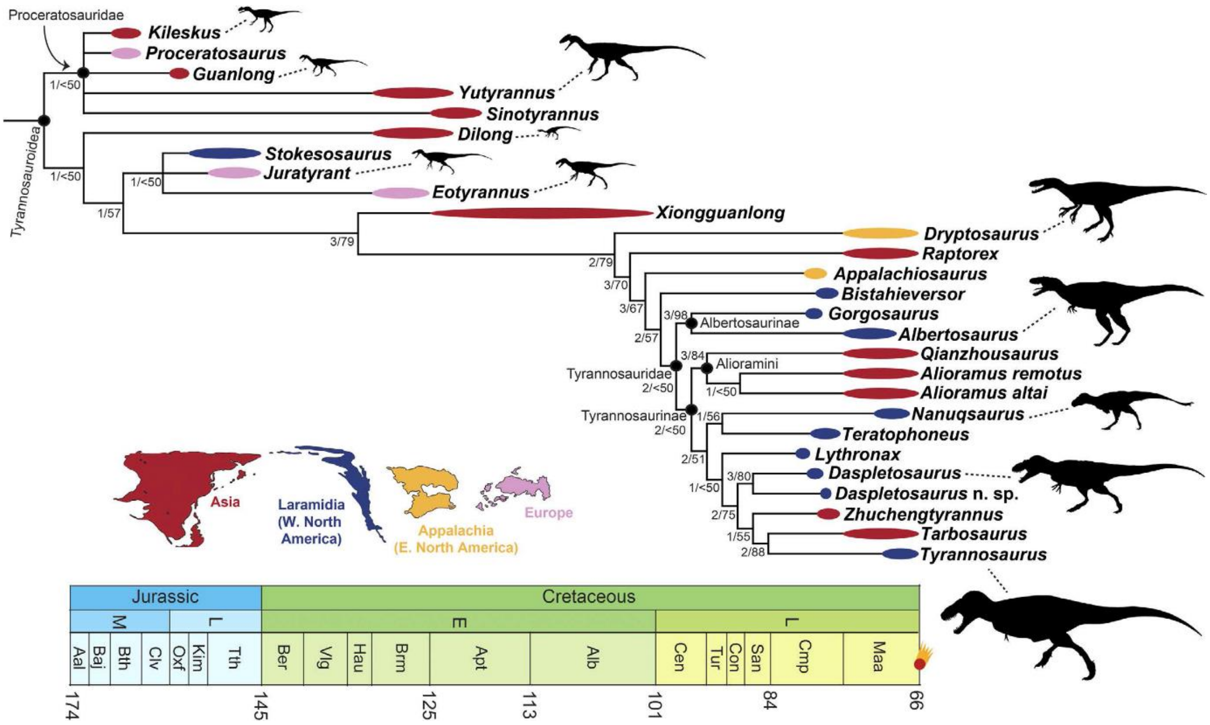
T. rex is probably the most notorious and infamous dinosaur of all time, and somewhat of an icon in both the scientific and public spheres. After all, it was a pretty fearsome and impressive carnivore, and arguably worthy of such admiration. But there were actually a lot of other dinosaurs similar to *T. rex*, together forming a group known as tyrannosauroids.

Recently, a whole series of new findings is helping us to unlock the secrets of these fascinating beasts, and we can now begin to answer questions about their evolutionary relationships, biogeography, and how decent their fossil record is. In fact, half of all known tyrannosauroid species have been discovered in the last decade alone!

Tyrannosauroid species were actually around way before *T. rex*, which only occupied the top of the food chain right at the end of the Cretaceous reign of the non-avian dinosaurs. Actually, the largest tyrannosauroids only seemed to appear around 20 million years before this. Before they achieved such terrifyingly gigantic sizes, most were actually quite small-bodied (for a dinosaur), and quite ecologically diverse.

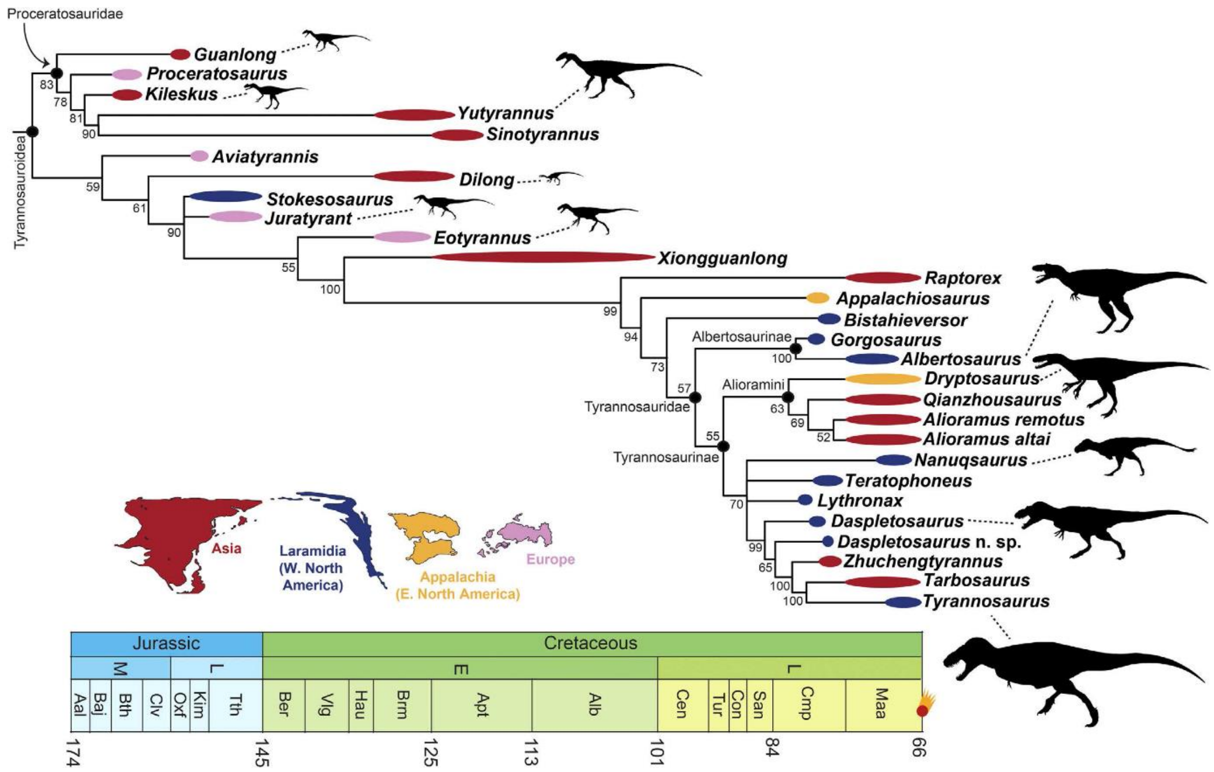
Steve Brusatte, Thomas Carr and their colleagues visited the question of the inter-relationships of tyrannosauroids back in 2010. Forming hypotheses of relationships like this forms the basis for assessing important evolutionary factors, such as the origins and evolution of particular anatomical features, rates of evolution, diversity, anatomical disparity, and biogeography. So when another study produced alternative results to their earlier study, Brusatte and Carr decided to go back to the Mesozoic and reanalyse tyrannosauroids, but incorporating all of the recent bits of knowledge we have gained about them over the last few years.

In addition to this, Brusatte and Carr decided to approach this with a dual method. Typically, when palaeontologists create trees that form the basis of assessing evolutionary relationships, we use a method called parsimony. This looks at how many different anatomical changes have occurred between different species, and tries to provide the minimum number of changes in order to build a tree. They also decided to go Bayesian on their dataset though, something which hasn't really taken off in palaeontology yet, and has been more widely applied to molecular analyses. This works slightly differently by analysing anatomical data (in the form of a character matrix) in a probabilistic framework, and by using more complicated models that treat characters in different ways. By using this combination of techniques, it is possible to see which results are congruent, and therefore which conclusions can be best supported.



Results obtained using parsimony methods (Brusatte and Carr, 2016).

Fortunately for Brusatte and Carr, the results of both analyses were quite similar overall, lending support to their conclusions. There are slight differences, which you can see by comparing the two trees figured here. The overall structure reveals that tyrannosauroids can be sub-divided into a basal clade of proceratosauroids, which includes taxa such as the feathered *Yutyrannus* and *Guanlong*; an intermediate grouping or grade of small- to medium-sized beasties; and the gigantic apex predators such as *T. rex* and *Tarbosaurus* that we all know thanks to the best scientific minds in Hollywood.



Results obtained using Bayesian methods (Brusatte and Carr, 2016).

The authors do a great job of trying to work out why their results differ slightly, but as always, the devil is in the details and it can be quite difficult to figure out. Part of the reason for some of the discrepancies might be to do with missing data – we can never fully sample every organism that has lived, and palaeontologists accept that limit of the fossil record. In the case of tyrannosauroids, there is a 20-million-year gap in their fossil record from just before the time when the Western Interior Seaway covered much of North America. What this means is that animals simply weren't preserved in the right time in the right place to be preserved as fossils. Yet, at least. Discovering new tyrannosauroids from this gap might be critical in working out how more derived tyrannosauroids evolved during a clearly important time in their history.

But what does all of this mean then for the evolution of tyrannosauroids? Well, for starters, it shows that the evolution of their large body size appeared to happen more gradually, rather than a rapid burst. Accompanying this, it shows that bite forces increased incrementally too, and that their elaborate facial ornamentations gradually became more complicated along with increasing body size. The first truly gigantic tyrannosauroids, coming in at more than 1.5

tonnes in mass and 10 metres in body length, didn’t appear in the fossil record until around 80 million years ago.

In terms of their biogeography, some interesting patterns emerge. It seems like there was episodic interchange between Asia and North America during the Late Cretaceous. What this means, and I’m sure Donald Trump will love this, is that *T. rex* actually appears to have been an Asian immigrant that colonised North America. However, this understanding might change as we recover ever more tyrannosauroid fossils from the latest Cretaceous of Asia and North America.

So, that’s a quick update on what we know about tyrannosauroids. Despite them clearly winning a cross-dinosaur popularity contest, there is still much we can learn about these creatures, and only time and future exploration can tell what we’ll discover!

Reference

Brusatte, S., Carr, T. The phylogeny and evolutionary history of tyrannosauroid dinosaurs. Sci Rep 6, 20252 (2016). https://doi.org/10.1038/srep20252.

The ecology of mass extinctions

Mass extinctions are profound events in the history of life that dramatically affect global ecosystems. Our understanding of these events is based on the fossil record, and can help us to understand the ecological impacts of extinction, as well as what caused them. Gaining insight into mass extinctions in the past is becoming increasingly important as we are now well into the sixth mass extinction, thanks to the global damage that humans are causing.

Not all mass extinctions were the same. Of the five known from the fossil record, the number of species that went extinct, and the subsequent impact this had on different ecosystems, varied massively. This is because different modes of extinction have different disruptive effects on the organisation, and subsequent reorganisation, of ecosystems. For example, the Late Ordovician crisis around 450 million years ago documents one of the most severe losses of life overall, but with limited ecological consequences based on the distribution of those extinctions. On the other hand, we have the end-Cretaceous mass extinction, which was comparatively less severe based on the number of species lost, but led to a global reorganisation of animal groups as some major ones (like dinosaurs) went extinct, while others took advantage of this and diversified (like mammals).

(Source).

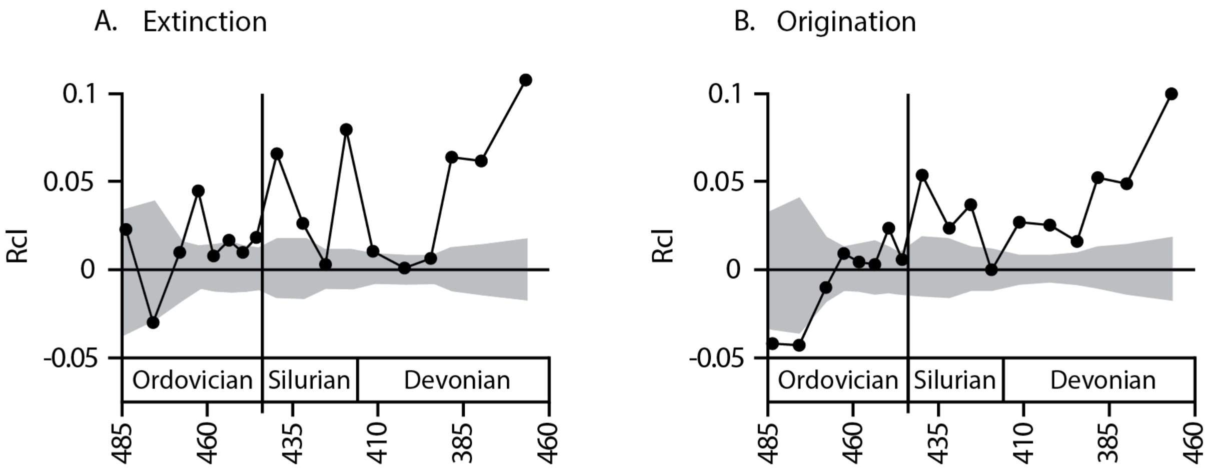
A new study by Andrew Krug and Mark Patzkowsky from Penn State University, and published in the open access journal PLOS ONE, sheds some light on this variety by investigating how the relatedness of species affects their disposition to extinction. This is significant for investigations of modern extinction, as we might expect external factors, such as climate change, to impact more similarly upon more closely related species. Evolutionary relatedness can be measured fairly simply as the amount of evolution that has happened between two species since they diverged, based on the lengths of their branches in an evolutionary tree.

The reason why this is important, is because if an extinction is shown to be phylogenetically selective, or clustered in similar species, then this can explain why a greater portion of evolutionary history or relatedness disappears. This then provides a mechanism for why we sometimes see disconnect between the magnitude of an extinction and the ecological severity of it.

Krug and Patzkowsky decided to look at brachiopods, small shelly invertebrates, from a period spanning the Middle Ordovician to the end of the Devonian, an interval which includes the Late Ordovician mass extinction. What they found was pretty unusual, and pretty cool from an evolutionary perspective.

(Source).

In the Ordovician, both speciation and extinction rates of families of brachiopods are almost entirely random, meaning that there is little evolutionary or phylogenetic selectivity. However, in the Silurian and Devonian, these shift to being strongly clustered, implying that extinction was highly selected for based on phylogenetic similarity. This shift appears to be associated with the timing of the beginning of the recovery period following the Late Ordovician mass extinction. During the mass extinction itself, brachiopod extinction was only weakly clustered, suggesting that there was little selectivity acting during this event.



Taxonomic clustering of A. extinction and B. origination for brachiopod genera within families for the Ordovician through the Devonian. Grey region represents 95% confidence intervals. (Krug and Patzkowsky 2015).

This means that, in this case, it's the recovery from the Late Ordovician extinction which is responsible for major shifts in the diversification of brachiopods, rather than the extinction interval itself. The cause for such a shift remains a bit of a mystery at the present. It could be due to the geography of surviving species, which resulted in rapid diversification in new environments, or perhaps some aspect of their ecology such as body size.

These new results stand in stark contrast to other patterns in Cretaceous-Cenozoic bivalves, which show almost the exact opposite patterns. During the end-Cretaceous mass extinction, extinctions were extremely strongly clustered, far beyond the rest of the Cretaceous.

What this helps to show is that there is a complex relationship between the nature of extinction and the evolutionary relatedness of organisms, and it certainly isn't consistent through time or between different groups. In the cases mentioned here, this lends support to the hypothesis that there is a link between higher relatedness between organisms and their sensitivity to extinction, and the ecological severity of mass extinctions.

In addition to this, species which are more closely related evolutionarily tend to also be more closely ecologically – think about wild cats as an example for this. This means that a phylogenetically sensitive extinction event will impact upon more ecologically similar organisms, based purely on the fact that they will have a similar life history. The result of this is a longer-term ecological impact of extinctions, irrespective of the relative proportion of species to become extinct.

This new study should set the groundwork for further investigations into the causes and structure of major extinction events.

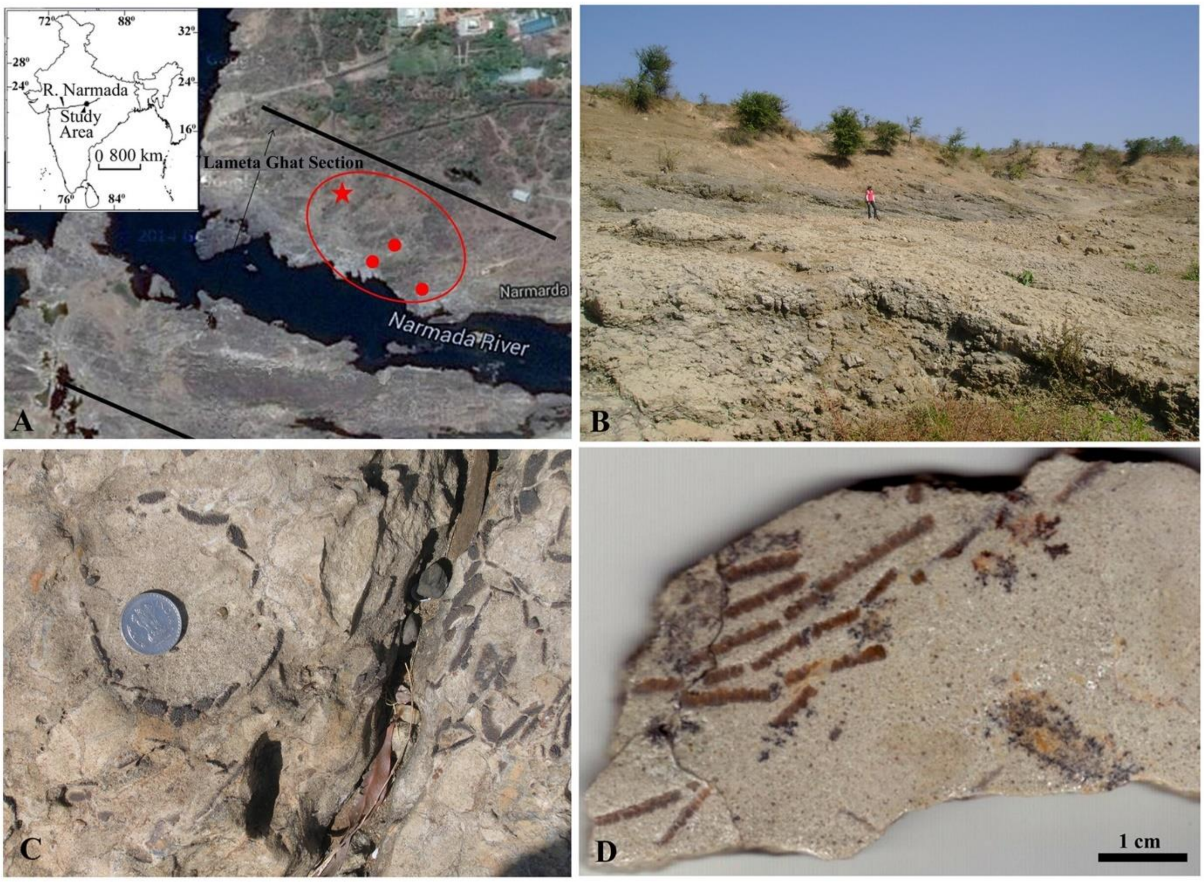
Reference

Krug, A. Z., & Patzkowsky, M. E. (2015). Phylogenetic clustering of origination and extinction across the Late Ordovician mass extinction. PloS one, 10(12). https://doi.org/10.1371/journal.pone.0144354.

