

NEW

↓ BIGGEST

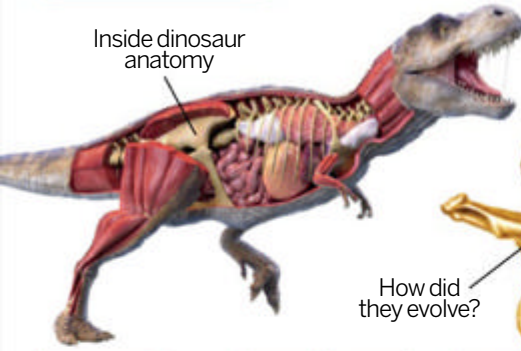
↓ FASTEST

↓ TALLEST

↓ LONGEST

↓ GREATEST

Inside dinosaur anatomy



Why did Triceratops have horns?



How did they evolve?



HOW IT WORKS
BOOK OF

The weird and wonderful



From egg to adult



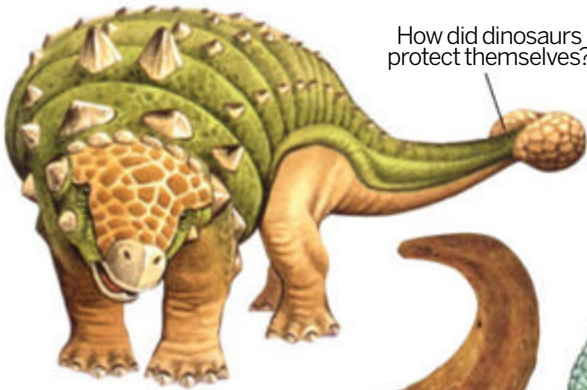
Did they hunt in packs?



DINOSAURS

VOLUME 1

How did dinosaurs protect themselves?



Terrors of the sky



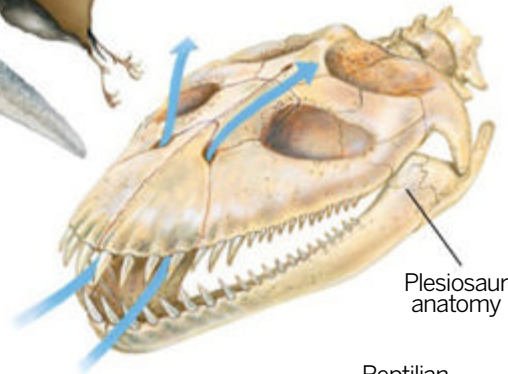
Dinosaur weaponry



How did they hunt?



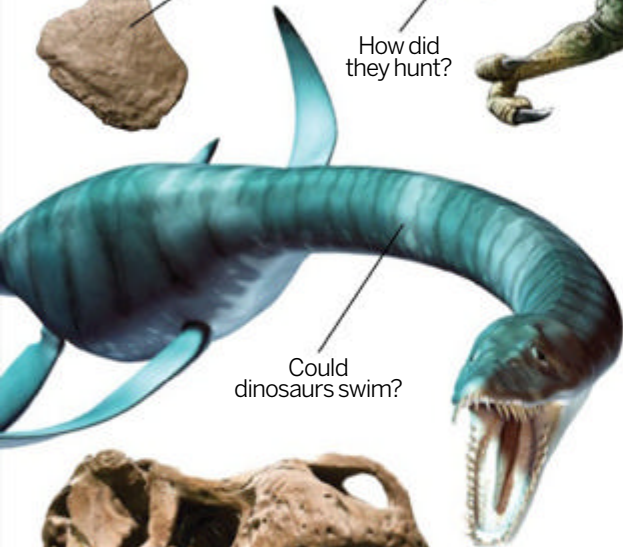
Plesiosaur anatomy



Reptilian relatives



Could dinosaurs swim?



Weapon or tool?



How fast did T-rex run?

How are fossils created?



Were dinosaurs intelligent?



AN IN-DEPTH LOOK INSIDE THE WORLD'S MOST INCREDIBLE DINOSAURS

WELCOME TO
**HOW IT
WORKS**
BOOK OF
DINOSAURS

At first, dinosaurs seem like the product of a wild imagination - how could such weird and wonderful creatures ever have existed on our Earth 65 million years ago? Before the extinction event that changed their world forever, dinosaurs and their reptilian relatives of the sea and sky ruled the prehistoric world. From Allosaurus to Zuniceratops, travel back in time to the age of the dinosaurs with the How It Works Book of Dinosaurs and discover the "terrible lizards" for yourself. We've gathered together some of the most amazing creatures and got right under their skins so we can demonstrate to you how they work. Did the Tyrannosaurus rex hunt or scavenge? Why did herbivores grow so massive? Find out how the dinosaurs survived and thrived, about the mass extinction that ended it all and what the dinosaurs left behind for us to find.