Sneaky crocodiles occupied sauropod hatcheries

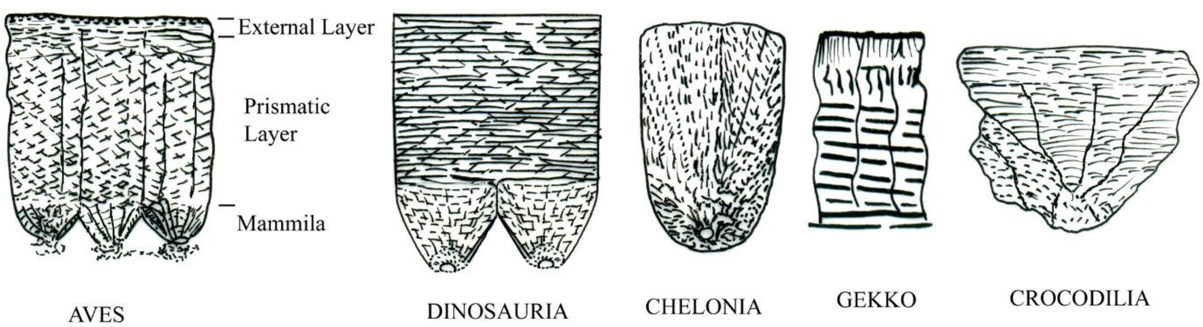
The nesting grounds of sauropod dinosaurs where absolutely astonishing, covering hundreds of square miles in cases, forming vast playgrounds to rear their young. Some of the most exquisitely preserved sauropod hatcheries are from Jabalpur in India, and offer a unique window into investigating the reproductive and parental behaviour of these magnificent giants.

Recently, researchers have revisited old discoveries, and uncovered a mysterious stranger among the sauropod nesting sites from the Cretaceous Lameta Ghat locality.



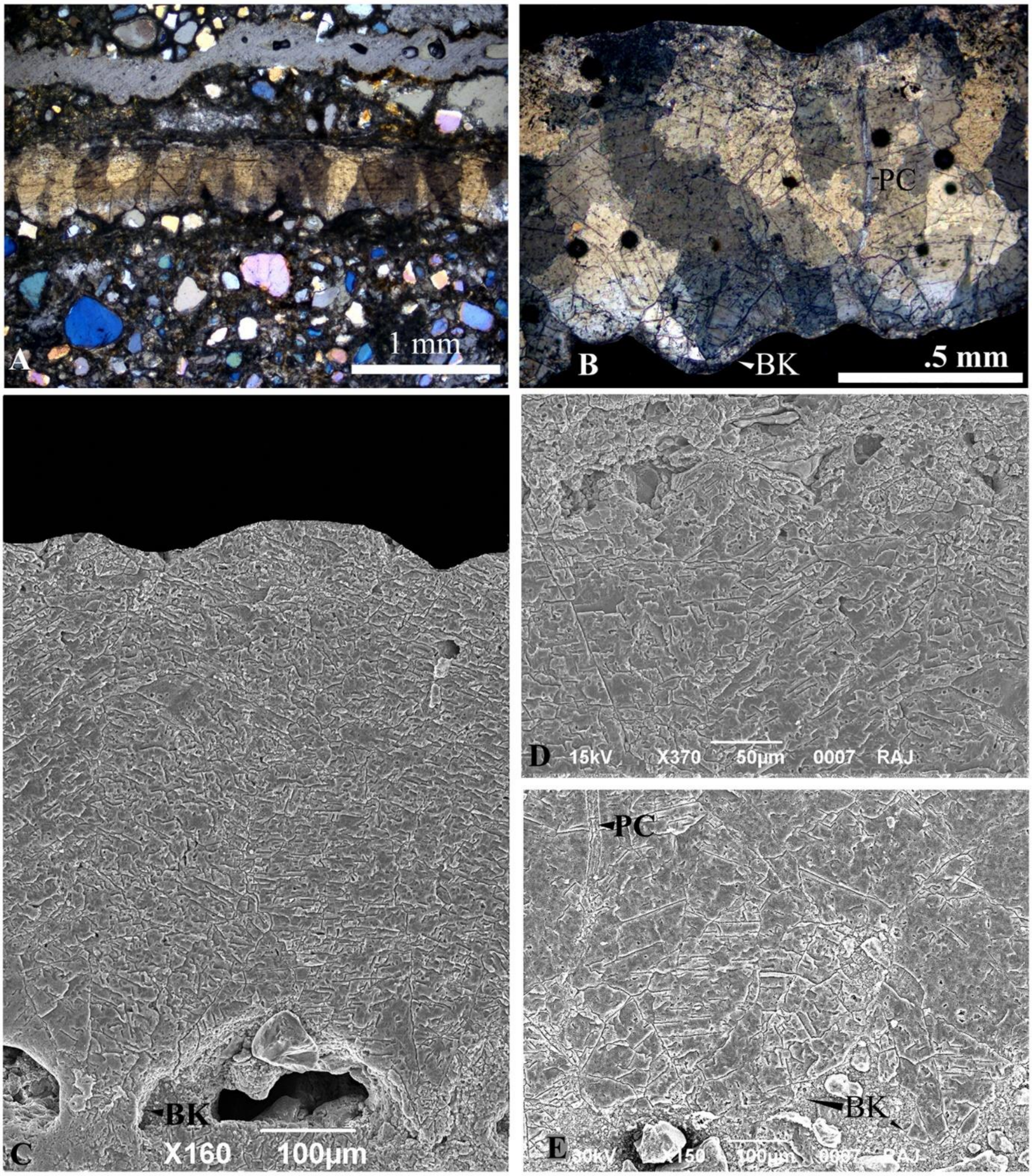
The nesting site and some of the fossilised eggs. (Srivastava *et al*. 2015).

At a superficial level, the eggs of reptiles might all appear to be quite similar to each other. However, we can actually gain a lot of insight from detailed examination of their chemistry and ultrastructure, and scientists now know that different groups of reptiles have very different egg types.



Different types of reptilian eggs in cross section. (Srivastava *et al*. 2015).

In 2013, fossilised eggs were reported from the Lameta Ghat nesting site. The eggshells were originally thought to belong to a large fossilised lizard. However, reanalysis of them shows that they more likely come from a crocodylomorph – the ancestors of modern crocodilians. This is based on several delicate details of the eggshell, including a sub-spherical to ellipsoid shape, a smooth and uneven external surface texture, and distinctly shaped shell units typically found in crocodilian eggs.



Thin sections of the crocodylomorph eggs, including under-crossed polars to give some funky colours! (Srivastava *et al*. 2015).

The eggshells might have belonged to dyrosaurid crocodyliforms. These are typically regarded as having lived out to sea, but like modern saltwater crocodiles, might have been able to come out onto land for short spells. Dyrosaurids were quite common in South-East Asia towards the closing of the Cretaceous, and even survived the mass extinction that saw the demise of the non-avian dinosaurs. The nesting site is fossilised in rocks that represent an ancient estuarine environment, not too far from the shoreline, so perhaps young dyrosaurids were born on land, taking to the waters only at a later age when they had levelled up their swimming abilities.

Fossilised crocodile nests are remarkably rare in the fossil record, with only around 20 known to date. What this new finding tells us is that sauropod hatchery sites were also used by other large reptiles, including crocodylomorphs, for laying their eggs. How cool is that!

Reference

Srivastava R, Patnaik R, Shukla UK, Sahni A (2016) Correction: Crocodilian Nest in a Late Cretaceous Sauropod Hatchery from the Type Lameta Ghat Locality, Jabalpur, India. PLOS ONE 11(1): e0146736. https://doi.org/10.1371/journal.pone.0146736.

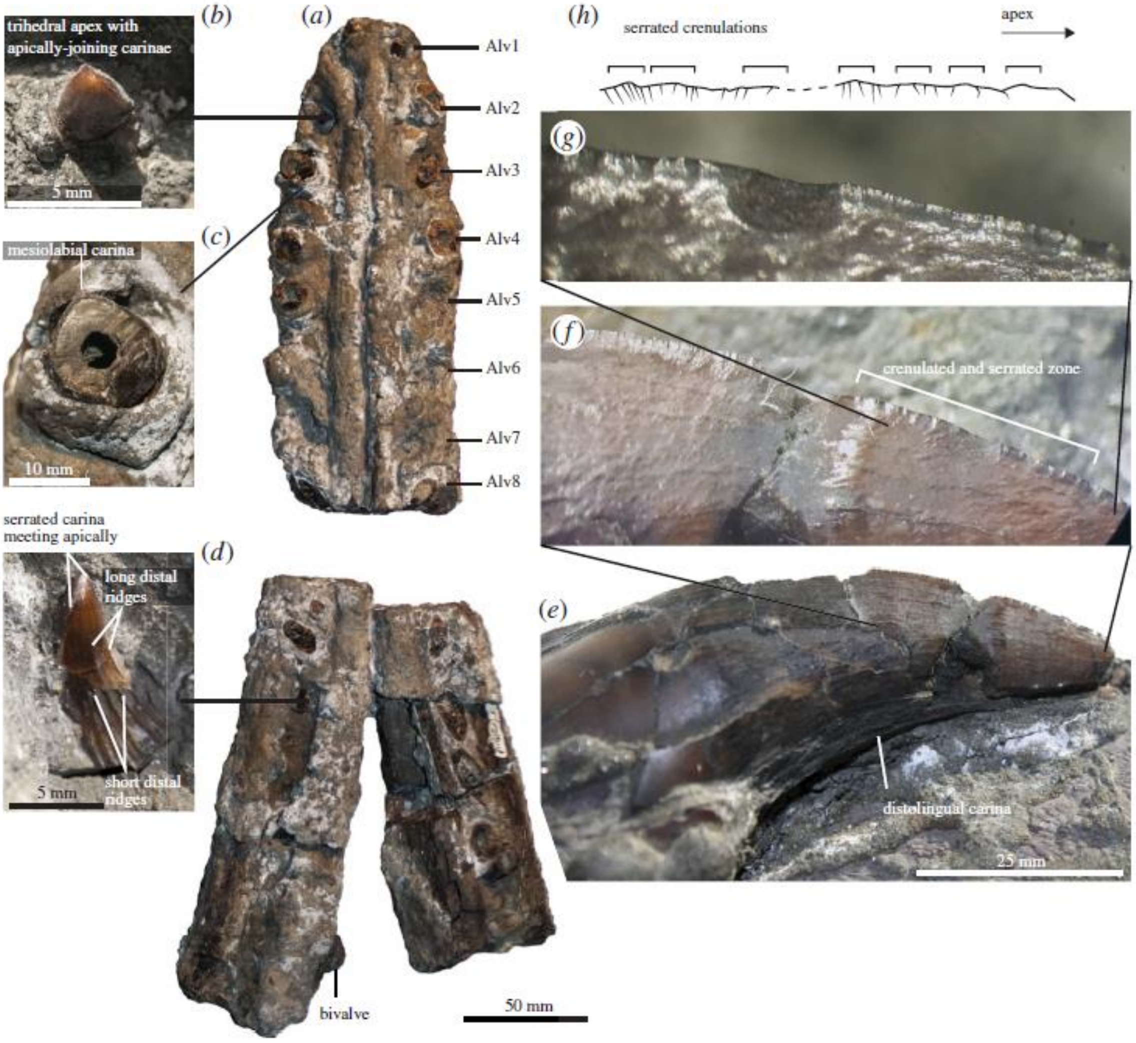
Newly discovered pliosaur terrorised ancient Russian seas

The Mesozoic played host to some of the most dangerous predators to ever swim the Earth's oceans. Among these, pliosaurs were lethal hunters, and some of the largest predators ever on this planet. They were the shorter-necked cousins of the plesiosaurs, which are often spoken of in reference to their superficial similarity to the Loch Ness Monster, which we're definitely not going to do here. Together, pliosaurs and plesiosaurs form a group known as Sauropterygia, which existed in the oceans from the Triassic right until the end of the Cretaceous, when they went extinct along with the non-avian dinosaurs and other vertebrate groups. This actually makes sauropterygians the longest living group of marine-adapted tetrapods (animals with four limbs), which is quite an impressive feat!

New discoveries show that perhaps this evolutionary success can be attributed to the ecological diversity that this group possessed, and in particular an ability to adapt to different feeding styles.

Valentin Fischer from the University of Oxford and an international team of researchers have discovered a new pliosaur from western Russia, named *Makhaira rossica*. The name derives from the Latinized Ancient Greek word ‘mákhaira’, which describes a blade with a curved outline, as well as the Latin word ‘rossica’, which means Russian. The specimen comprises a fragmentary skeleton of a sub-adult animal, found within a series of limestone nodules along the banks of the Volga River.

Makhaira comes from a period in Earth’s geological history, known as the earliest part of the Cretaceous, where our knowledge of vertebrate life is relatively poor due to the way in which fossils are differentially preserved through time. Sadly, this lack of knowledge means that our understanding of how faunas changed from the latest part of the Jurassic period into the first part of the Cretaceous is relatively poor compared to other important geological boundaries.

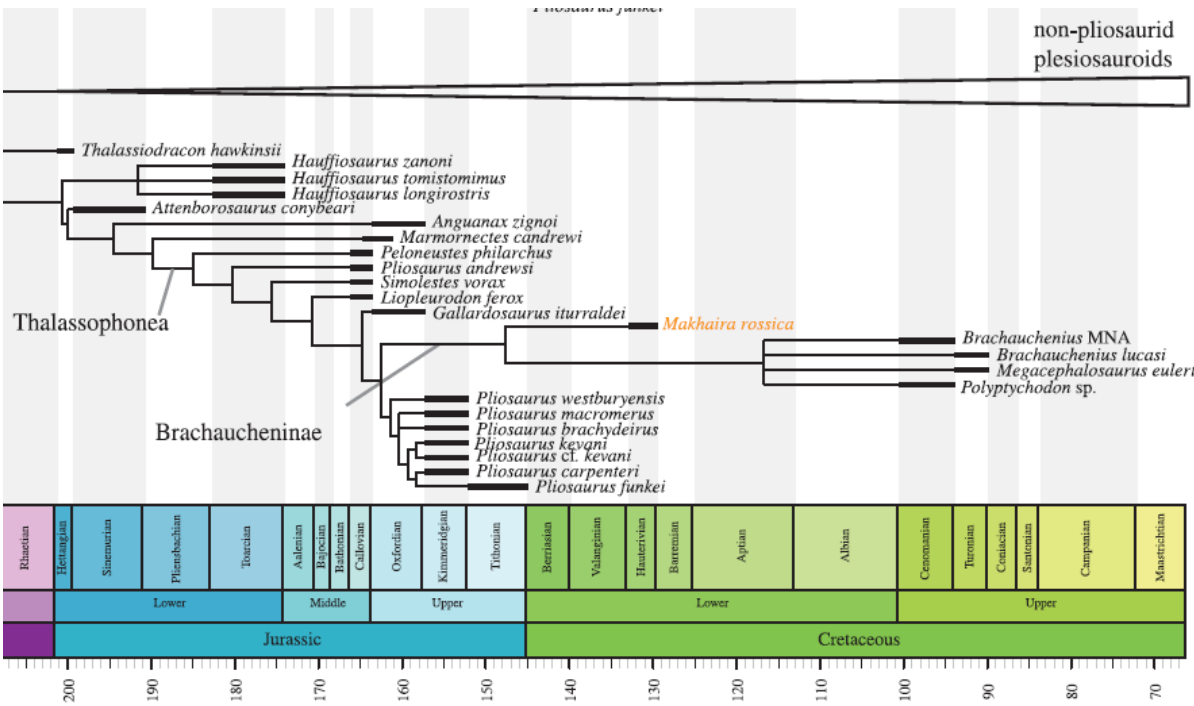


Fossils of the new pliosaur, *Makhaira*. (Fischer *et al*. 2015).

Analysis of the evolutionary placement of this new species places it as the most basal member of a group known as Brachaucheninae, which survived through the Cretaceous. However, the new species is different in being a little smaller than some of its more advanced relatives.

The weirdest feature of the new beasty has to be the teeth. The teeth occur in pairs, and have a trihedral form, meaning they had three peaks on each alveolus, and the edges of the teeth were adorned with wicked serrations. They were also very large, similar even to some teeth from theropod dinosaurs roaming the lands at the time!

The morphology of these teeth suggest that they were equipped just for one thing – devouring other large animals! This form of feeding is known as macrophagy, and was a common form of predation at the time for giant marine crocodyliforms (the ancestors of modern crocodiles) called metriorhynchids. Importantly, this feeding style previously seemed to have been lost in the early evolution of other brachauchenine pliosaurs, but now appears to have been present in at least one species from this group. This shows that Early Cretaceous pliosaurs were still well adapted to hypercarnivory, and retained a high feeding diversity at the beginning of the Cretaceous, and not lost from their Jurassic ancestors.



Evolutionary relationships of *Makhaira* with other Jurassic and Cretaceous pliosaurs. (Fischer *et al*. 2015).

Recently, Alessandro Chiarenza, a colleague of mine at Imperial College London, reported on what appeared to be the youngest metriorhynchid remains currently known, from a fossil site in Sicily. Based on a single fossilised tooth from a period known as the Aptian, later on in the Cretaceous than when *Makhaira* was found, these remains extended the duration of metriorhynchids, and their eventual extinction, by several millions of years. However, the morphology of the teeth of *Makhaira* wasn't known at the time of publishing the crocodyliform fossils, and it seems that it is actually impossible to distinguish between these and the teeth of some metriorhynchids. This means that the Sicilian tooth cannot be referred unequivocally to either a metriorhynchid or a pliosaur – the teeth of some species is just too similar to say for certain! What does this imply though? Well, it seems that the fate of metriorhynchids is still a mystery concealed by the fossil record, and is only something that future study of these fossils, their other monstrous counterparts, and discovery of new fossils can hope to solve!