HOW IT
WORKS
BOOK OF
DINOSAURS

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Website: www.imagine-publishing.co.uk
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William Gibbons, 26 Planetary Road, Willenhall, West Midlands, WV13 3XT

Distributed in the UK, Eire & the Rest of the World by
Marketforce, Blue Fin Building, 110 Southwark Street, London, SE1 0SU
Tel 0203 148 3300 www.marketforce.co.uk

Distributed in Australia by
Network Services (a division of Bauer Media Group), Level 21 Civic Tower, 66-68 Goulburn Street,
Sydney, New South Wales 2000, Australia Tel +61 2 8667 5288

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How It Works Book Of Dinosaurs © 2015 Imagine Publishing Ltd

ISBN 978-1785 460 678

Part of the
**HOW IT
WORKS**
bookazine series





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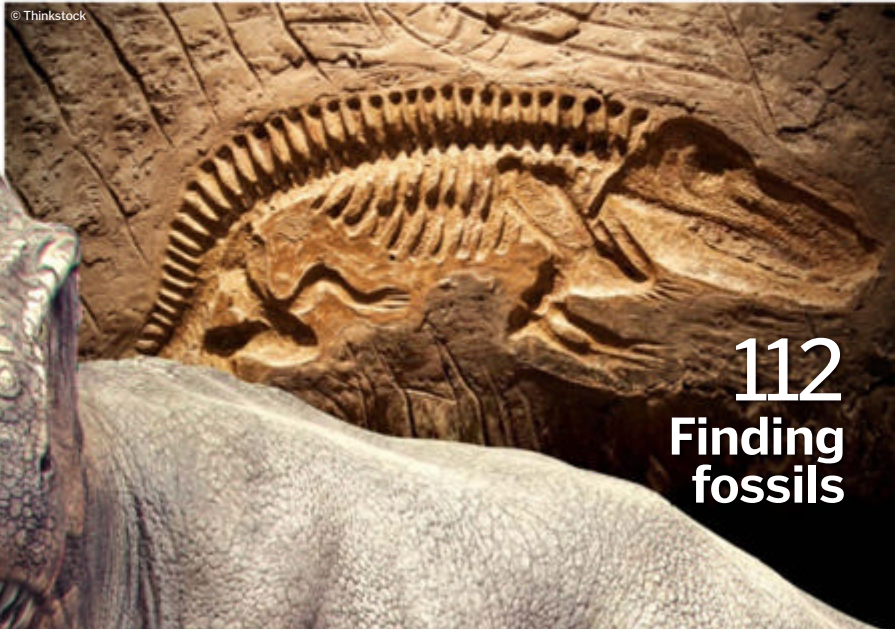


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© SOL50

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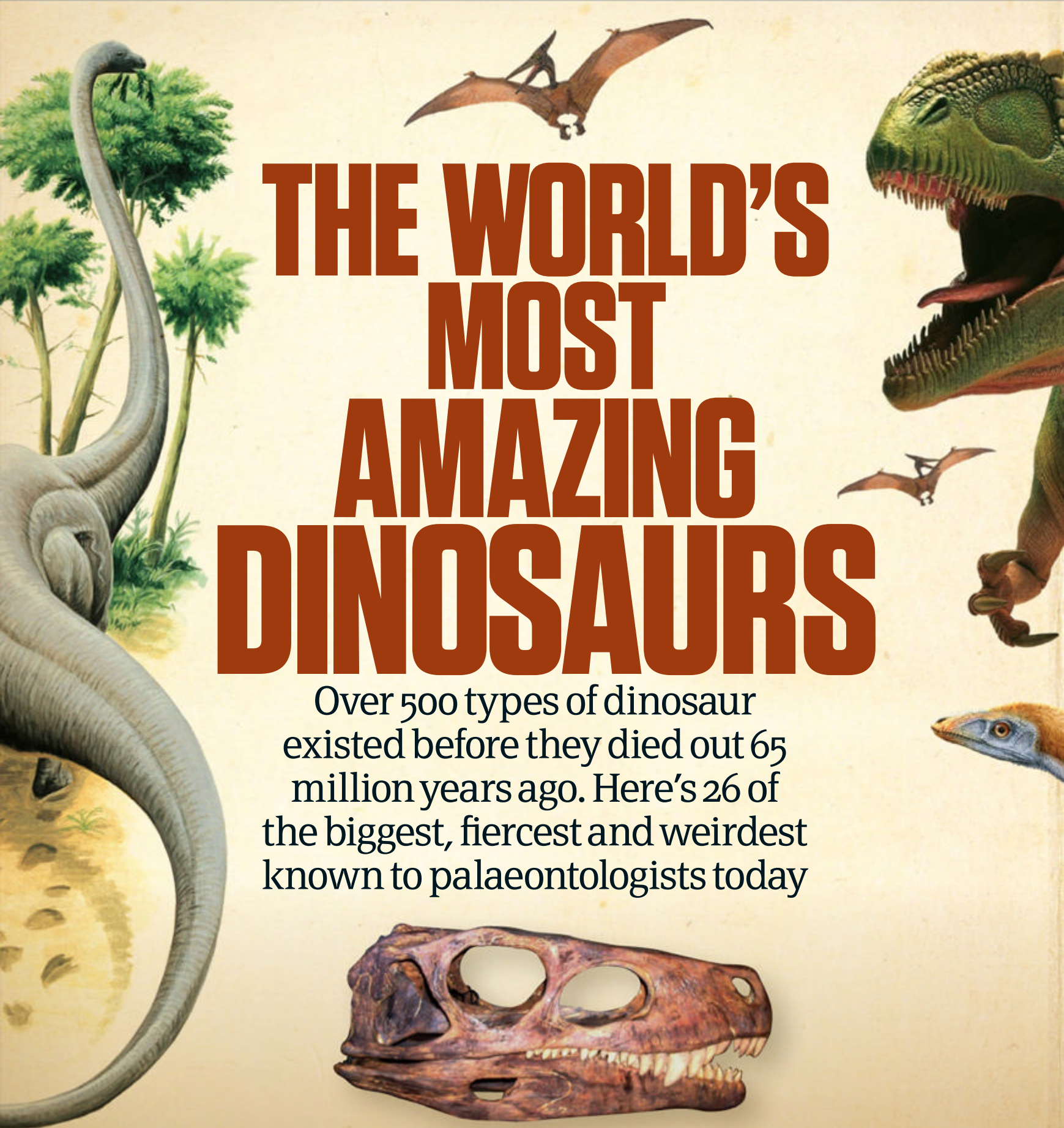


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HOW IT
WORKS

MOST AMAZING DINOSAURS

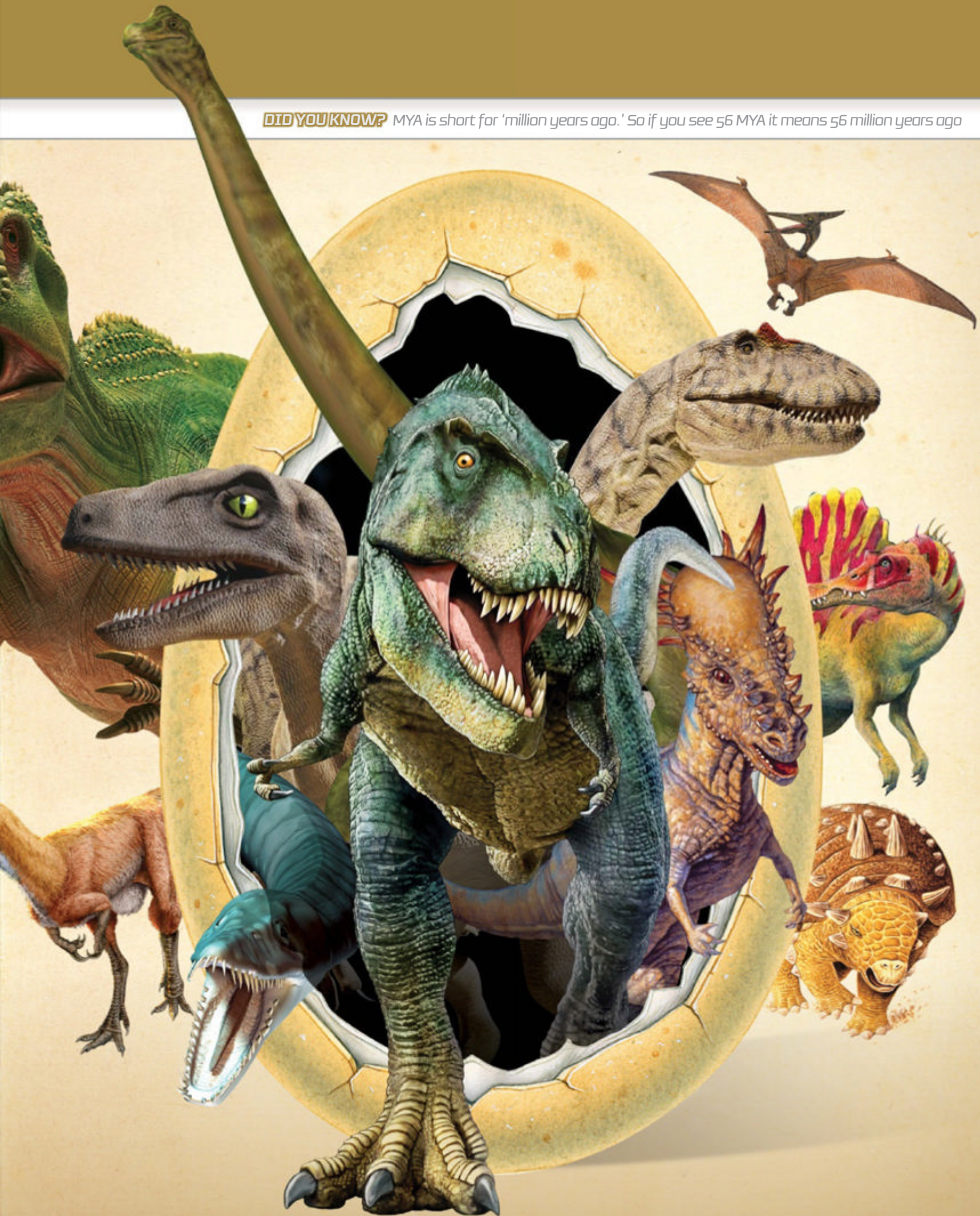


THE WORLD'S MOST AMAZING DINOSAURS

Over 500 types of dinosaur existed before they died out 65 million years ago. Here's 26 of the biggest, fiercest and weirdest known to palaeontologists today



DID YOU KNOW? MYA is short for 'million years ago.' So if you see 56 MYA it means 56 million years ago





HOW IT WORKS

MOST AMAZING DINOSAURS

Tyrannosaurus rex

(‘Tyrant lizard king’)

Carnivore

Cretaceous period, 67-66 MYA

Found in: **Western North America**

Lived in: **Forests with swamps and rivers**

Long-lived

T-rex was able to live for up to 30 years

Balance

T-rex’s huge head was balanced by its heavy tail

Scales or feathers?

T-rex may have had feathers on at least part of its giant body, just like a bird

Fact

The largest T-rex skulls ever to be found are 1.5m across, and some of the T-rex teeth were up to 30cm long

Clawed grip

Although T-rex’s arms were small, each with two claws, they were strong, able to grip prey or push itself off the floor



Dino skill

Tyrannosaurus rex

T-rex may have had the most vicious bite of any animal to have lived, many times stronger than lions and sharks and capable of crunching bone and ripping apart its prey.