Reference

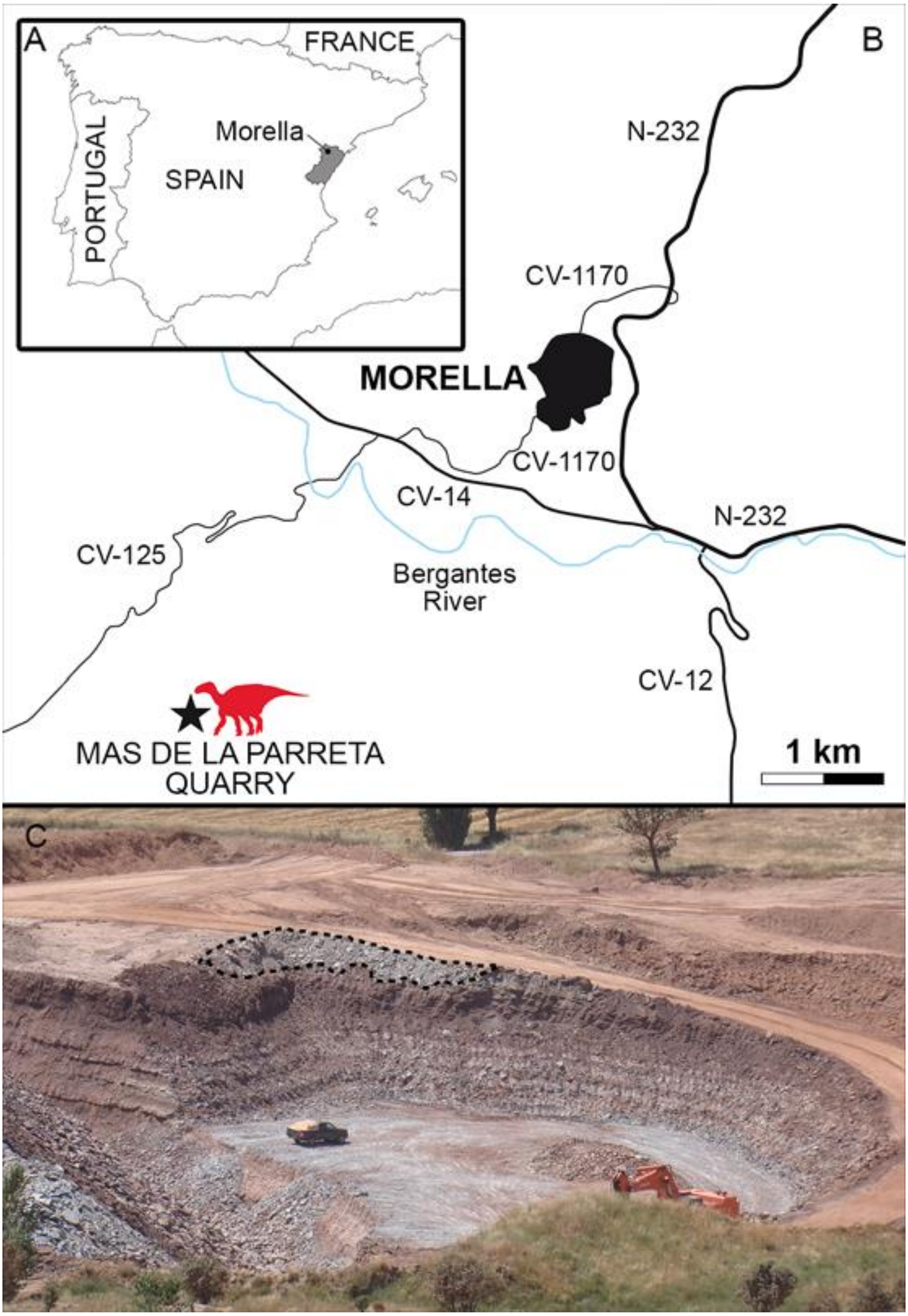
Fischer, V., Arkhangelsky, M. S., Stenshin, I. M., Uspensky, G. N., Zverkov, N. G., & Benson, R. B. (2015). Peculiar macrophagous adaptations in a new Cretaceous pliosaurid. Royal Society Open Science, 2(12), 150552. https://doi.org/10.1098/rsos.150552.

Thumbs up to new sail-backed dinosaur!

Many of you probably know *Iguanodon* as being classically depicted as 'The Fonz' of the Cretaceous, always posing with its thumb sticking up*. But since its original description in 1825 by the infamous geologist, Gideon Mantell, the name of *Iguanodon* has become sort of a taxonomic plaything, being sliced and diced and knocked around in almost every way possible.

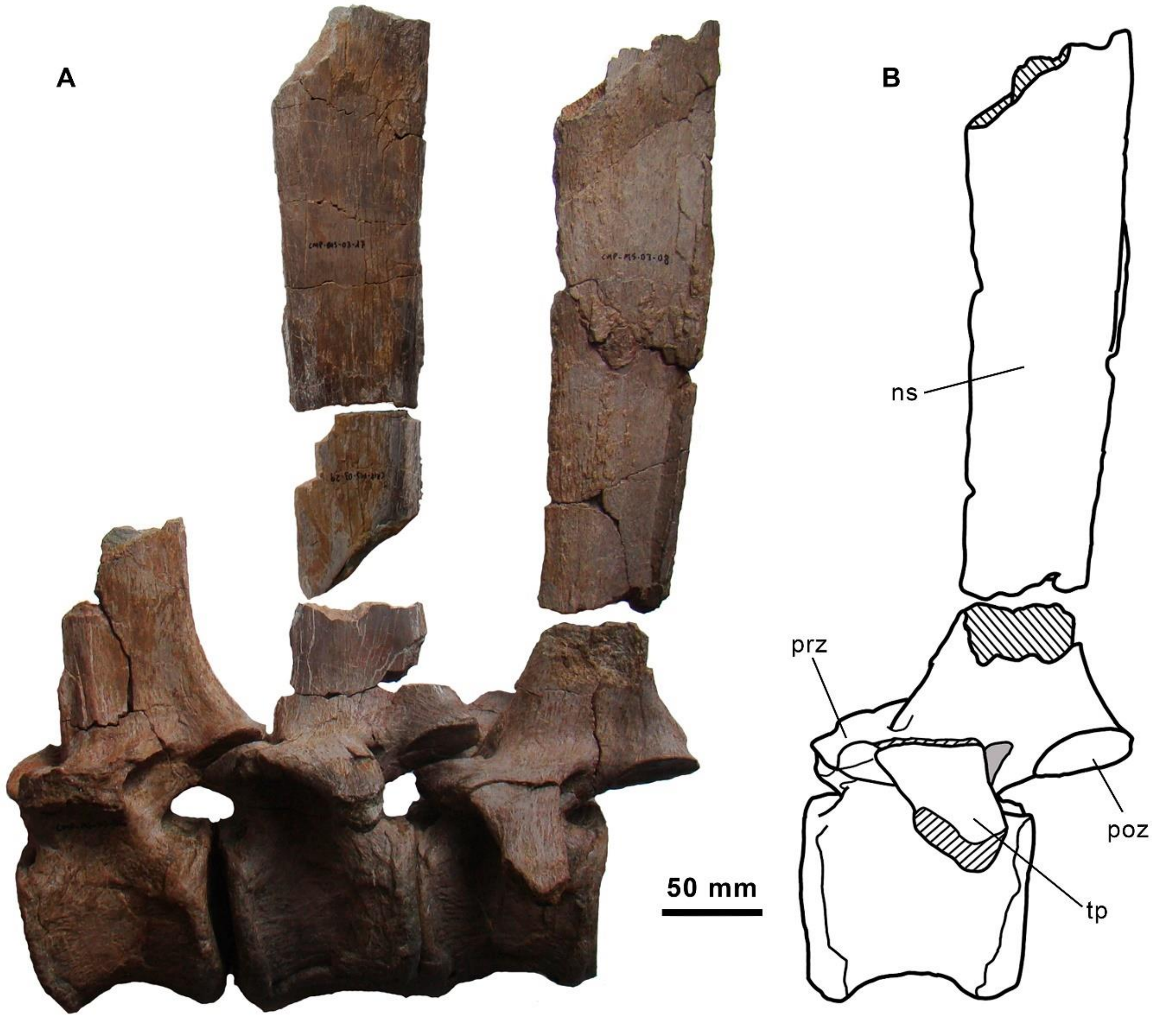
Hundreds of specimens were originally assigned to *Iguanodon*, and now scientists recognise that these represent numerous different species, each occupying a distinct time frame and geographical location. Some researchers even refer to them as the 'cows of the Cretaceous' as they're commonly depicted as lumbering grazers, with nothing better to do than be prey for other dinosaurs...

Despite the impressive history of these dinosaurs, the fossil record still has the ability to surprise us with new discoveries. A new specimen from Castellón, Spain, from rocks dated to around 125 million years ago has been identified as a close cousin of *Iguanodon*, and named *Morelladon beltrani* in honour of Víctor Beltrán for his assistance at the dig sites. This dinosaur would have grazed the ancient forests of Europe, and came in at around 6 metres long and 2.5 metres tall (picture a super-sized cow...)



Map and photo of the site were *Morelladon* was excavated.

When it comes to dinosaur fashion, iguanodonts and their ornithopod relatives don't exactly come across as trend-setters when compared to the gigantic sauropods and eagle-eyed theropod predators of the time. But relatively speaking, *Morelladon* was a bit of a flashy dresser! The vertebrae of the fossil possess tall dorsal spines, the bony projections coming off the top of the vertebrae that muscles attached to for spinal support. This would have given *Morelladon* a pretty cool sail, similar to other dinosaurs such as *Spinosaurus*, although not quite as big. What is interesting is that it shows that sails evolved multiple times in different dinosaur lineages, so must have conferred some sort of important advantage on them.



Spines of *Morelladon*. (Gasulla *et al*. 2018).

Why some dinosaurs developed these weird sails still remains a bit of a mystery for palaeontologists, at least until we get a time machine and go back to see how dinosaurs actually used them. It could perhaps have been used for identification purposes, or perhaps signalling, or maybe even similar to camels as a storage place for fat during periods of migration or food shortages.

Beautiful reconstruction of *Morelladon*, by Carlos de Miguel Chaves.

The discovery of *Morelladon* continues to add evidence to the Early Cretaceous of Europe playing host to a highly diverse array of iguanodontians dinosaurs, often with multiple different species co-existing. Co-author Dr. Escaso said, “We knew the dinosaur fauna from Morella was similar to those of other contemporary European sites. However, this discovery shows an interesting rise of the iguanodontoid diversity in southern Europe around 125 million years ago.”

An analysis of the evolutionary relationships of *Morelladon* shows that it is most closely related to *Iguanodon* and *Mantelliaurus* species also from the same location in Spain. This suggests that in the Early Cretaceous of Europe, which would have been an island archipelago at the time, we had endemic pockets of dinosaurs living and evolving alongside one another.

One thing is for sure though, and that's that even well-studied localities such as the Iberian Peninsula still have many fossil surprises in store for us, each one contributing to our knowledge and understanding of dinosaur evolution.

* Someone totally needs to name an iguanodont species after The Fonz now

Reference

Gasulla JM, Escaso F, Narváez I, Ortega F, Sanz JL (2015) A New Sail-Backed Styracosternan (Dinosauria: Ornithopoda) from the Early Cretaceous of Morella, Spain. PLoS ONE 10(12): e0144167. https://doi.org/10.1371/journal.pone.0144167.

'White whale' is a ghost of sperm whales' past

Whales are pretty majestic creatures, in spite of their enormous size. Among living whales, the sperm whale is the largest of the toothed whales, and the largest toothed predator on Earth. It comes from a group known as Physeteridae, which includes just two other species: the dwarfed sperm whale, and pygmy sperm whale of the genus *Kogia*.

While the larger species of sperm whale is considered to have a vulnerable conservation status, both the pygmy and dwarf sperm are data deficient, which means that any information we can glean on this group could be super important for helping to protect them. Physeterids are considered to the earliest branching group of the larger group of toothed whales, known as odontocetes. This also means that any fossils we can find of sperm whales can help us to understand the origins and early evolution of odontocetes.

Researchers have identified a new genus of ancient sperm whale based on re-examination of fossils known for over a century, and published in the open access journal PLOS ONE.

The fossils of the new whale date from an epoch known as the Miocene, around 14-16 million years ago. The remains, including a skull, jaws and teeth, were actually discovered in Santa

Barbara County, California, in the 1880s, but their true identity and importance remained locked away until now.

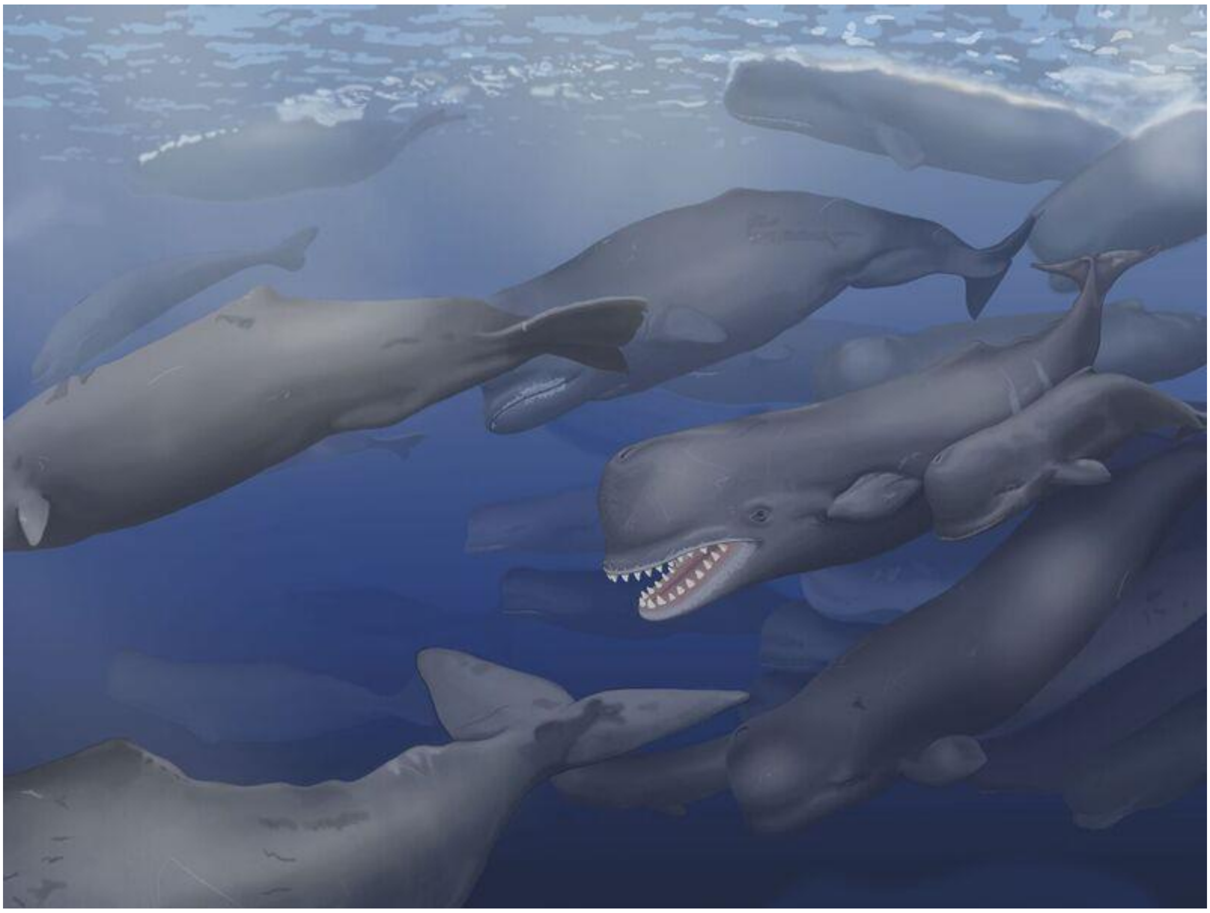
Lead author A. Boersma with the partial whale skull fossil. Image credit: Jame di Loreto, Smithsonian.

The bones are bleached white, reflected in the new genus name, *Albicetus*, which translates in Latin to 'white whale', in honour of Herman Melville's notorious leviathan, Moby Dick. "It only seemed appropriate to evoke Melville's white sperm whale, Moby Dick, especially since we studied *Albicetus oxymycterus* alongside the skeletons of some of its modern day relatives in the collections here at the Smithsonian", says Nick Pyenson, curator of marine mammals in the Department of Paleobiology at the Smithsonian, Washington DC, and co-author of the study. The jaws of *Albicetus* have been displaced through the ravages of times, providing the inspiration to connect the specimens to the famous literary monster, which was described as a creature of 'unwonted magnitude' with a 'deformed lower jaw'.

Alexandra Boersma, lead author of the study, and an undergraduate student at Vassar College in New York, noticed that the fossils were unlike any known whale species while surveying the collections at the Smithsonian. They were originally described by Remington Kellogg in 1925, and as part of the genus *Ontocetus*, which is actually an invalid taxonomic name now with the original fossils actually represent a walrus tusk!

Despite their impressive size, and weight of more than 100kg, Boersma managed to construct a cool 3D model of the fossil specimens, which can be found (and played with!) here. *Albicetus* would have reached a maximum size of around 6 metres in length, much smaller than modern sperm whales which can reach over 20 metres in length. Species of *Kogia* are much smaller, in case you couldn't tell from their names, coming in at only around 2.5-3.5 metres in maximum length. As the oldest member of Physeteridae, this implies that large body size in sperm whales evolved independently at least twice.

Larger whales usually tend to have larger teeth, which were probably for catching larger prey to sustain the increasing demands that come with being bigger bodied. *Albicetus* had very large teeth for its size, which indicates that it might preferentially have chowed down on other marine mammals like seals and smaller whales, differently from modern sperm whales which primarily dive deep to feed on squid, and actually don't really use their teeth. "This find means that, around 15 million years ago when there were a lot of large sperm whales with big teeth like *Albicetus*, it may have been a moment of peak richness in the number and diversity of marine mammals serving as prey to these whales," Boersma suggests.



A pod of *Albicetus* taking it easy out on the ocean. Image credit: A. Boersma.

The re-discovery of *Albicetus*, and new estimates of its size, have important ecological implications. During the middle of the Miocene epoch, this means that there were multiple, large and hypercarnivorous whales roaming the oceans, and often living alongside one another. Such communities simply do not exist in modern oceans, where hypercarnivory is relatively rare. This might have been due to the high diversity of marine mammals as prey items, but shows once again that we cannot use modern animals exclusively to reconstruct the history of different groups of animals – the fossil record is key!

The timing of this discovery couldn't be any better, coinciding with the release date of Ron Howard's new epic, 'In the Heart of the Sea', based on the story of Moby Dick and the sinking of the ship, *Essex*, by Nathaniel Philbrick in a novel of the same name. The film is set to hit screens in the US on December 11th.

Reference

Boersma, A. T., & Pyenson, N. D. (2015). *Albicetus oxymycterus*, a new generic name and redescription of a basal physeteroid (Mammalia, Cetacea) from the Miocene of California, and the evolution of body size in sperm whales. PloS one, 10(12). https://doi.org/10.1371/journal.pone.0135551.

New fossil croc on the block

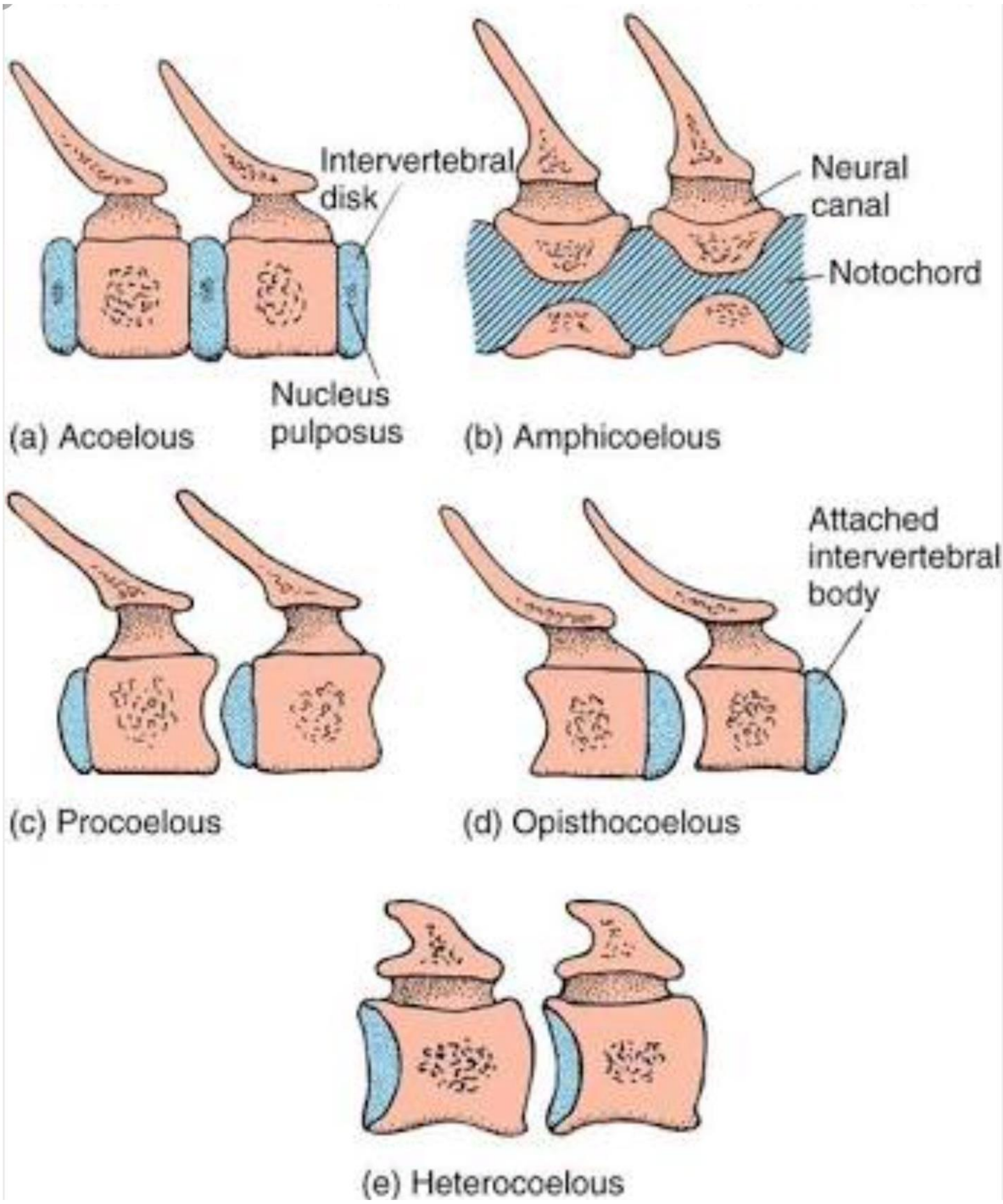
Crocodiles are freakin' amazing animals. They've been around for about 250 million years, and throughout this time have survived two mass extinctions, and at least twice decided to hitch up and take to the seas. Their historical diversity, and general weirdness, was vast compared to what we see in modern crocs, which are on the face of it all fairly similar. Extinct forms included those that looked like armadillos and even ate plants, as well as some that became gigantic and streamlined for swimming out to sea. Others were up to 12 metres long, and snacked on dinosaurs!

All modern crocs, alligators, caimans, and gharials belong to a group known as Crocodylia. The origins of this group can be traced back to the Cretaceous, when many of these bizarre croc-cousins, known collectively as crocodyliforms, where still around. Trying to work out the evolutionary origins of modern crocs though has proven to be a bit confusing for palaeontologists. Part of this is simply due to the fact that the fossil record preserves incomplete remnants of the lineage leading to modern crocs, which in turn creates issues in our understanding the relationships and anatomical changes that led to the origin of Crocodylia.

One thing we do know is that a group known as Eusuchia are the direct ancestors of modern crocs – Crocodylia belongs to Eusuchia, but not all eusuchians are crocodylians, if that makes sense. That's because some eusuchians went extinct during the Cretaceous, leaving just crocodylians (and a couple of other non-eusuchian groups like the now extinct marine dyrosaurids) around to take charge. One of the problems which croc workers have been trying to figure out is what defines Eusuchia, and therefore what croc species can be assigned to this group. If we know this, then we can look at the evolutionary changes that led to the origins of modern crocodilians, and why these chappies became so successful.

Eusuchians have been traditionally recognised based on a couple of really important modifications to the 'standard' crocodyliform skeleton that reflect major changes in their lifestyle. One of these involves the movement of the choanae, an opening in the top of the mouth that helped crocs to breathe more efficiently, from a position closer to the nostrils to a position further back in the skull. This was due to the development of what's called the secondary palate, the bony surface in the roof the mouth which grew as the overall skull lengthened in crocs to form the snout. Another important development of eusuchians was to do with the vertebrae. Until eusuchians, crocodyliforms (remember, the ancestors of modern crocs) had vertebrae in which the articular surfaces were either flat or concave, which limited mobility of the vertebral column. In Eusuchia, the articular surface facing towards the tail became progressively more hemispherical-shaped, or convex outwards, to what we call a 'procoelous condition', forming a sort of ball and socket articulation. This would have allowed greater flexibility of the vertebral column, which is a pretty useful adaptation to have.

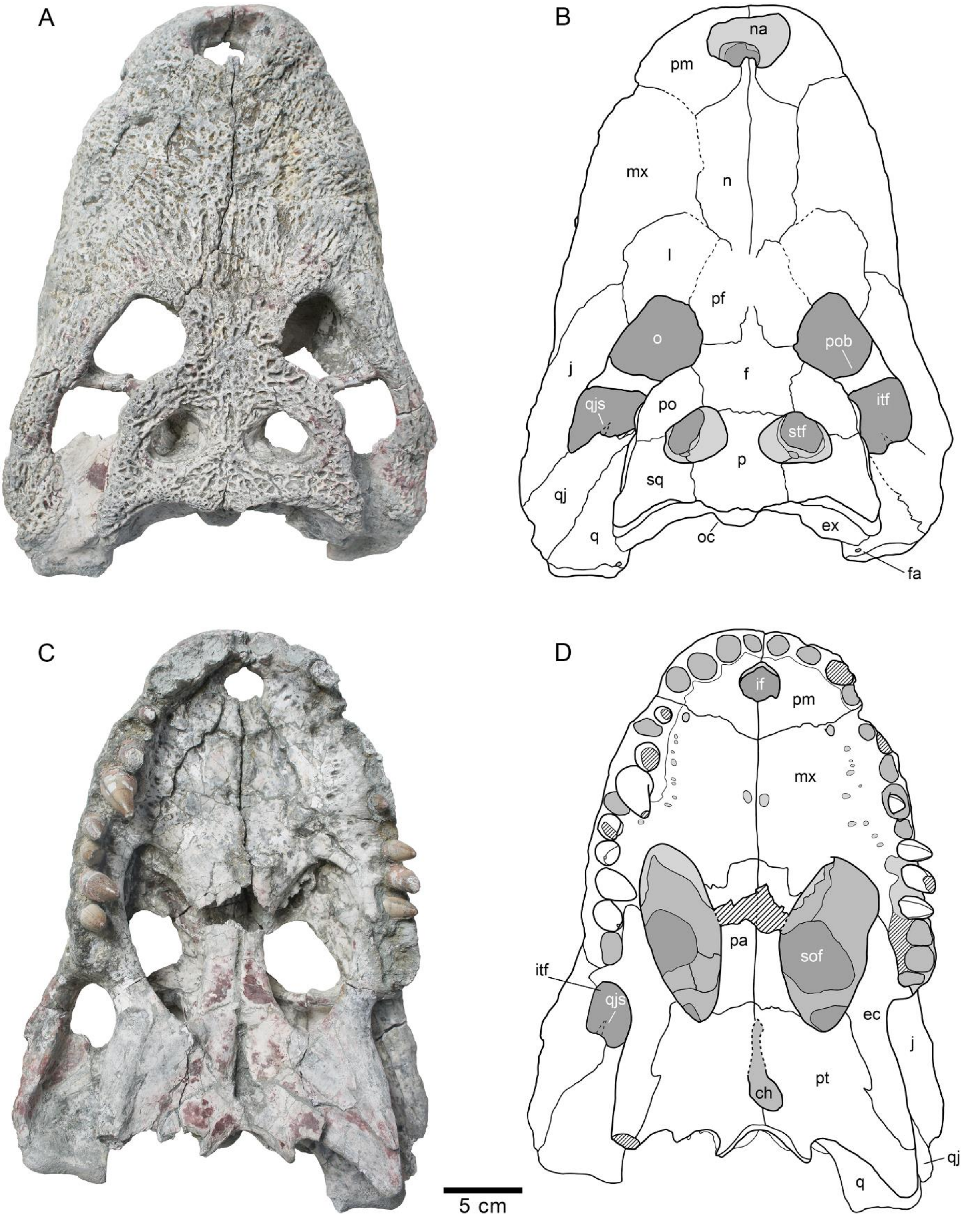
So why the confusion about what the origins of Eusuchia? Well, for starters, a lot of fossils that look like they could be a eusuchian are often preserved in a way that we can't tell what the choanae and vertebral columns looked like, or these bits are just missing. This leads to quite a lot of uncertainty about what constitutes a 'true' eusuchian, and has complicated both the species that can be assigned to Eusuchia, and the pattern of acquisition of these important anatomical features. Recently, a couple of papers by Alan Turner overhauled Eusuchia, and he suggested that other groups, including Paralligatoridae and Atoposauridae could both be included within Eusuchia too (see here and here – both open access). However, I don't think this is 100% correct, as few if any of the species from these groups can be conclusively shown to have the features that define Eusuchia as mentioned above, and it is possible that atoposaurids and paralligatorids lie outside of Eusuchia (disclosure: I have a paper in review discussing this a bit at the moment). So that's a nice additional layer of confusion to add in!



The different types of joint between vertebrae. (Source).

So that's a whole lot of background, and I think important to wrap our heads around for a couple of reasons. Firstly, it shows that trying to figure out the taxonomy and evolutionary relationships of extinct animals is complicated, and pretty dynamic as far as what constitutes science (evidence-based inference) goes. Secondly, it shows how complicated our current understanding of the origins of modern crocs is, and the reasons for this complexity. Thirdly, it highlights how important new fossil finds might be in helping to unravel some of this evolutionary mess, which provides us with a nice segue into…

New croc species klaxon! Well, actually, two new crocs! A new study in PLOS ONE has identified two new species of crocodyliform from the same genus, *Lohuecosuchus* (Low-hay-kwo-soo-kus). The first of these new crocs comes from near the village of Fuentes, Cuenco, in Spain, from a fossil locality known as Lo Hueco. The fossils here come from a time right towards the end of the Cretaceous, in time intervals known as the Campanian and Maastrichtian. This new species was called *Lohuecosuchus megadontos*, and it's probably pretty obvious where the genus name comes from. The species name means 'big tooth', and refers to the well, uniquely big teeth this new croc has! '*suchus*' is Latinized from the Greek word *souchos*, and refers to an Egyptian crocodile-headed god!

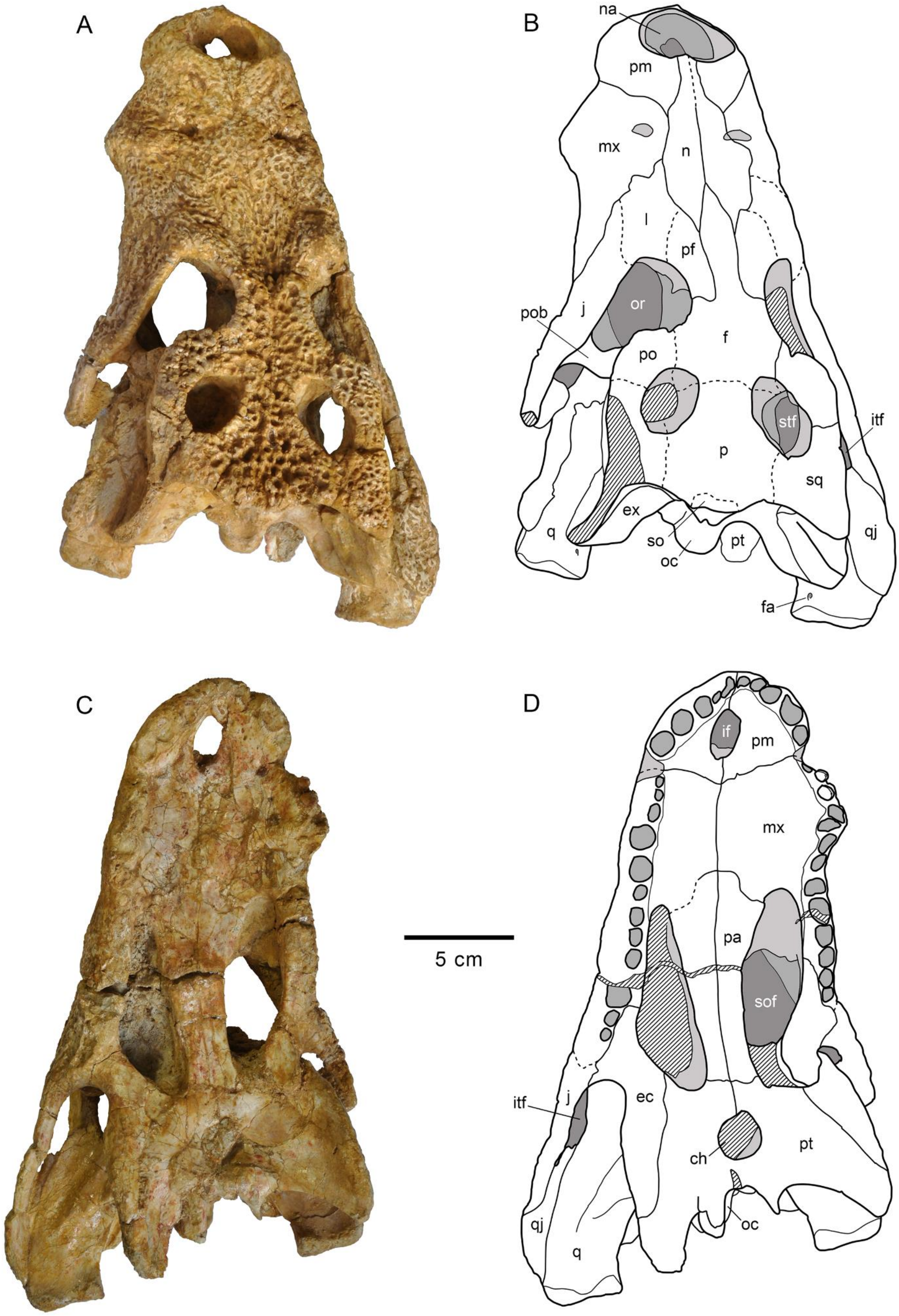


The holotype (specimen upon which a name is founded) of *Lohuecosuchus megadontus* in above (dorsal) and below (ventral) views.

As well as this new genus and species, they named a second new species referred to the new genus, *Lohuecosuchus mechinorum*, from the Fox-Amphoux site from Department of Var in

France, and based on extensive comparisons with previously known material referred to a different species. The species name '*mechinorum*' in this case is from the Mechin Collection (in honour of Patrick and Annie Mechin) at the Muséee des Dinosaures in Espéraza, France, which houses the specimens.

These new findings seem to provide a bit of insight into how Late Cretaceous crocs from Europe are related. They all fit within a newly resolved group known as Allodaposuchidae, named after *Allodaposuchus* as is common when naming these types of group. *Allodaposuchus* has been known for quite a while from multiple localities referred to several species from the Late Cretaceous of Europe. It's what we like to call in palaeontology a 'taxonomic nightmare'.