Killer rating:	5/5
Speed:	3/5
Defence:	3/5



Stegosaurus

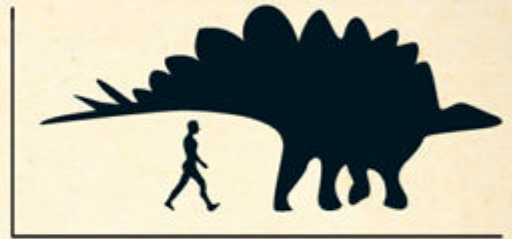
('Roof lizard')

Herbivore

Late Jurassic period, 150 MYA

Found in: **Europe and Eastern North America**

Lived in: **Forests and vegetated plains**



Dino skill

Stegosaurus

Stegosaurus had sharp 60-90cm-long tail spikes that it could swing at an attacker to defend itself.

Killer rating: 1/5
Speed: 1/5
Defence: 3/5

Hefty giant

Stegosaurus weighed about 5,000kg - that's about half as much as a double-decker bus

Bony plates
Stegosaurus had 17 plates along its back

Fact
Stegosaurus's distinctive back plates may have been a type of air conditioning. Air cooled the blood running through the plates

Tail spikes
The spike at the end of a Stegosaurus's tail was called a thagomiser

Fossilised remains

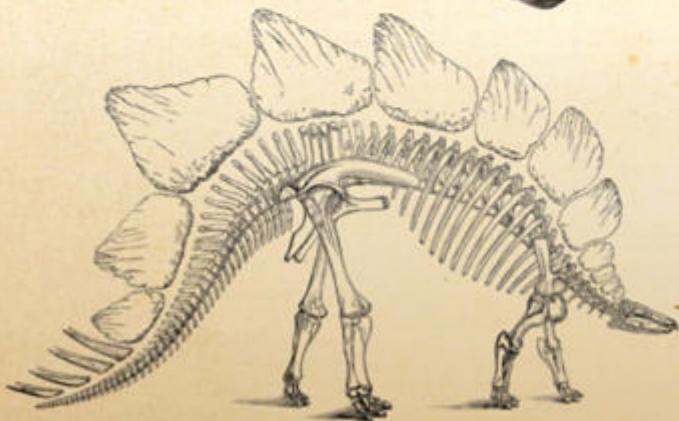
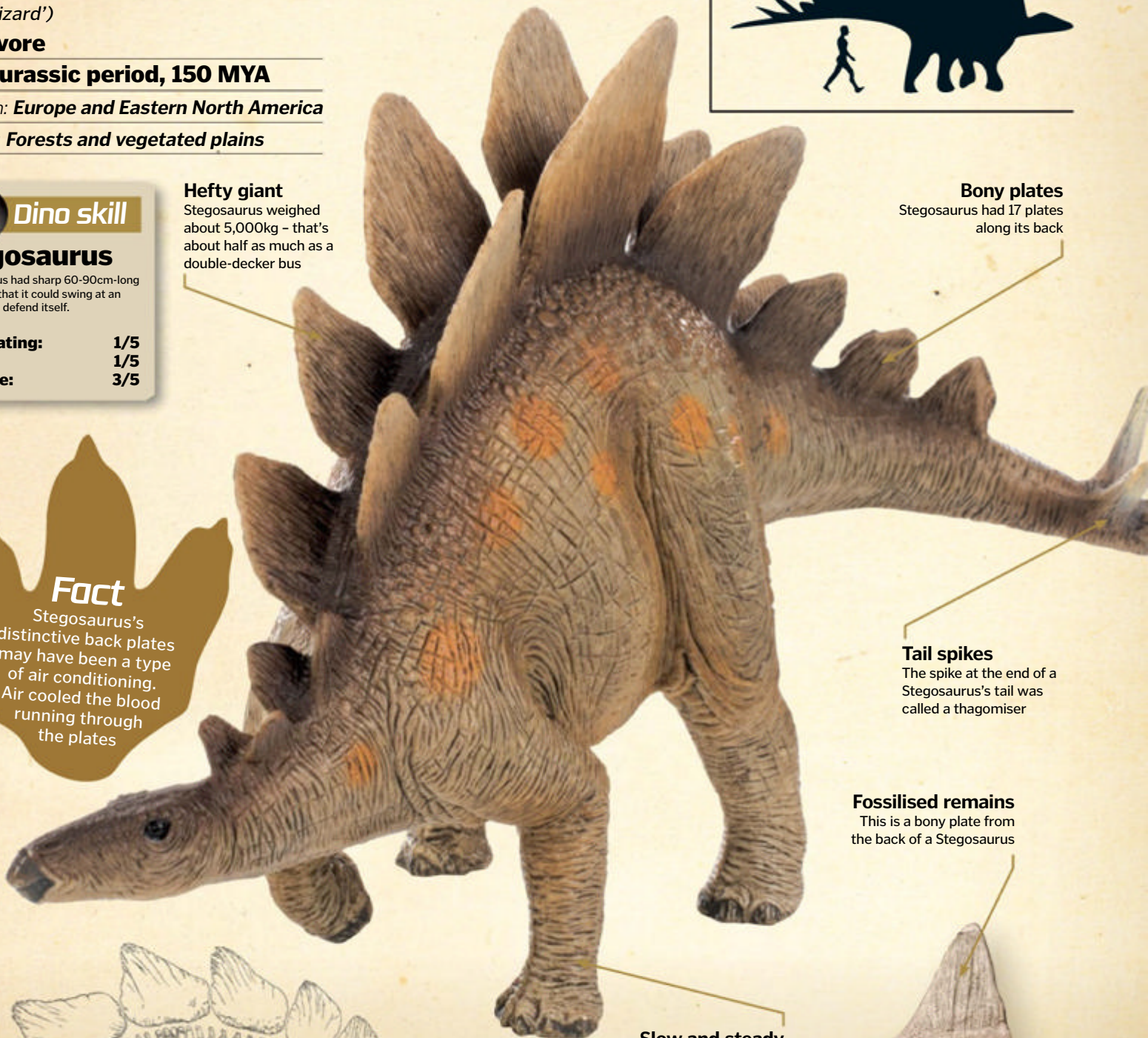
This is a bony plate from the back of a Stegosaurus

Slow and steady

Its short, stumpy legs meant that Stegosaurus could barely walk faster than a human being

Brain power

Stegosaurus was not a very smart dinosaur - it had a brain no larger than a dog's





HOW IT WORKS

MOST AMAZING DINOSAURS

Triceratops

(‘Three-horn face’)

Herbivore

Late Cretaceous, 67-65 MYA

Found in: **Western North America**

Lived in: **Forests with prairies**



Colourful frill

The large frill was probably used to attract a mate, like a peacock’s feathers, but it could also have doubled up as a way of keeping their blood cool

Combat ready

Powerful horns helped protect from predators



Dino skill

Triceratops

Triceratops’ three horns and frill were used for courtships and combat, using them to take on and beat the dreaded Tyrannosaurus rex.

Killer rating:	2/5
Speed:	2/5
Defence:	4/5

Heavy skull

Triceratops were big-heads - the largest triceratops skulls found by dinosaur-fossil hunters are over 2m in length

Heavyweight

Triceratops weighed the same as two West African elephants - that’s almost 12 tonnes

Fact

During their lifetime Triceratops would go through between a massive 400 to 800 teeth as they browsed on ferns



DID YOU KNOW? Velociraptors probably hunted as individuals, rather than in a pack

Velociraptor

(‘Swift plunderer’)

Carnivore

Cretaceous period, 75-71 MYA

Found in: **China, Mongolia**

Lived in: **Desert**

Warm-blooded

Velociraptors were probably warm-blooded

Feathered fiend

Their feathers were used for display, covering nests or providing added speed when running uphill

Fact

In the Jurassic Park films Velociraptors were tall and scaly, but in reality they were more like large birds and were much, much smaller

Small size

Velociraptors were small, like a large chicken



Dino skill

Velociraptor

Velociraptors were loners, hunting other small dinosaurs by launching surprise attacks and then chasing down their prey.

Killer rating: 2/5
Speed: 2/5
Defence: 4/5

Hunting

Their curved claw was a frightening weapon, able to stab and cut open prey



Pounce

They had very strong back legs and sharp claws on their feet





HOW IT WORKS

MOST AMAZING DINOSAURS

Brachiosaurus

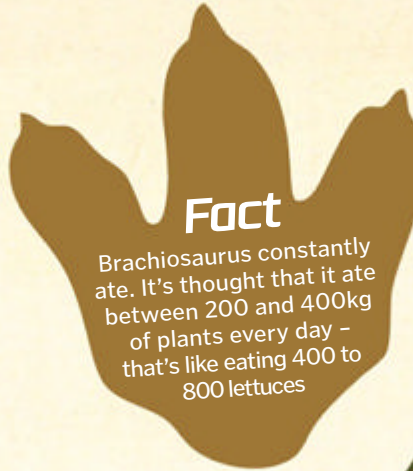
(‘Arm lizard’)

Herbivore

Jurassic period, 150 MYA

Found in: **North America**

Lived in: **Forests**



Fact

Brachiosaurus constantly ate. It's thought that it ate between 200 and 400kg of plants every day - that's like eating 400 to 800 lettuces

Small skull
Brachiosaurus had a tiny head

Earth-shaker
Adult Brachiosaurus weighed over 100 tonnes



Vertebra
This is a bone from the long neck of the Brachiosaurus called a vertebra

Extra height
Unlike many other dinosaurs, their front legs were longer than their back legs, which provided additional elevation for their neck and head

Foraging
Brachiosaurus may have often held its long neck parallel to the ground to sift through the undergrowth for food, as well as to reach up to leaves on trees



Dino skill

Brachiosaurus

Brachiosaurus just spent its day lumbering around, so wasn't particularly skilful, but it was so large that no predator could harm it.

Killer rating: 1/5
Speed: 1/5
Defence: 4/5

Pteranodon

(‘Toothless wing’)

Carnivore

Late Cretaceous, 88-80 MYA

Found in: **North America**

Lived in: **Coastal/lake areas**

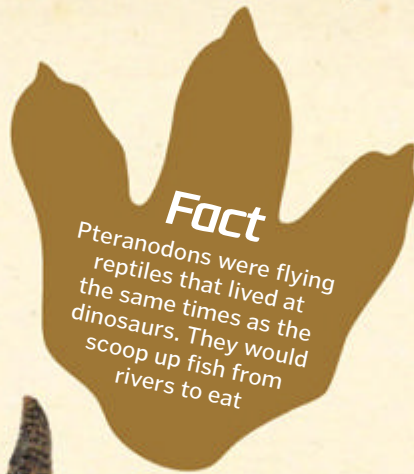


Dino skill

Pteranodon

Pteranodons were able to walk on four legs when on the ground, using their claws attached to their wings.