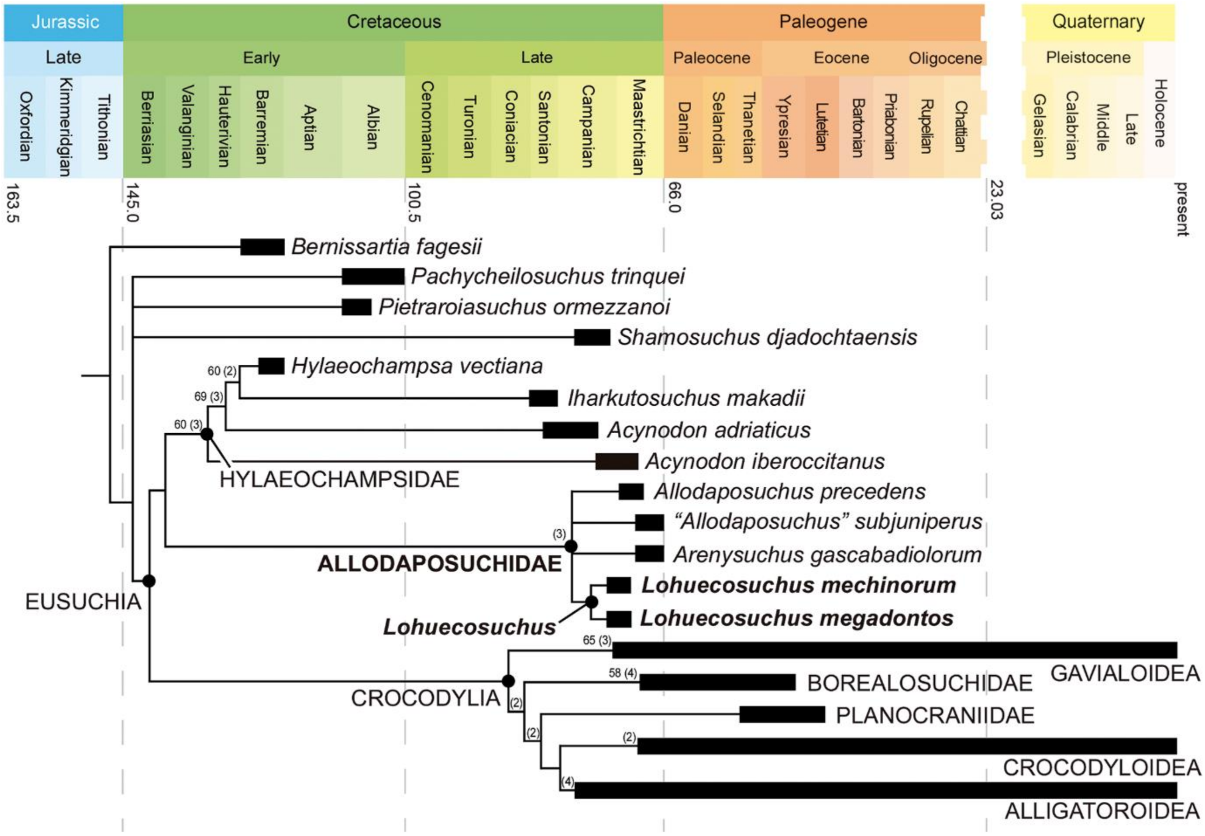
Holotype specimen of *Lohuecosuchus mechinorum*.

Allodaposuchidae seems to be related to another group of fairly unusual crocs known as Hylaeochampsidae, named after (you guessed it) *Hylaeochampsa*, another croc known from the Early Cretaceous of the Isle of White in Europe. Now Hylaeochampsidae is a bit of a taxonomic mess. Previously, species from the Cretaceous of North America (known as *Pachycheilosuchus*) and another from Italy called *Pietraroiasuchus* (I can't say it either..), where assigned to this group, along with others from Europe like *Acynodon* and *Iharkutosuchus*. But membership has always been in a bit of a state of flux, depending on which researchers you ask. This is important as historically, hylaeochampsids have been regarded as the earliest, or most basal, eusuchians. Solve Hylaeochampsidae, solve Eusuchia. Oh yeah, it's all coming together now.

Importantly, this new study finds both Allodaposuchidae and Hylaeochampsidae together to be the sister group to Crocodylia. In non-phylogenetics speak, this means that these groups are the closest relatives to the group that includes all modern crocodiles, alligators, and gharials, with the three of them together sharing a common ancestor (i.e., common origin). Hylaeochampsidae is found to comprise just *Hylaeochampsa*, *Acynodon*, and *Iharkutosuchus* – three exclusively European crocs. This is important, as it pretty much cements the idea that Crocodylia originated in Europe from an exclusively European stock of eusuchian crocs. Or so it would seem...

However, I wouldn't be a croc palaeontologist if I didn't raise a few potential issues. Or at least, things that spring to mind. The way in which palaeontologists analyse the relationships of organisms is though what we call phylogenetic analysis. These produce 'phylogenies', commonly depicted as trees, which illustrate the hierarchical relationships of organisms. These analyses are based on data matrices that comprise the morphology of organisms reduced to numerical codes that describe different aspects of their anatomy, and the different conditions these can take across all animals considered. What this means is that often when designed, these character matrices are created to test very explicit hypotheses about organismal relationships, based on whatever it is you want at the time, such as the relationships of a group or the position of a particular animal (taxon). But what a lot of researchers do, I imagine mostly for convenience, is to take data matrices used to test previous hypotheses, and simply add a new species into that matrix to test what is by default a very different hypothesis. And that's what happened here. The new study uses a matrix by

Chris Brochu and Glenn Storrs, published back in 2012, designed to test the relationships of a new crocodylian species from the Pliocene-Pleistocene (the last few million years) of Kenya. So, the question is, is that matrix adequate to test the relationships of a 'basal eusuchian' from the Late Cretaceous of Europe? As Chris was one of the co-authors on the new study, I'm sure they gave lots of thought to this. But by using a matrix designed to test the relationships of more advanced crocodylians, the character matrix will contain a lot more characters (anatomical features) that are found in more advanced crocodylians in order to resolve their relationships. By extension, this means that fewer of these characters will be appropriate to test 'deeper' crocodylian relationships back in the Cretaceous, and might explain why several species previously regarded as eusuchians are falling outside of this group in their analyses. If you think about the logic behind this, it's like looking just at modern birds, and trying to figure out what the relationships of *Archaeopteryx* are from it. You have to sample much deeper from down in the tree at older forms more closely related to the target animal in order to adequately test its relationships. While I don't think this is a major issue with the results and placement of *Lohuecosuchus*, and the resolution of the new group Allodaposuchidae, I think it would have been really good to test alternative relationships for it by using different and possibly more appropriate matrices.



Time-calibrated phylogeny based on the new analyses.

As well as this, such potential inadequacy might help to explain a few of the oddities in their results. As well as just using the matrix of Brochu and Storrs, they added several taxa mentioned above to this matrix and 'coded' them for their morphology. These included *Shamosuchus*, *Pietraroiasuchus*, and *Pachycheilosuchus*, and which the new analysis found all to be outside of Eusuchia. Weird that. While perhaps not unexpected for anyone familiar with these crocs, it is probably due to the issues mentioned above, and not sampling other crocs from deeper down in the tree related to these. In addition, the use of the closely related *Bernissartia* as what we call an outgroup (the taxon used to define the sequence of morphological evolution by being the most 'basal' in the analyses) is probably not appropriate, as typically more distantly related taxa are needed in order to understand what the actual 'basal' features of a group are. This issue has been raised recently with crocs, which found a completely different placement for a major marine radiation known as Thalattosuchia to be in a different phylogenetic placement depending on what is used as an outgroup.

But, if the resolution of an allodaposuchid-hylaeochampsid only Eusuchia is true (along with Crocodylia), then it has some pretty important implications. Both of these groups went extinct at the end of the Cretaceous, in the mass extinction that also took out the pterosaurs, marine reptiles, and the non-avian dinosaurs. Could it be that this removed competition with early crocodylians, and allowed them to radiate in their absence? This supports recent studies which showed that crocs actually seemed to do pretty well after the end-Cretaceous mass extinction, and shows that while we might think of extinction as generally bad, it really depends on whether you're one of the survivors or not...

So, for now, I'd still say we still haven't fully resolved Eusuchia, and the results of this new study should be taken with a pinch of salt. Still, a cool new croc, and I look forward to seeing future analyses including it to see where it fits within the broader scheme of croc evolution.

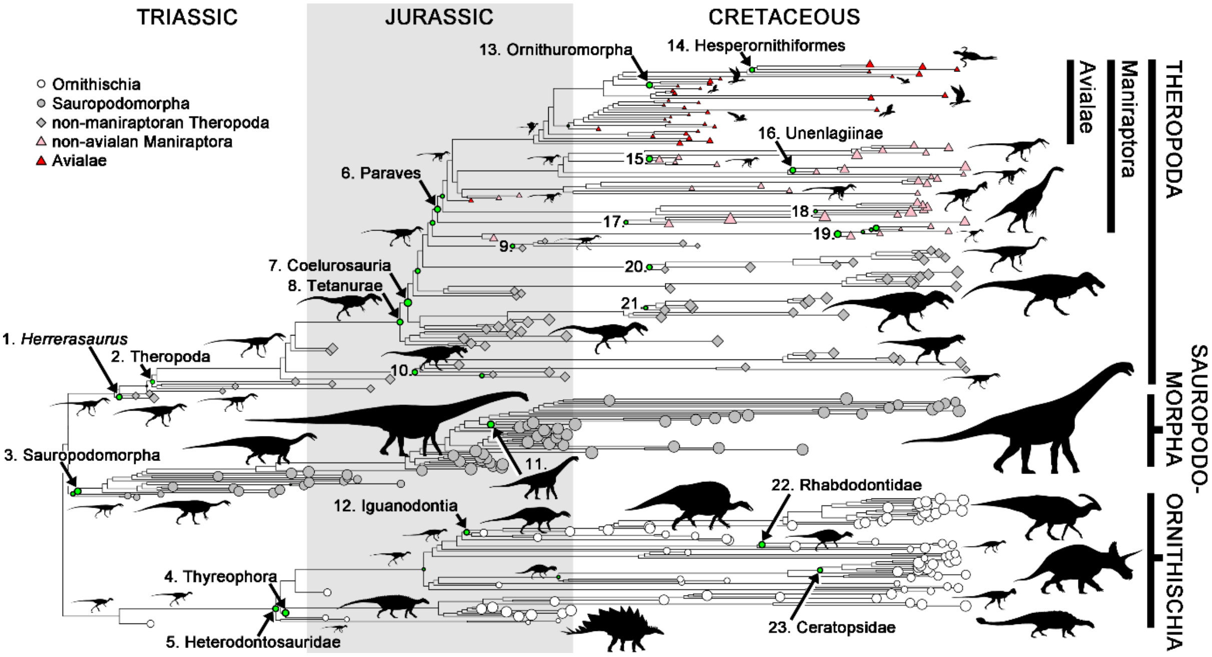
Reference

Narváez I, Brochu CA, Escaso F, Pérez-García A, Ortega F (2015) New Crocodyliforms from Southwestern Europe and Definition of a Diverse Clade of European Late Cretaceous Basal Eusuchians. PLoS ONE 10(11): e0140679. https://doi.org/10.1371/journal.pone.0140679.

Does this dinosaur make me look fat?

Body mass is probably the most important physiological features for all animals. It corresponds strongly with a range of life features, including metabolic and growth rates, population density, diet and dietary strategy, locomotion style and mechanics, and mode of reproduction.

It comes as perhaps no surprise then that body mass is one of the most widely explored features of extinct organisms by palaeontologists. Last year, a slew of papers explored the evolution of body size in dinosaurs, including birds (e.g., this one in PLOS Biology). Most of these found that rapid changes in maniraptoran theropods, the dinosaurian lineage leading to modern birds, occurred from the Middle Jurassic (about 160 million years ago) and onwards.



Different rates of body size evolution across dinosaurs (including birds). (Benson et al., 2014).

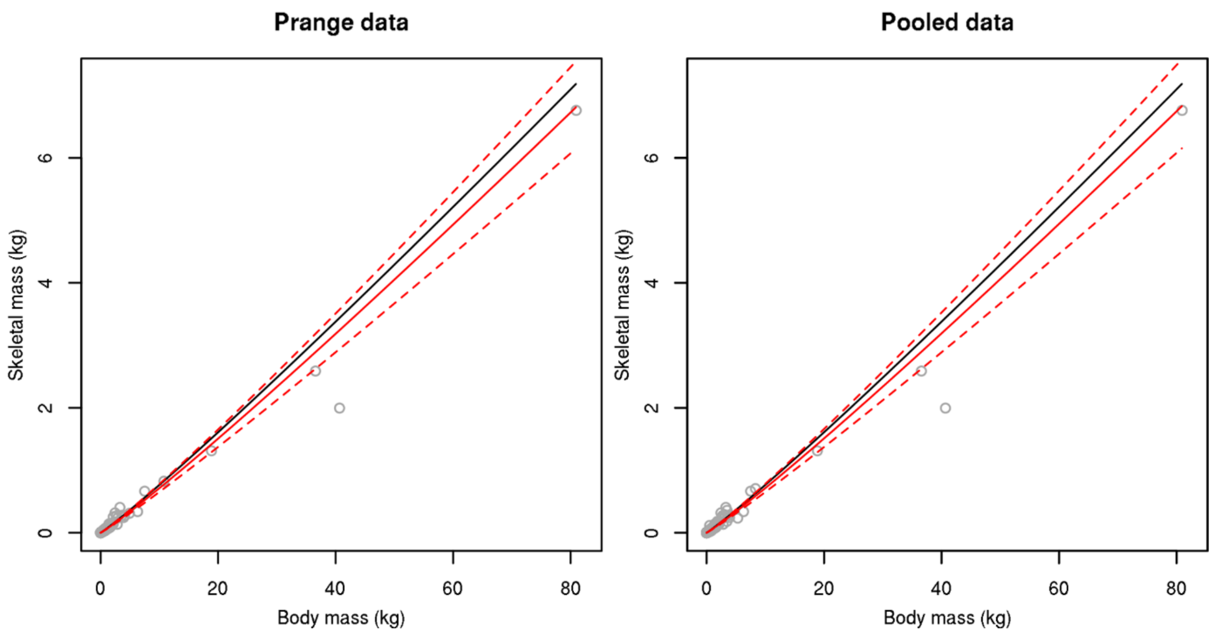
Importantly, this means that, in terms of body size, birds were constantly and rapidly innovating and changing, which might have set the scene for the origins of the great bird radiation. It’s weird to think about, but with 10,000 living species of bird, we are still technically in the ‘reign of the dinosaurs’, and it might be due to an early ability to rapidly evolve body size and adapt to changing conditions.

In birds, body mass has one additional and unique factor in that it correlates with the amount of lift an animal can generate, and therefore influences whether or not they can fly! Therefore, being able to accurately estimate body mass in extinct birds has important implications for our understanding of the origins of flight.

Previous studies, including those mentioned above, have had to rely on proxies to estimate body mass. It’s ridiculously unlikely that we’ll ever find a complete dinosaur, and we only have their skeletons to go off. One way of estimating body mass has been to use the circumference of the femur, which correlates strongly with body mass in a range of living organisms – known as an ‘allometric’ relationship. Estimates of body mass in birds have also been applied to pterosaurs, a group of now extinct flying reptiles related to dinosaurs. But the question remains, how accurate are our estimations of body mass in the fossil record?

A new study, led by Liz Martin-Silverstone at the University of Southampton in the UK, set out to divine the relationships between skeletal mass and complete or total body mass in birds (i.e., involving all the fleshy parts).

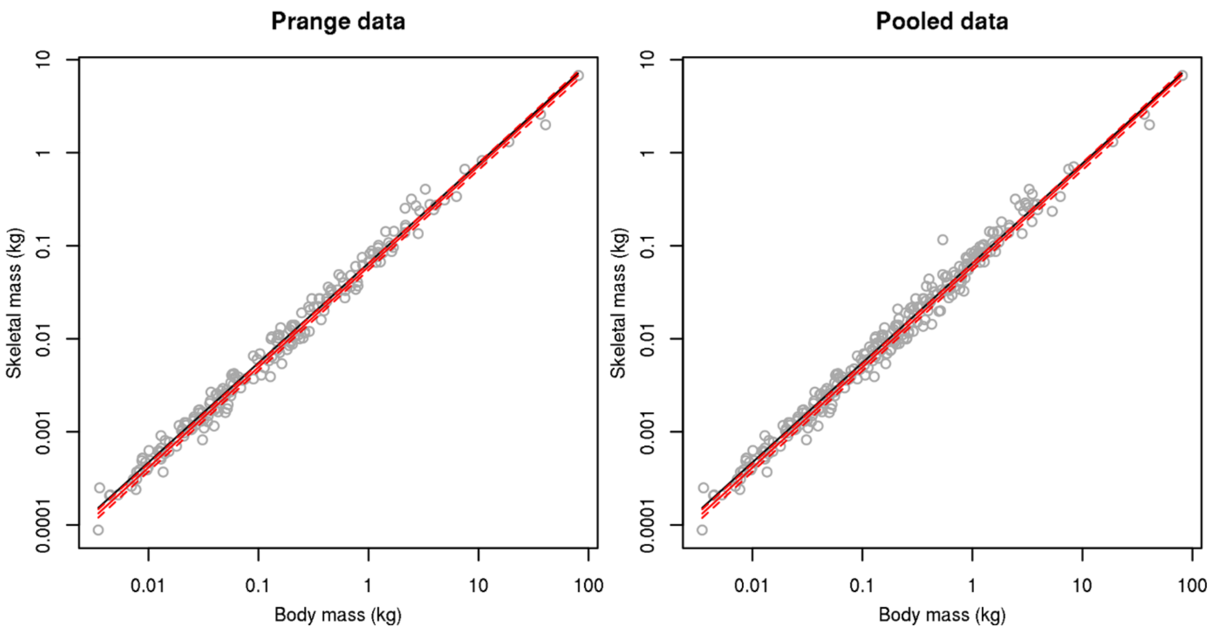
What they found, using a range of analyses and datasets, was a strong positive association between body mass and skeletal mass, as we might expect – as the skeleton of an animal gets bigger, so does its overall mass. This is important, as it means that for living neornithine birds (at least), estimates of skeletal mass accurately reflect total body mass, and therefore skeletal mass can be used as a proxy to estimate the life traits mentioned at the beginning of this post.



Linear scale association between total body mass and skeletal mass in birds.

Despite overall good correlations, the authors found quite a lot of natural variation within species, based on an extensive new dataset compiled from the collections at the Royal British Colombia Museum (Victoria, Canada). This is simply due to the fact that we have different animals of different sizes within species – take a look at humans, for just one obvious example of this. An example from birds is the rhinoceros auklet, which has a total body mass ranging from 258-616.2 grams!