Killer rating: 2/5
Speed: 4/5
Defence: 4/5



Fact

Pteranodons were flying reptiles that lived at the same times as the dinosaurs. They would scoop up fish from rivers to eat

Head wear

The raised crests at the back of their heads may have been used to attract mates, as well as help change direction in flight

Leathery wings

Pteranodons had no feathers

Fish eater

Pteranodons are thought to have been able to swim on the surface of water, dipping their beaks beneath the waves to grab fish

Massive wingspan

Males had a 3m wingspan

Clawed hands

These creatures had small hands with four claws on them

Crest

The male Pteranodon *sternbergi* had a larger upright crest on top of the head compared to females' smaller crest





Allosaurus

('Different lizard')

Carnivore

Late Jurassic, 155-150 MYA

Found in: **North America**

Lived in: **Semi-arid plains and forests**



Dino skill

Allosaurus

Allosaurus was able to sniff out its prey, like Stegosaurus and Diplodocus, with a keen sense of smell.

Killer rating:	4/5
Speed:	4/5
Defence:	4/5

Keeping balance
Its large and terrifying skull was balanced by its heavy tail, so that it didn't fall forward all the time

Eyesight
Forward-facing eyes helped focus on prey

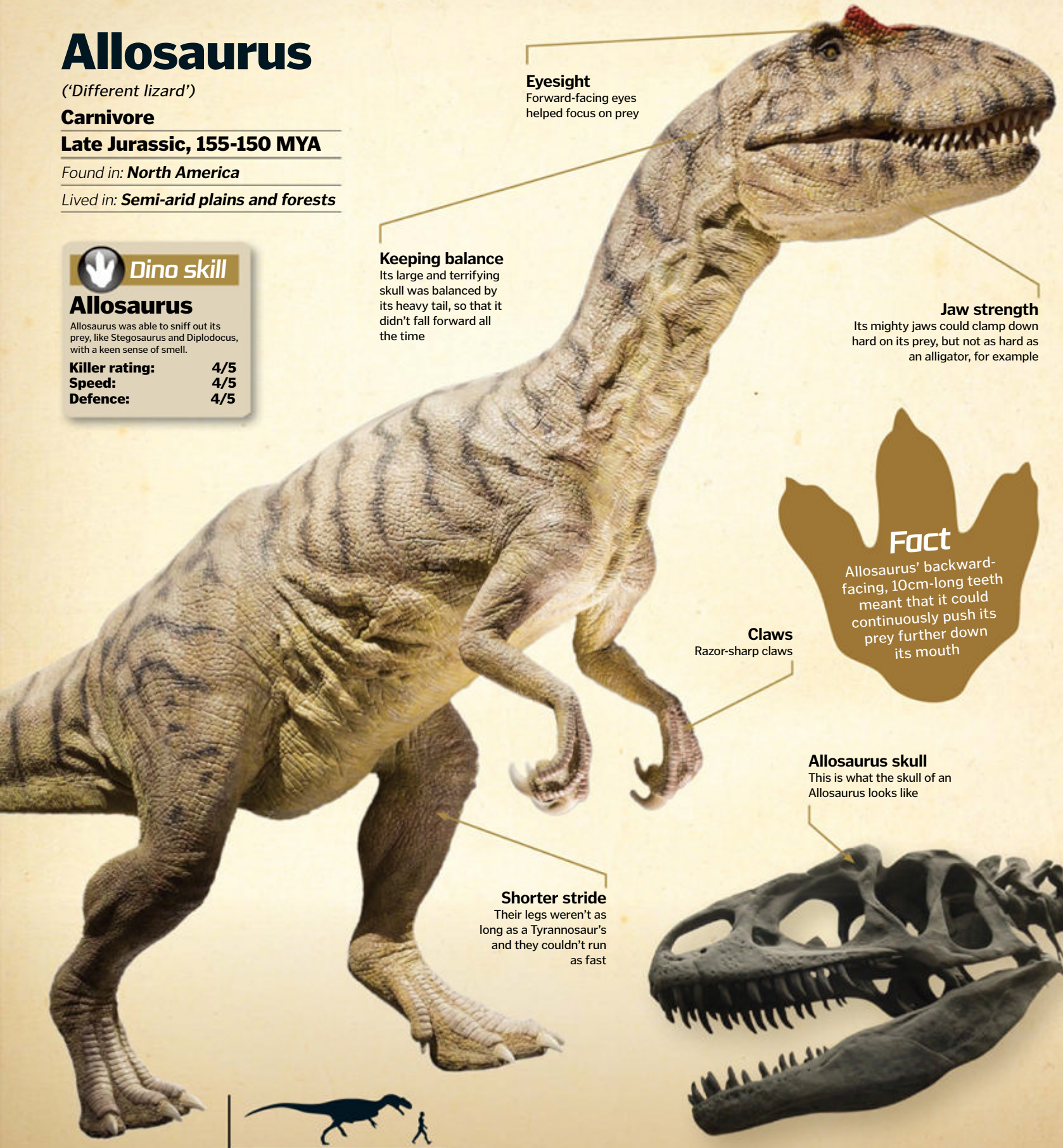
Jaw strength
Its mighty jaws could clamp down hard on its prey, but not as hard as an alligator, for example

Fact
Allosaurus' backward-facing, 10cm-long teeth meant that it could continuously push its prey further down its mouth

Claws
Razor-sharp claws

Shorter stride
Their legs weren't as long as a Tyrannosaur's and they couldn't run as fast

Allosaurus skull
This is what the skull of an Allosaurus looks like



DID YOU KNOW? Separated by millions of years, T-rex and Spinosaurus would never have met

Spinosaurus

(‘Spine lizard’)

Carnivore

Cretaceous period, 112-97 MYA

Found in: **North Africa**

Lived in: **Forests**

Largest carnivore

Spinosaurus was taller than T-rex

Fact

Spinosaurus is the largest meat-eating animal that has ever existed, bigger than a T-rex. Its diet consisted of fish and land animals

Sail back

The giant 1.5m spine, sometimes called its ‘sail’, could have been used to attract mates, control body temperature and warn off competitors

Crocodile-like

Its head was the longest of any carnivorous dinosaur, the size of a human being, and was shaped like a crocodile’s head

Grasping arms

Claws on its small arms could grab prey



Dino skill

Spinosaurus

Its teeth were arranged in a ‘fish trap’ at the front of its mouth to better catch slippery fish, while its nostrils were turned inward, so it could eat and breathe at the same time while in the water.