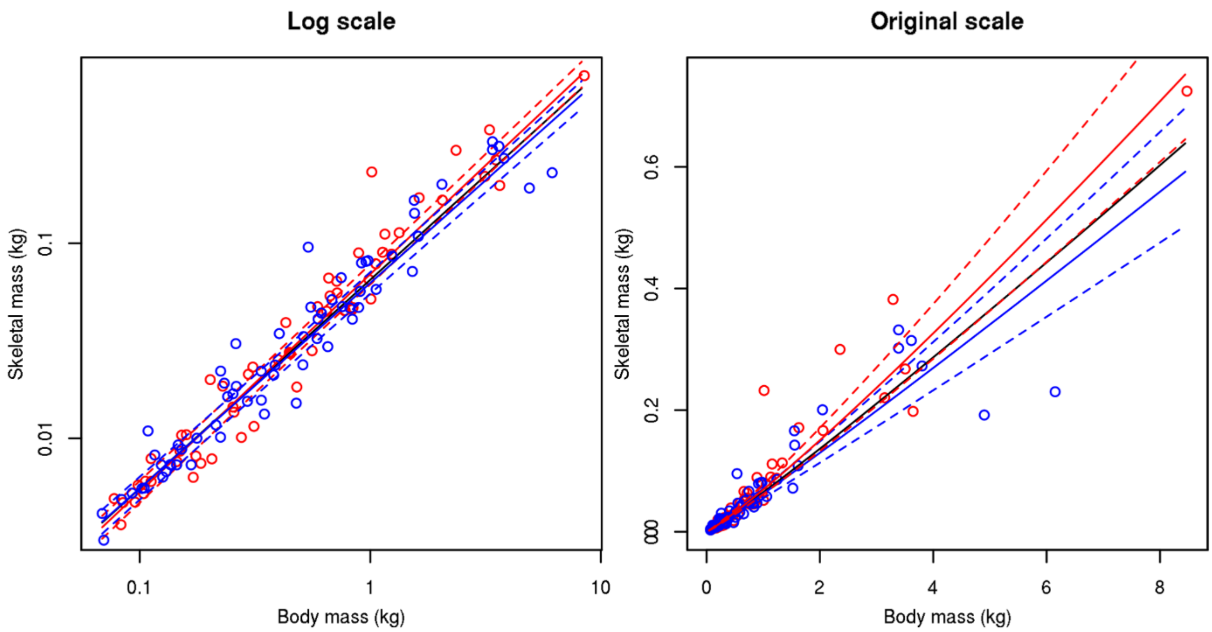
The reason for such variation can also be due to age – it's a pretty well-established phenomenon that animals get bigger as they grow up. This has drastically important implications for estimating skeletal mass across animals in the fossil record. For each animal, they would have to be shown to be the same growth stage, or ontogenetic age, so that their body masses could be directly comparable. There's not really much point comparing the body mass of a juvenile of one species to that for a fully grown individual of another! Birds also grow ridiculously fast (when was the last time you saw a baby pigeon?), so it can be very difficult to accurately tell what their ages are without detailed examination.



Logarithmic scale association between total body mass and skeletal mass in birds.

The authors also identified a range of confounding factors that influence estimates of body mass. For example, when female birds are ready to lay eggs, they accumulate and deposit more calcium within their bones to save it for egg production. So, we might expect the skeletal mass to vary between males and females of the same species, depending on sexual maturity. However, there were no significant differences between the sexes, despite this possible variation. As well as this, migratory birds have very different weights before and during migrations, although this is relatively slight at just a few percent difference, but whether or not this affected the results is unknown.

What about flight mode? Does this affect estimates of body mass, as we might expect flight capable birds to have bigger muscles for flapping their wings, or perhaps be lighter in order to generate more lift for flight. Martin-Silverstone and colleagues found, however, that there was again no statistical difference in the relationship between body mass and skeletal mass across different flight modes. This is great, as in fossil birds, it suggests that even if we don't know their flight style, as it's notoriously difficult to infer in extinct animals, we can still accurately estimate their body mass. The authors are careful to note though that their analyses did not cover all birds, and seems to have excluded a whole range including penguins, ratites (kiwis, emus, and ostriches), cormorants and a whole load of other avian weirdos.



Sexual variation between total body mass vs. skeletal mass relationships in birds.

Importantly, this scalar relationship between skeletal mass and body mass changes when evolutionary relationships are accounted for. When analysing the evolution of 'traits' such as body mass, a portion of similarity between species will simply be due to the fact that we expect more closely related organisms to adopt similar morphologies. This suggests that when estimating body mass, or using raw body mass estimates to make big macroevolutionary statements, that we should make sure that phylogeny (the evolutionary relationships of organisms) is well accounted for.

What does this mean overall for estimating body sizes in extinct organisms? Well, the raw scalar relationship between skeletal mass and body mass is clear for birds, that is, the clade known as Neornithes. However, in different but closely related groups, such as extinct birds like Enantiornithes, Hesperornithes, as well as pterosaurs and non-avian dinosaurs, it is likely that this scalar relationship will be invariably different. This is due to the simple fact that each of these groups of animals are distinct from modern birds – that's what makes them different groups! The authors suggest that there might be better ways of estimating the body mass in organisms like dinosaurs, such as using allometric relationships (such as the femur circumference one mentioned above), or estimates of whole-body volume by using scanning methods! Both of these have been widely used, but often produce quite different results.

For pterosaurs, the close cousins of dinosaurs, the scaling relationships between skeletal mass and body mass have been used before to predict the body masses of a range of species. However, this comparison might not have been appropriate, as pterosaurs are vastly different animals to birds, and have completely different wing anatomy, as well as individual bone masses. This means that previous estimates of body mass in pterosaurs might not have been too accurate, and probably need refining in light of the relationship between skeletal mass and body mass, as well as a deeper understanding of the morphology and pneumatisation (how much air a bone contains) of different pterosaur species.

So, the tl;dr version of this would be: body mass is really difficult to estimate in extinct organisms, should be cross-checked using extant organisms where possible, and confounding factors such as phylogeny, mode of life, sex, and ontogeny must be accounted for!

References

Benson RBJ, Campione NE, Carrano MT, Mannion PD, Sullivan C, Upchurch P, et al. (2014) Rates of Dinosaur Body Mass Evolution Indicate 170 Million Years of Sustained Ecological Innovation on the Avian Stem Lineage. PLoS Biol 12(5): e1001853. https://doi.org/10.1371/journal.pbio.1001853.

Martin-Silverstone E, Vincze O, McCann R, Jonsson CHW, Palmer C, Kaiser G, et al. (2015) Exploring the Relationship between Skeletal Mass and Total Body Mass in Birds. PLoS ONE 10(10): e0141794. https://doi.org/10.1371/journal.pone.0141794.

Life, sex and death for dinosaurs

Stegosaurus is arguably one of most iconic dinosaurs we know, with a back bristling with armoured plates and a wickedly spiked tail. Recently, the Natural History Museum in London acquired an exquisite specimen of *Stegosaurus* from North America, nicknamed Sophie. Sophie has been on display in the museum for several months now, and will be the focal dinosaur attraction as Dippy the *Diplodocus* heads for greener pastures.

Stegosaurus is part of a group called Stegosauridae, all characterised by armour plating across their backs, and known from the Middle Jurassic to Early Cretaceous. They're known from almost all over the world through this time, except for Antarctica and Australia.

Sophie was found in Red Canyon Ranch Quarry in Wyoming, and presents an unparalleled opportunity to perform a detailed study on this important, but actually relatively under-studied dinosaur. She was discovered in 2003 by Bob Simon, actually completely by accident! Apparently, Simon was moving a bulldozer during a windstorm one evening, and accidentally grazed the side off a hill. The next morning, lo and behold, the remains of a dinosaur were waiting there!

Now, Susie Maidment from Imperial College London and Colleagues from the Natural History Museum in London have performed one of the most detailed descriptions of any dinosaur to date, and published in PLOS ONE. At a whopping 107 pages, the paper is packed with new information about the anatomy of Sophie, and has more than 70 figures to illustrate her in beautiful detail.

Importantly, this detailed analysis allows us to gain insight into the growth, sex, and death of Sophie. By looking at different features of the preserved bones, Maidment and colleagues were able to tell that Sophie hadn't finished growing before she died. They were able to show this, as parts of the vertebral column remained unfused to each other, which indicates that the skeleton was not fully mature.

The mounted specimen of *Stegosaurus*, now on display at the Natural History Museum, London!

Additionally, by chopping open Sophie's bones, and looking at them in cross-section using a microscope, they were able to tell that she was a young adult. This was based on features called lines of arrested growth that, much like the rings of a tree, can be used to tell how old an animal is.

Perhaps most bizarrely, the researchers were unable to show whether or not Sophie was a male or a female dinosaur! Perhaps a little misleading based on her name. But it can be very difficult to determine the sex of a dinosaur based purely on features of their skeletons.

Mysteriously, the cause of death for Sophie remains unknown too. Often, dinosaurs are preserved with marks or traces that we can use to infer how they met their end. Fractured bones or tooth marks, for example, are pretty reliable. But for Sophie, there is no evidence of predator or scavenging interaction, and no other pathologies to provide clues. The researchers conclude that the probable cause of death then could be starvation, or perhaps even a disease that doesn't leave traces by only affecting parts of the body that aren't preserved.

It's thanks to the completeness of this specimen, and the great work of excavators, preparators, and researchers, that we're able to get such insight into an animal that has been dead for around 150 million years. Let's hope Sophie will continue to delight visitors to the Natural History Museum for years to come!

Reference

Maidment SCR, Brassey C, Barrett PM (2015) The Postcranial Skeleton of an Exceptionally Complete Individual of the Plated Dinosaur *Stegosaurus stenops* (Dinosauria: Thyreophora) from the Upper Jurassic Morrison Formation of Wyoming, U.S.A. PLoS ONE 10(10): e0138352. https://doi.org/10.1371/journal.pone.0138352.

One-toed Brazilian dinosaur dashed across ancient deserts

A new theropod dinosaur has been discovered from the little-explored region of northern Paraná in modern Brazil. Named *Vespersaurus*, it had a lightweight skeleton, similar to modern birds, and sharp teeth and claws like most of its flesh-eating cousins. The new partial skeleton represents one of the most well-preserved dinosaurs now known from Brazil, adding to an impressive existing national dinosaur record.

However, distinct from most of its theropod relatives, such as *Velociraptor*, this little dinosaur danced around just on one of its toes! This is a condition known as being 'monodactyl', and the first time it has been discovered in a dinosaur from Brazil. Modern examples of this include kangaroos, and even horses with their hooved feet. Researchers were able to see this based on fossilised one-toed footprints known from the 1970s, now thought to belong to these species.

Artist reconstruction, by Rodolfo Nogueira.

"Although difficult to substantiate, it is tempting to speculate whether some of those theropod footprints were produced by an animal similar to the new taxon. Indeed, Leonardi suggested that one such track, found in the same stratigraphic unit at a site about 50 km northwest of Cruzeiro do Oeste, was produced by a functionally monodactyl bipedal "coelurosaur"", say the authors, in their recently published study. These were discovered near the same locality as the new bones. It is thought that the middle toe would have taken all the weight while moving, with another toe on each side held off the ground.

But why did some dinosaurs become monodactyl? If we look at modern animals who have this condition, they are extremely efficient runners and jumpers. Clearly an advantage for any desert-dwelling predator. Equipped with wicked claws on its feet, this Great Dane-sized little beast would have been able to leap onto its prey before trying to rip them apart. This includes many of the now fossilised lizards, mammals, turtles, and pterosaurs that have previously been discovered nearby.

Fact file

Name: *Vespersaurus paranaensis*

Group: Noasaurine, theropod

Age: 90 million years old, Late Cretaceous period

Location: Paraná state, southern Brazil

Geological group: Caiuá Group, Bauru Basin

Rocks found in: Dark red quartz-sandstone

Environment: Inner desert, arid climate – known now as the “Southern Hot Arid Belt”

Diet: Meat, carnivorous, small prey

Size: 5 feet in length, 80cm in height

Weight: Around 33 pounds

The name, *Vespersaurus*, derives from the word ‘vesper’ in Latin, which means evening or west. This is in reference to the name of the town it was discovered near, Cruzeiro de Oeste, or the ‘Western Cross’. ‘Sauros’ is Greek for lizard or saurian, and a common ending for dinosaur names.

This latest discovery helps to reveal to us just how weird and diverse many different dinosaur species were. No longer seen as lumbering giants, we now know they came in all shapes and sizes. Many had the ability to dig burrows for safety, glide and fly, climb trees, swim and fish, sprint at amazing speeds, and even brood over eggs like modern birds.

Relatives of *Vespersaurus* have been found across the southern continents, known geologically as Gondwana, in places like Argentina, India (it used to be much further south during the Cretaceous), and Madagascar. It is likely that as we continue to explore across Africa and South America, new discoveries will continue to challenge and shape our understanding of these beautiful animals.

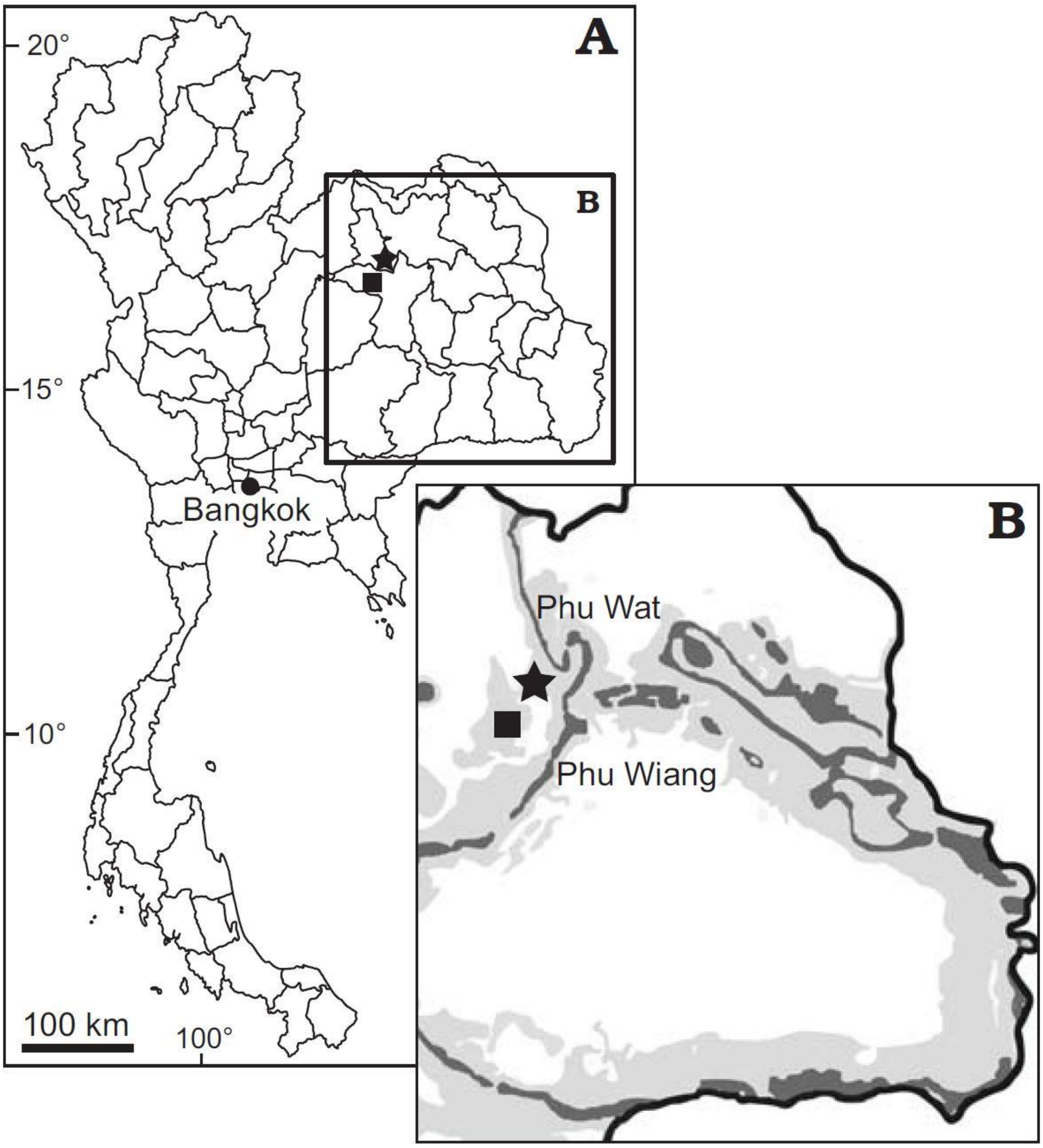
Reference

Langer, Max Cardoso, Neurides de Oliveira Martins, Paulo César Manzig, Gabriel de Souza Ferreira, Júlio César de Almeida Marsola, Edison Fortes, Rosana Lima et al. “A new desert-dwelling dinosaur (Theropoda, Noasaurinae) from the Cretaceous of south Brazil." *Scientific Reports* 9, no. 1 (2019): 9379. https://doi.org/10.1038/s41598-019-45306-9.

Mega-raptors were top predators in Thailand 100 million years ago

If you go to an average Thai island today, you find a very different "predator" to what existed 100 million years ago during the Cretaceous period. Instead of your average-IQ'd Australian male 'gap yah' backpacker, back in the age of dinosaurs there existed a group of ferocious carnivores called megaraptorans.

Megaraptorans were a group of medium- to large-sized dinosaurs with long snouts and large, elongated claws on their hands, ideal for slashing and gashing their prey.



Map of Thailand (A) and close-up of north-eastern Thailand (B) showing the location of Phu Wiang locality, Khon Kaen Province (square) and Phu Wat locality, Nong Bua Lamphu Province (star). (Samathi et al., 2019).

Now, two new species of megaraptoran have been identified from the Sao Khua formation, famous for its dinosaur fossils – five theropod species alone have been named from here! The new additions are called *Phuwiangvenator yaemniyomi* and *Vayuraptor nongbualamphuensis*.

The first identified specimens of *P. yaemniyomi* were discovered by Preecha Sainongkham, a staff member of Phu Wiang Fossil Research Center and Dinosaur Museum in 1993. The name is in honour of Sudham Yaemniyom, former geologist of the Department of Mineral Resources, Bangkok, who found the first dinosaur bone of Thailand in 1976 at Phu Wiang Mountain.

The first fossils of *Vayuraptor* were discovered by Paladej Srisuk in 1988. Its genus name, *Vayuraptor*, comes from Sanskrit 'Vayu', the God of Winds, and the Latin 'raptor', meaning thief – so meaning 'raptor of the wind'. All of the fossils for both species are currently housed at the Sirindhorn Museum, Kalasin Province, under the Department of Mineral Resources, in Thailand.