Killer rating: 4/5
Speed: 4/5
Defence: 4/5





HOW IT WORKS

MOST AMAZING DINOSAURS

Argentinosaurus

(‘Argentine lizard’)

Herbivore

Cretaceous, 95 MYA

Found in: **Argentina**

Lived in: **Forests**

Egg production

Adult Argentinosaurus would lay dozens of eggs each year

Intelligence

Its small brain meant that Argentinosaurus was not particularly intelligent

Armoured

We can tell from fossil finds that its skin was armoured

Slow mover

Argentinosaurus was incredibly slow and walked at 8km/h – a human could beat it in a walking race

Manure

Argentinosaurus would have produced 15 litres’ worth of dino droppings each time – that’s about five big buckets of poo in one go

Fact

Argentinosaurus was the largest animal to walk the Earth. Babies had to grow a massive 25,000 times their original size

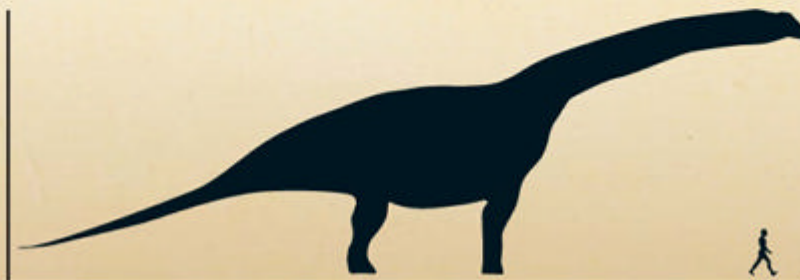


Dino skill

Argentinosaurus

Argentinosaurus had the ability to stand up on its back legs, then come crashing down on any attackers.

Killer rating: 2/5
Speed: 1/5
Defence: 3/5



DID YOU KNOW? Carnotaurus was given its name due to the bull-like horns on its head

Carnotaurus

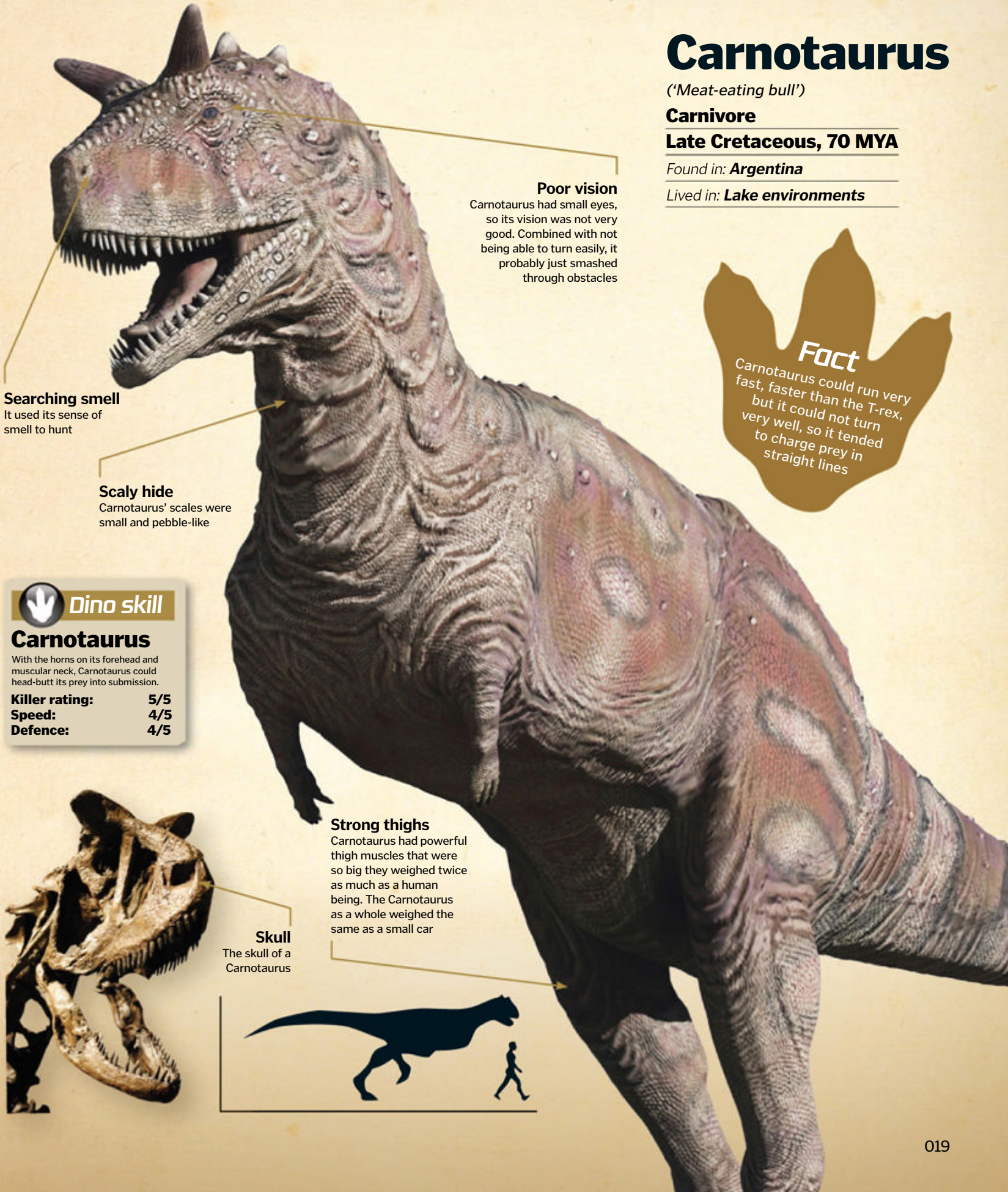
(‘Meat-eating bull’)