Why are they important

Fossils of their cousins are known almost only from Asia, with a couple of fragments known from South America and Australia. It is likely that the group formed a clade of top-tier predators that was endemic to the Asian continent back during the earlier parts of the Cretaceous period; while North America and Europe were dominated by groups like tyrannosaurs.

Either way, the fossil record of SE Asia still holds lots of promise in unravelling the ongoing evolutionary mysteries of the dinosaurs! Road trip, anyone?

Reference

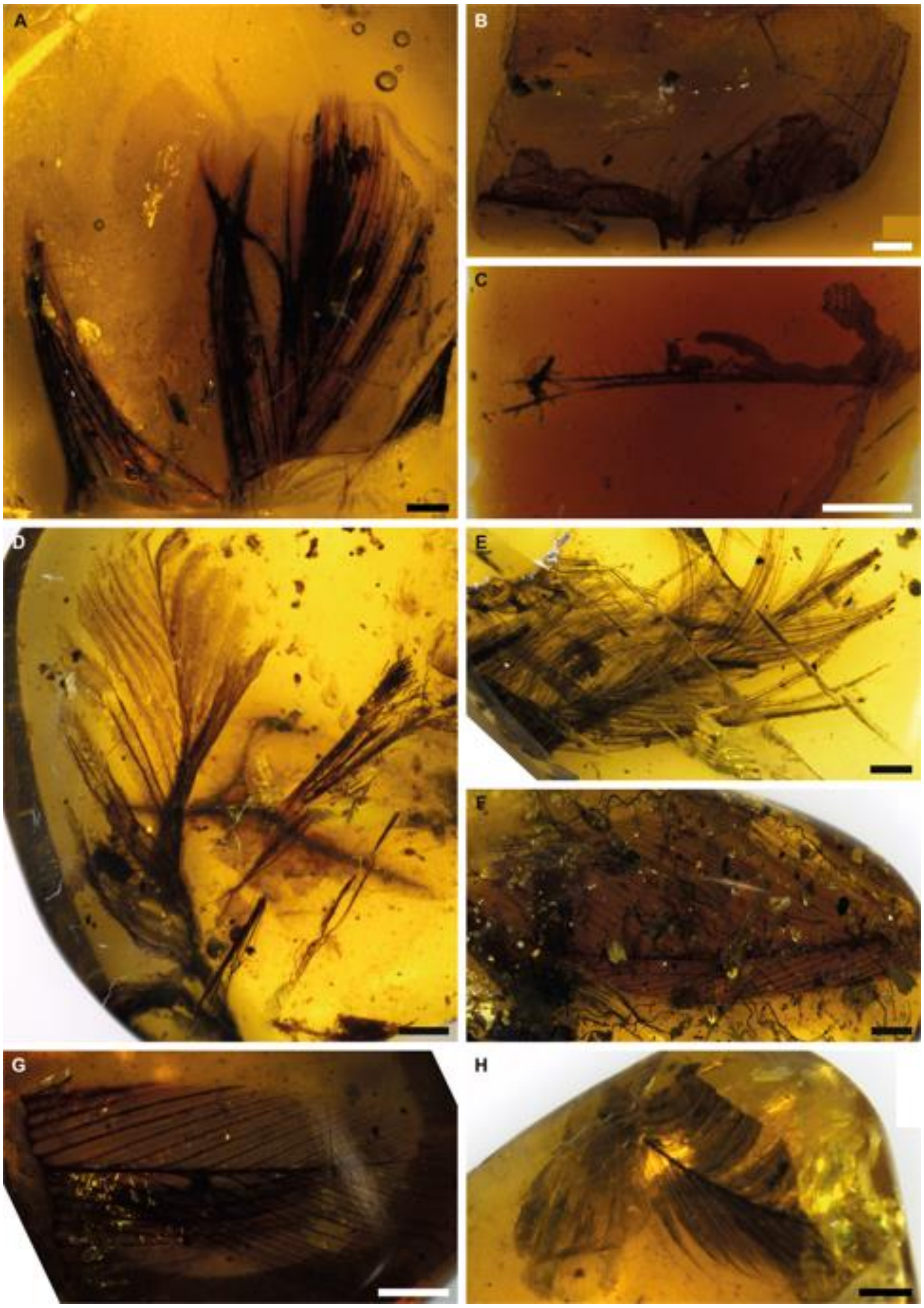
Samathi, A., Chanthasit, P., and Sander, P.M. 2019. Two new basal coelurosaurian theropod dinosaurs from the Lower Cretaceous Sao Khua Formation of Thailand. Acta Palaeontologica Polonica 64 (2): 239–260. https://doi.org/10.4202/app.00540.2018.

Ancient amino acids from 100-million-year-old dinosaur feathers in amber

Then fossil record sometimes is one of those things which just stops you dead in your tracks, with 'wow' written all over your face. Today, one of those moments just happened.

Researchers have now discovered fossilised amino acids, entombed for more than 100 million years in amber.

Now, this is not the first time such things have been discovered. Typically, when proteins have been found fossilised it has been within bones from large, terrestrial vertebrates. This is the first time they have been discovered within amber, within a smaller organism.



Specimens of amber from the Baltic sea, Spain, and Burma. (McCoy et al. 2019).

Critically, amber allows the exceptional preservation of the organic soft tissues, right down to the microscopic scale. This includes amino acids.

What is an amino acid? Well, they form a key part of all life, being the building blocks of proteins. A large proportion of our cells, muscles and tissue are made up of amino acids, meaning they carry out many important bodily functions, such as giving cells their structure.

As the authors state: "…identification of protein sequences from fossil feathers, combined with their morphological investigation, would allow important functional and evolutionary information to be determined over long timescales."

So, this is a really cool step closer to understanding the physiology and evolution of dinosaurs and birds, that just a few years ago would have been virtually unthinkable!

Reference

McCoy, V.E., Gabbott, S.E., Penkman, K. et al. Ancient amino acids from fossil feathers in amber. Sci Rep 9, 6420 (2019). https://doi.org/10.1038/s41598-019-42938-9.

Out of Africa: A new hypothesis for the world's biggest ever dinosaurs

Most of our most beloved and well-known dinosaurs tend to come from Europe and North America. *Diplodocus*, *T. rex*, *Triceratops*, all household names that have been known for decades now. Most of this reflects the fact that this is where most original professional dinosaur hunting and fossil collecting began, and entered into the attention of the media and public.

However, in the last couple of decades, we are seeing a huge surge in dinosaur discoveries from across South America, Asia, and Africa. Some of the largest dinosaurs ever known are being unearthed in Patagonia, and a huge diversity of feathered fiends have been collected from across China.

In Africa, recent discoveries have revealed a number of absolutely bizarre dinosaur species, really helping to shape our understanding of their incredible diversity. Recently, a new one was discovered and identified, given the name *Mnyamawamtuka*, from Tanzania. The species is from a group of giant sauropods with barrel-like bodies and long necks and tails called titanosaurs. During the Cretaceous period, these animals represented the largest to have ever walked the planet.

The full name of the new species is *Mnyamawamtuka moyowamkia* (Mm-nya-ma-wah-mm-too-ka Mm-oh-yo-wa-mm-key-ah), and is one of the most complete and oldest titanosaur skeletons ever found. It was named after its place of discovery along the Mtuka River in southwest Tanzania.

Mnyamawamtuka moyowamkia, artistic reconstruction by Mark Witton.

Its scientific name derives from Kishwahili (Swahili) words meaning “beast of the Mtuka” and “heart of the tail,” referring respectively to the location it was found and to the uniquely heart-shaped centrum of its tail vertebrae (‘moyo’ is the Kiswahili word for heart and ‘wa mkia’ is Kiswahili for ‘of the tail’). The rocks it was found in are part of the Galula Formation, and thought to be around 100-110 million years old, from a time known as the middle Cretaceous.

Mnyamawamtuka is closely related to other titanosaurs from the Late Cretaceous, specifically from South America. This suggests that there might have been a close connection between the two continents during the middle to later parts of the Cretaceous period. Such a pattern is also seen in other groups around at the time, such as the weirdly herbivorous crocodile-like animals known as notosuchians, which are known exclusively from the southern hemisphere.

"Although titanosaurs became one of the most successful dinosaur groups before the infamous mass extinction capping the Age of Dinosaurs, their early evolutionary history remains obscure, and *Mnyamawamtuka* helps tell those beginnings, especially for their African side of the story," said lead author of the study, Eric Gorscak.

Of course, like all discoveries, this one opens up more questions that can only be answered by finding new fossils from the poorly sampled records of Africa. Time for a new expedition?

Reference

Gorscak E, O'Connor PM (2019) A new African Titanosaurian Sauropod Dinosaur from the middle Cretaceous Galula Formation (Mtuka Member), Rukwa Rift Basin, Southwestern Tanzania. PLoS ONE 14(2): e0211412. https://doi.org/10.1371/journal.pone.0211412.

Mongolian proto-thief dinosaur had egg-crushing jaws

Our understanding of dinosaurs is constantly changing. From centuries old views of slow, lumbering, lizards to a modern understanding of nimble, often feathered, diverse and intelligent animals. We now know that dinosaurs occupied almost every possible habitable niche on land, and were highly successful before the tragic events of 66 million years ago.

Perhaps one of the greatest examples of this changing understanding of dinosaurs comes from a group known as oviraptorosaurs. Anyone with a keenness for Latin here will understand this word to mean 'egg thief lizard', which is exactly what paleontologists thought they first were. The animal *Oviraptor*, the most famous of the group, was originally discovered, fossilized in what was thought to be the process of stealing eggs from a nest!

However, as our understanding of dinosaurs developed, and the link between dinosaurs and birds was cemented, things changed. It was noticed that *Oviraptor* was not stealing the eggs – it was brooding them! This exposed a whole new dimension to our understanding of dinosaurs, but poor *Oviraptor* still carries the mistaken label around with it.

Even today, new discoveries are helping to shape our understanding of oviraptorosaurs. A number of species are now known from across North America and Asia. They are readily identified by their strange, parrot-like faces. Some were very small, no more than the size of a turkey, whereas others like *Gigantoraptor* grew to more than 8 metres in length!

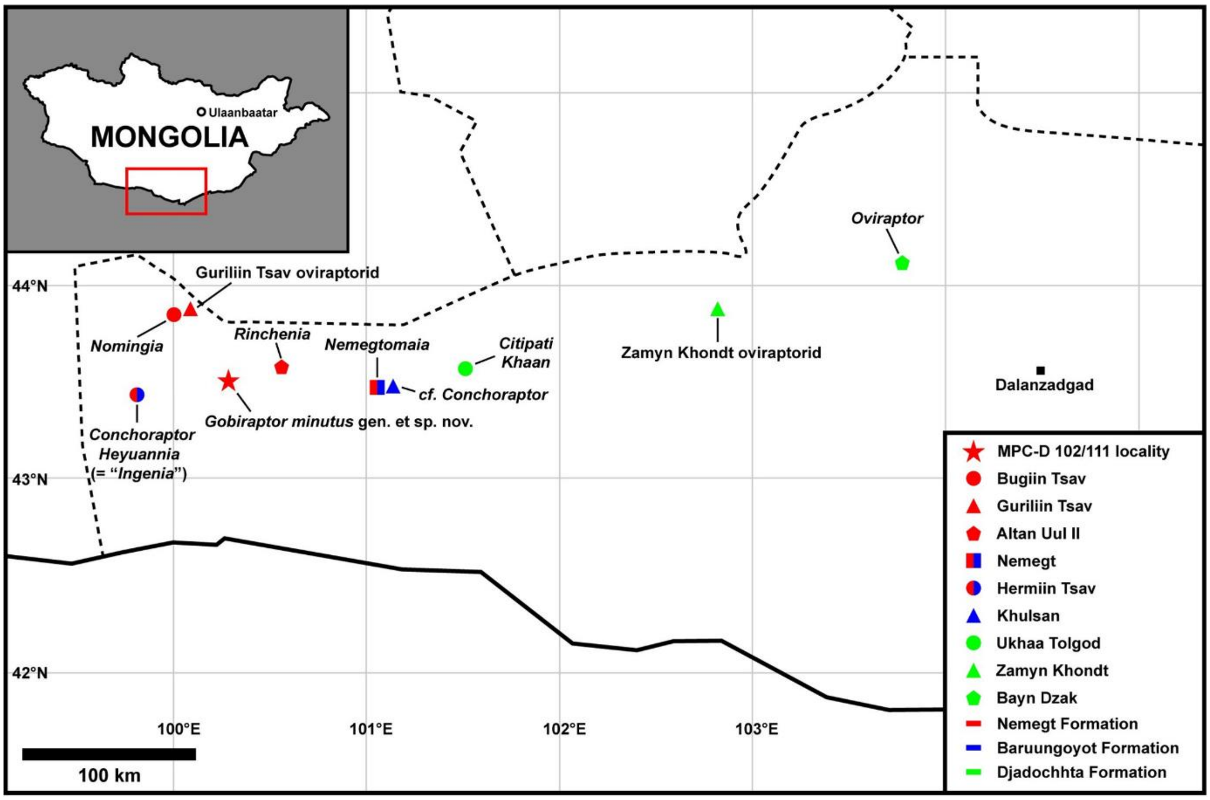
Many fossils have also been found with feather impressions, and it is thought that they are closely related to the origins of birds.

The latest species to be added to the oviraptorosaur family tree is *Gobiraptor minutus*, described by scientists this week. This absolutely adorable new species is known from a juvenile specimen, and the reconstruction below by Do Yoon Kim reveals just how cute this little proto-thief could be.

Reconstruction of *Gobiraptor*, by Do Yoon Kim.

Gobiraptor comes from the Late Cretaceous of what is now the Gobi Desert of Mongolia. Many wonderful species of dinosaur have been found here thanks to international collaboration efforts. Back 70 million years ago, what is now called the Nemegt Formation of rocks used to consist of a thriving ecosystem around lakes and rivers.

Gobiraptor is unusual among other oviraptorosaurs in that it has uniquely thickened jaws. Oviraptorosaurs, unlike most other theropod dinosaurs at the time, were likely omnivorous, rather than pure meat eaters. *Gobiraptor* likely had a strong, crushing bite, which it would have used to snack on hard objects, such as seeds, eggs or even molluscs. You can picture it now, skitting across the shoreline rocks, snacking away on molluscs as the tide and sun went down after another playful day.



Map showing the occurrences of oviraptorids in the southern Gobi Desert of Mongolia. (Lee *et al*., 2019).

No other oviraptorosaur currently known from the Nemegt Formation is thought to have had such a specialized diet. The authors suggest that being able to adapt to a number of different feeding lifestyles might have given oviraptorosaurs an evolutionary edge, and diversify into a number of different species.

The new fossil specimen is permanently held in the Institute of Paleontology and Geology in Ulaanbaatar, Mongolia.

Reference

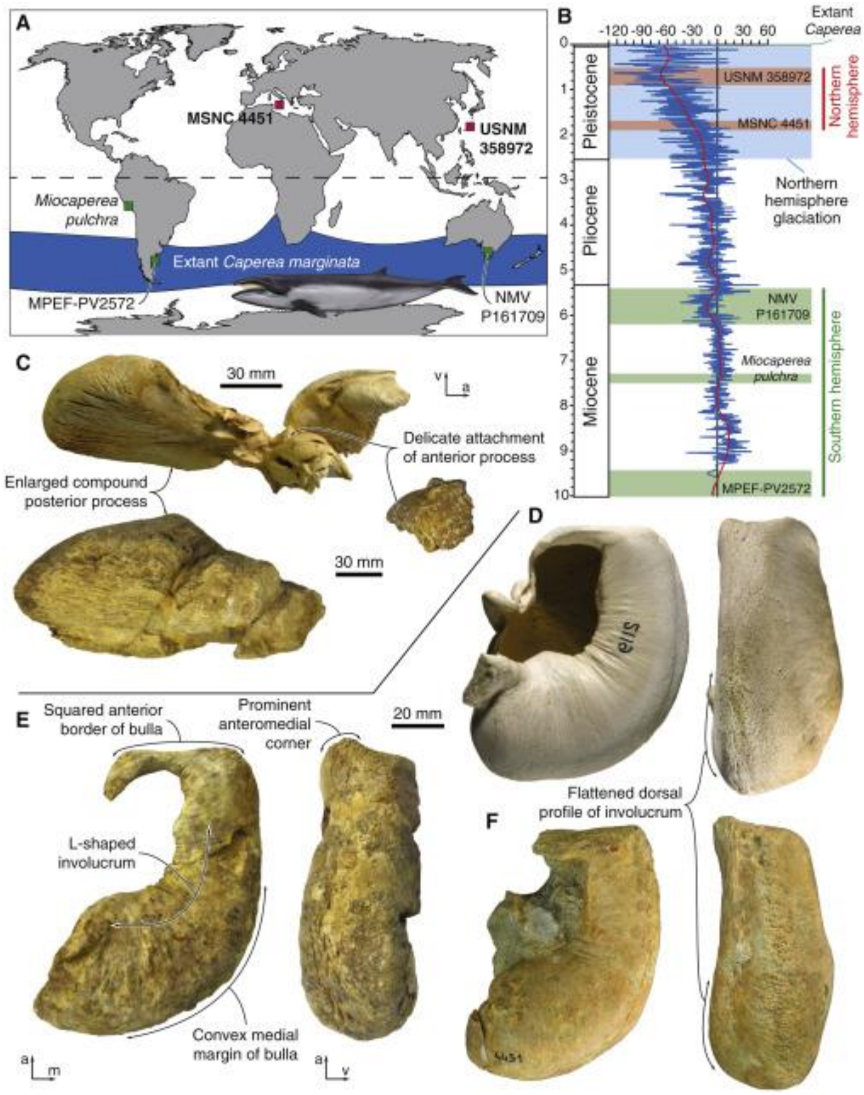
Lee S, Lee Y-N, Chinsamy A, Lü J, Barsbold R, Tsogtbaatar K (2019) A new baby oviraptorid dinosaur (Dinosauria: Theropoda) from the Upper Cretaceous Nemegt Formation of Mongolia. PLoS ONE 14(2): e0210867. https://doi.org/10.1371/journal.pone.0210867.

How pygmy whales were affected by historical climate change

In one of the latest posts here, we described to you a new discovery of giant ancient killer whales dominating the ancient seas that used to cover Egypt. Now, we are staying along the same taxonomic theme to being you a story of pygmy whales!

An article, published back in 2017, shows how fossils whales moved around the seas during intense glacial and interglacial periods. Importantly, it provides a strong case of how physical barriers can play a major role in the evolution of marine mammals – something we should be very much aware of as we continue to impact upon global climates.

The modern pygmy right whale, *Caperea marginata*, is known exclusively from the southern hemisphere – places such as southern Australia, New Zealand, and South America. It is well known as being the smallest of its kind, and due to some of its weird anatomy sometimes even called the 'platypus of whales'. Fossils of this baleen whale lineage are also exceedingly rare, and only ever found on the southern continents.



Distribution of modern and fossil pygmy right whales (Tsai *et al*., 2017).

Now, researchers have found fossils of this species, but as far north of the equator as Japan and Italy. The ones from Japan, consisting part of a skull, are between 0.5-0.9 million years in age. The Italian fossil comprises just a single ear bone, and is older at between 1.7-1.9 million years old. However, just from these elements it is possible to identify them as the same species as the modern pygmy whale, or at least a very, very close ancestor. This is the first time these animals have been found so far north, and prove quite an unexpected discovery.

“This is like finding a fossil kangaroo in Scotland. It us a totally unexpected discovery,” said Erich Fitzgerald, Senior Curator of Vertebrate Palaeontology, Museums Victoria, where the fossils are housed.

Modern pygmy right whale (credit: Robert Pitman).

Whales and global climate change

But perhaps most importantly, these whale fossils help to illuminate a whole new element of the environmental history during the Quaternary period. It means that climates that we now associate with the southern hemisphere were once common in the northern hemisphere too, which impacted the distributions of marine mammals at the time.

It is not uncommon for whales to migrate seasonally, but at this scale helps to tell us more about the environment at the time. During the Pleistocene period, when the fossils are known from, the Earth was still very different to how we know it today. Great ice sheets expanded and contracted across both hemispheres. These would force marine animals to migrate and shift their habitats north and south as the glaciers grew and declined.

Finding the pygmy whales so far north then suggests that they lived during a time when the southern ice caps had grown far north towards the equator, and perhaps even further. As the climate warmed again over many millennia, the ice caps retreated and the whales were able to slowly shift to their more southerly waters again. Fossils of this, and related, species are unknown from all other well-sampled fossil localities from around the same time in the northern hemisphere.

Where are the Japanese and Italian pygmy whales today?

But why are there no pygmy whales left in the North? Well, this is where the story gets a bit sad. As the climate continued to warm, it would make the equatorial waters more and more difficult to cross. So those pygmy whales left in the north would find it more difficult to migrate, become increasingly isolated, and eventually die out. Due to the time differences between the two fossils, however, it is difficult to say whether there was one longer lasting population or two population pulses of pygmy whales during this period.

Dr Felix Marx, Research Associate at Museums Victoria and Monash University, added that this points to the potential huge impact of ongoing climate change on today's whales: "The natural changes to the Earth's climate, now has an added human element, that may drive a reorganization of the current dispersal of whales and marine mammals. For example, a warmer world may see the pygmy right whales driven further south towards the pole."

In the future, this means that we might also expect to find fossils of other 'southern' animals in the northern hemisphere, such as penguins and even walruses. Discovering more fossils from this time will be important in helping to understand how these species might respond to future changes to our global climate.

Reference

Tsai, C.H., Collareta, A., Fitzgerald, E.M., Marx, F.G., Kohno, N., Bosselaers, M., Insacco, G., Reitano, A., Catanzariti, R., Oishi, M. and Bianucci, G., 2017. Northern pygmy right whales highlight Quaternary marine mammal interchange. Current Biology, 27(19), pp. R1058-R1059. https://doi.org/10.1016/j.cub.2017.08.056.

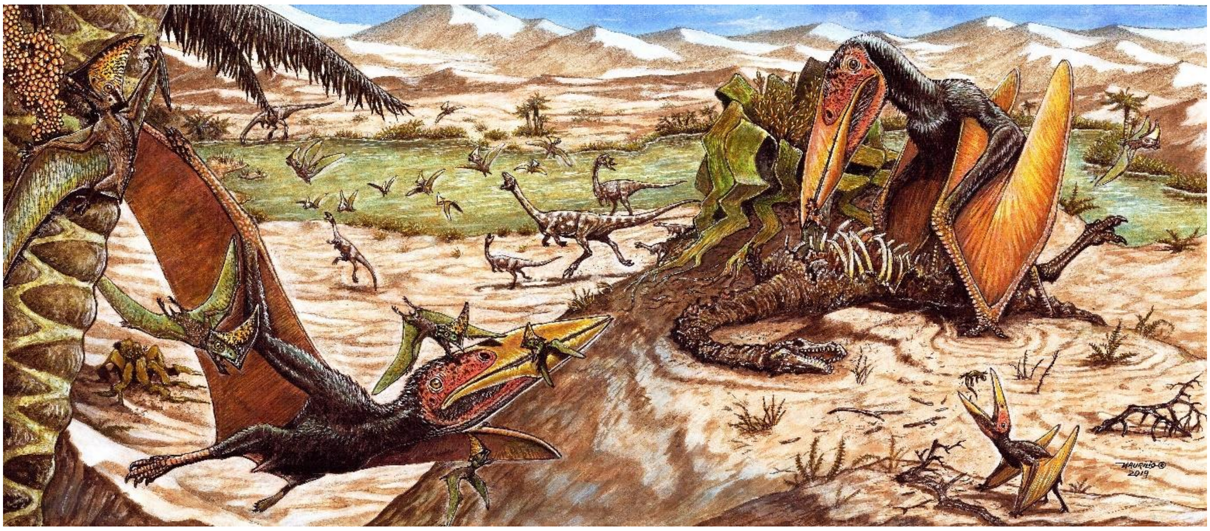
Death-spirit dragons stalked the ancient deserts of Brazil

One of my favourite parts of palaeontology is looking at how people choose to name newly discovered species. This is a core element of taxonomy, and understanding how many species exist or existed. Often though, the naming of a new species is simply based on a particular anatomical feature, or the location it was discovered.

But sometimes, researchers pull out a real treasure. Recently, a team of paleontologists from Brazil have discovered a new species of pterosaur. It was found near the town of Cruzeiro do Oeste, in Paraná State in Brazil.

This fossil locality is known locally as *cemitério dos pterossauros*; or, the cemetery of pterosaurs. What a hauntingly appropriate name for an ancient graveyard containing the fossilised remains of hundreds of the animals.

The newly discovered species has been named *Keresdrakon*. The first part of the word, Keres, comes from Greek mythology, and represents female death-spirits who personified violent deaths. The spirits also are associated with doom and plunder, and would fly over bloody conflict zones looking for the dying. Which is nice. The second part of the word, drakon, comes from the Ancient Greek for dragon or huge serpent. Overall, this brilliant name paints a gloriously horrific image in the mind.



Reconstruction of the paleoenvironment showing the possible interaction of the vertebrate fauna recovered from the 'cemitério dos pterossauros' site. Artwork by Maurilio Oliveira.

What is further interesting is that this is the first time that multiple species of pterosaur have been found together in the same geographic location. Another species called *Caiuajara* is known from many more fossils from the same place.

This represents a condition known as sympatry, and indicates that perhaps multiple species of pterosaur were able to live alongside each other in little ptero-communities.

100 million years ago, when these pterosaurs were still alive, Brazil was a vast, sandy desert. Perhaps here, pterosaur species were forced to live alongside each other in harmony, taking advantage of scarce water resources. Death-spirit dragons included.

Reference

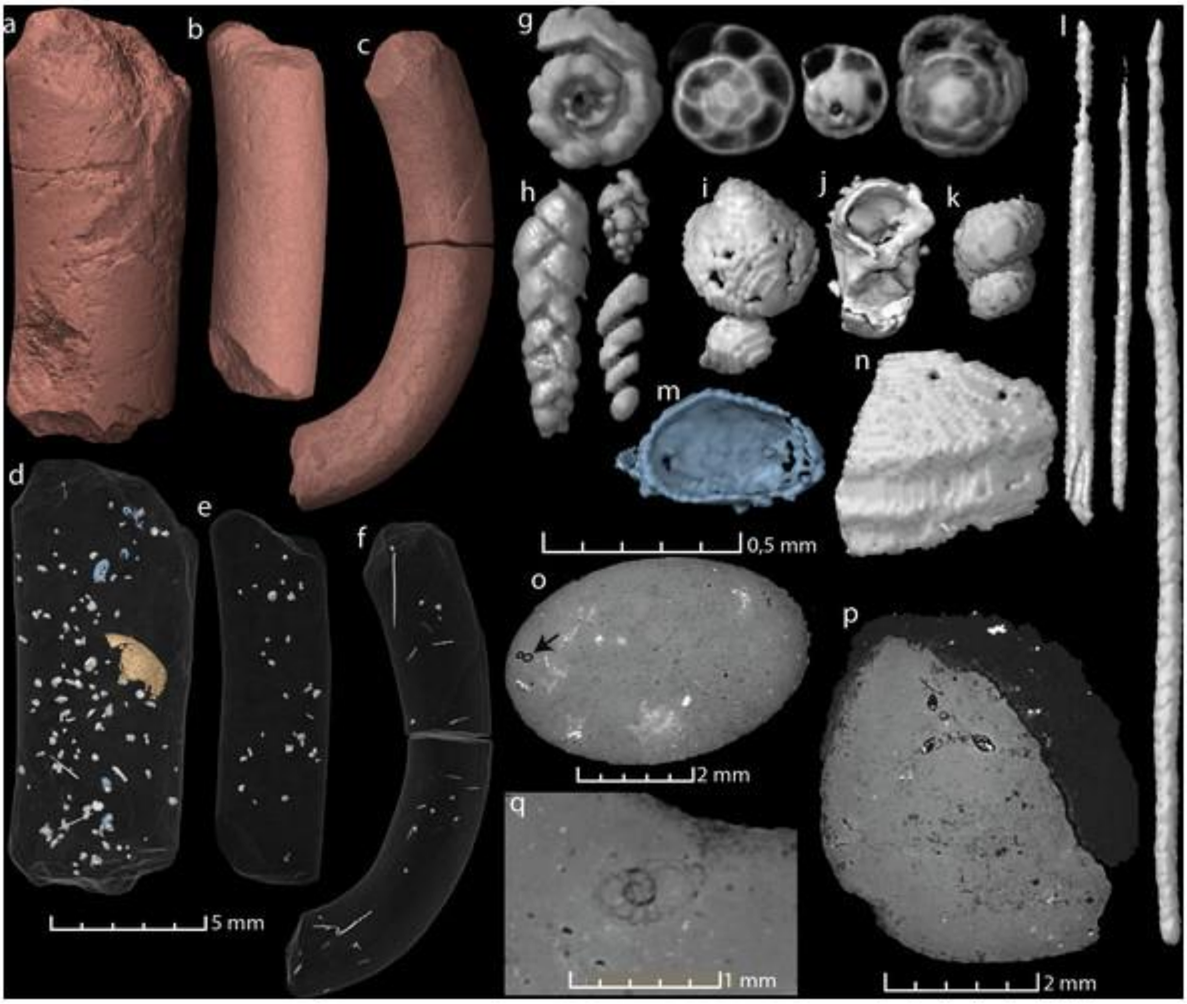
Kellner, Alexander W.A., Weinschütz, Luiz C., Holgado, Borja, Bantim, Renan A.M., & Sayão, Juliana M. (2019). A new toothless pterosaur (Pterodactyloidea) from Southern Brazil with insights into the paleoecology of a Cretaceous desert. *Anais da Academia Brasileira de Ciências*, *91*(Suppl. 2), e20190768. Epub August 19, 2019.https://dx.doi.org/10.1590/0001-3765201920190768

Were pterosaurs the flamingos of the Jurassic?

Never mind bats and birds, pterosaurs were the first real evolutionary heroes who gained the ability of powered flight. While often mistaken for dinosaurs, pterosaurs are actually more like their cousins. Being a bit of an evolutionary marvel, with their thin membranous wings, fragile skeletons, and long, pointed beaks, they have become quite a fascinating group to study the ecology of.

One of the most fascinating things that the fossil record can show us is evidence of feeding relationships. If you think about it, this is far more exciting than just finding skeletons. While the bones of animals might tell us more about how an animal died, it is the study of trace fossils – like trackways or burrows – that tell us what an animal was doing while it was actually alive.

For pterosaurs, such evidence in the fossil record is extremely rare, and we only have small glimpses into how these animals actually behaved. When it comes to diet, we know very little. Previously, researchers have carefully reconstructed the anatomy of pterosaurs and compared them with modern animals like birds to carefully infer what they might have fed on. For example, having long spiky teeth would have made perfect fishing hooks. Beyond inference though, there is little direct evidence of what they fed on. Some giant pterosaurs might have even fed on small dinosaurs!



Virtual reconstructions and virtual thin sections of coprolites and inclusions (Qvarnström et al., 2019).

Now for the first time, the fossilised poop (coprolite) of a pterosaur has been discovered with direct and identifiable remains of other animals. They come from the Wierzbic Quarry in Poland, near to the Holy Cross Mountains, and date to the Late Jurassic period around 160 million years ago.

Researchers fired up a powerful visualisation tool called a synchrotron, which is able to help measure and view even the smallest particles within materials. In this case, fossil poop. The details it produces are exquisite, allowing researchers to visually reconstruct the contents of the pterosaur's pre-poop meal.

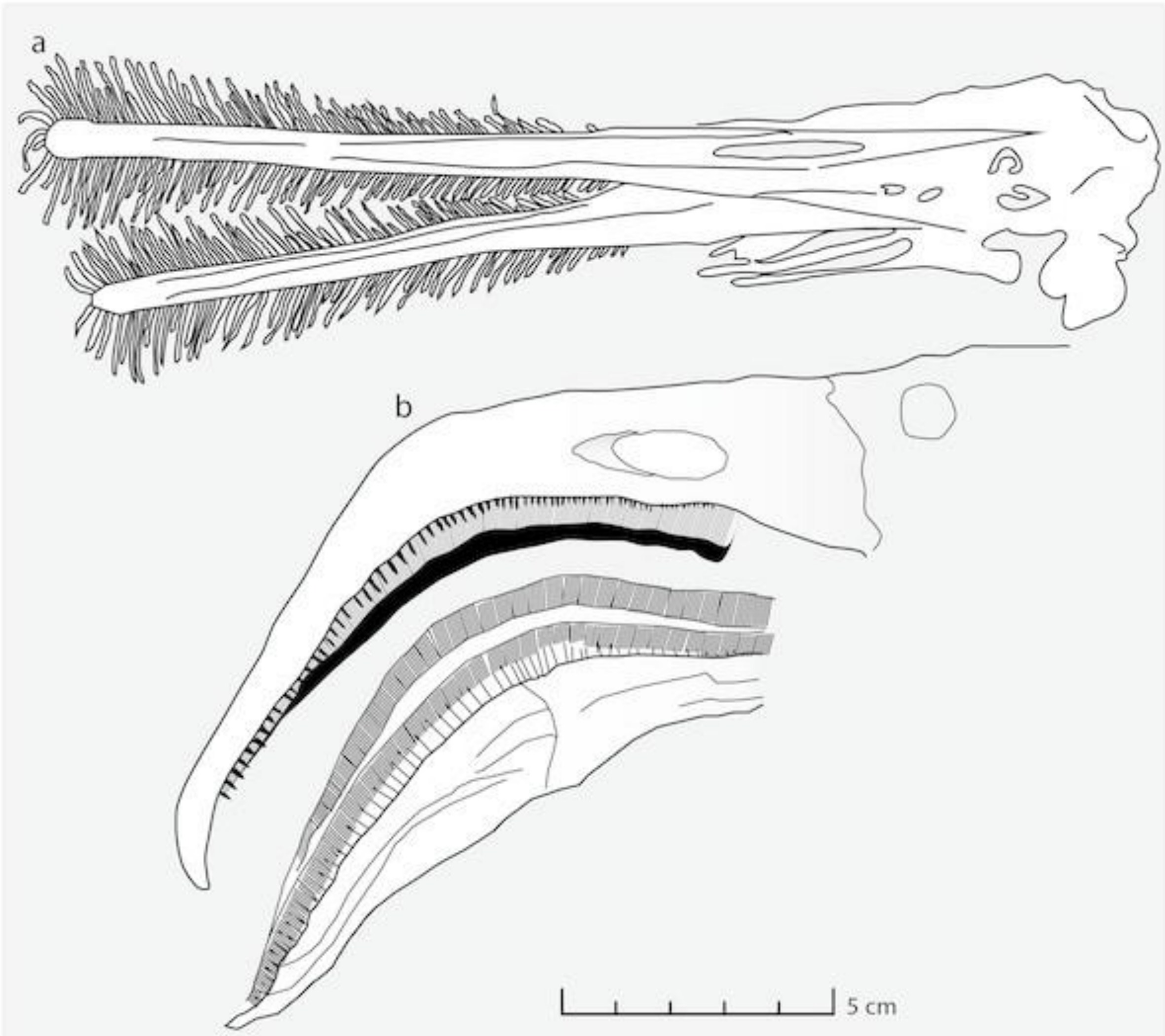
What the researchers found was a small medley of marine animals. The digested remains of bivalves, ostracods, gastropods, and other small crustaceans and arthropods were discovered. As well as some small bristles that might have belonged to polychaete worms.

Intriguingly, these fragments were contained within a poop-matrix comprising mostly foraminifera – small, microscopic and shelled protists. And too many of them just to be there by mistake, suggesting that our little flying friend was consuming them deliberately.

As such, this provides the first direct evidence of a pterosaur that probably utilised filter feeding as a feeding mode. Possibly species known from the same region include *Gnathosaurus* and *Ctenochasma*. Both of these show anatomical evidence that could indicate filter feeding, including an elongated beak, and many closely-spaced teeth to act like a sieve.

Such a feeding style is also known for the modern flamingo, whose droppings have also been examined (for science) and with evidence of foraminifer found.

"The similar contents of the droppings of these flamingos and the pterosaur coprolites could be explained by similar feeding environments and mesh sizes of the filter-feeding apparatus. It appears therefore that the pterosaurs which produced the footprints and droppings found in Poland were indeed the flamingos of the Late Jurassic," says Martin Qvarnström, lead author of the study.



Feeding apparatus of *Ctenochasma elegans* (pterosaur) and *Phoenicopterus chilensis* (flamingo) (Qvarnström et al., 2019).

So, for any palaeoartists reading this, you now have full scientific license to start painting pink pterosaurs.

Reference

Qvarnström M, Elgh E, Owocki K, Ahlberg PE, Niedźwiedzki G. 2019. Filter feeding in Late Jurassic pterosaurs supported by coprolite contents. PeerJ 7:e7375 https://doi.org/10.7717/peerj.7375.