Carnivore

Late Cretaceous, 70 MYA

Found in: **Argentina**

Lived in: **Lake environments**



Searching smell
It used its sense of smell to hunt

Scaly hide
Carnotaurus' scales were small and pebble-like

Poor vision
Carnotaurus had small eyes, so its vision was not very good. Combined with not being able to turn easily, it probably just smashed through obstacles

Fact
Carnotaurus could run very fast, faster than the T-rex, but it could not turn very well, so it tended to charge prey in straight lines



Dino skill

Carnotaurus

With the horns on its forehead and muscular neck, Carnotaurus could head-butt its prey into submission.

Killer rating: 5/5
Speed: 4/5
Defence: 4/5



Skull
The skull of a Carnotaurus

Strong thighs
Carnotaurus had powerful thigh muscles that were so big they weighed twice as much as a human being. The Carnotaurus as a whole weighed the same as a small car





Plesiosaurus

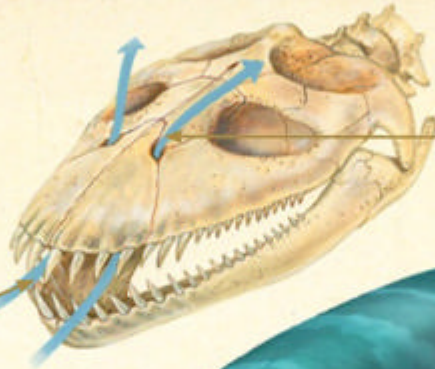
('Close to lizard')

Carnivore

Early Jurassic, 195 MYA

Found in: **England**

Lived in: **Forests**



Breathing out
When breathing out it would push the air out through its nostrils

Breathing in
The Plesiosaurus would breathe in through its mouth

Streamlined
Smooth skin helped the Plesiosaurus swim

Flippers
Plesiosaurus had flippers to push itself through the water at about 16km/h, which is slower than today's dolphins or whales


Sneak attack
Plesiosaurus's eyes were on the side of its head, so that it could look up at its prey, and attack from below

Fishy feast
Needle-like teeth were able to trap fish



Fact

As well as eating fish, Plesiosaurs also ate stones, which helped digest the fish by grinding them down inside their stomachs

 **Dino skill**

Plesiosaurus

The long neck of the Plesiosaurus has 40 bones compared to human necks that only have seven. This long neck allowed the Plesiosaurus to reach food in tight spaces.

Killer rating:	3/5
Speed:	2/5
Defence:	2/5



DID YOU KNOW? Diplodocus could replace teeth at a rate of one tooth every 35 days

Diplodocus

(‘Double beam lizard’)

Herbivore

Jurassic, 154-150 MYA

Found in: North America

Lived in: Forests, plains and rivers

Fact

The Diplodocus’s tail was an impressive weapon, capable of swinging it at an enemy faster than sound – just like a whiplash

Long tail

The long tail helped the Diplodocus to balance

Spiny back

Spines like an iguana ran along its back

Double beam

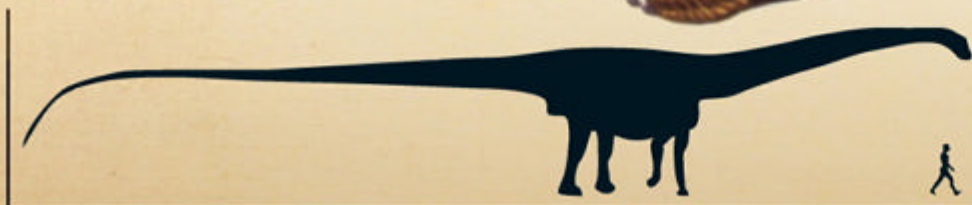
The ‘double beam’ meaning of the Diplodocus’s name is for the double v-shaped bones on the underside of its tail, which provided support for the tail

Vertebra

The neck and tail of a Diplodocus had 100 bones or vertebrae

Anatomy

Diplodocus was built like a suspension bridge, with the four legs acting like the pair of towers from which a long bridge is suspended

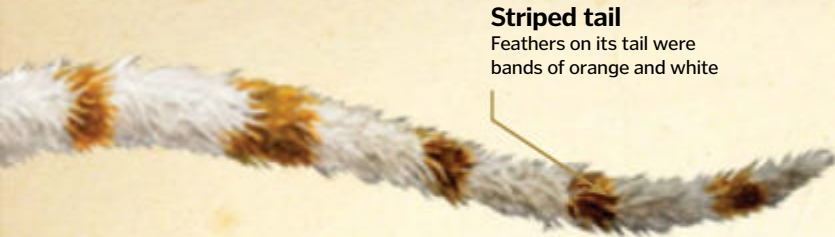


Dino skill

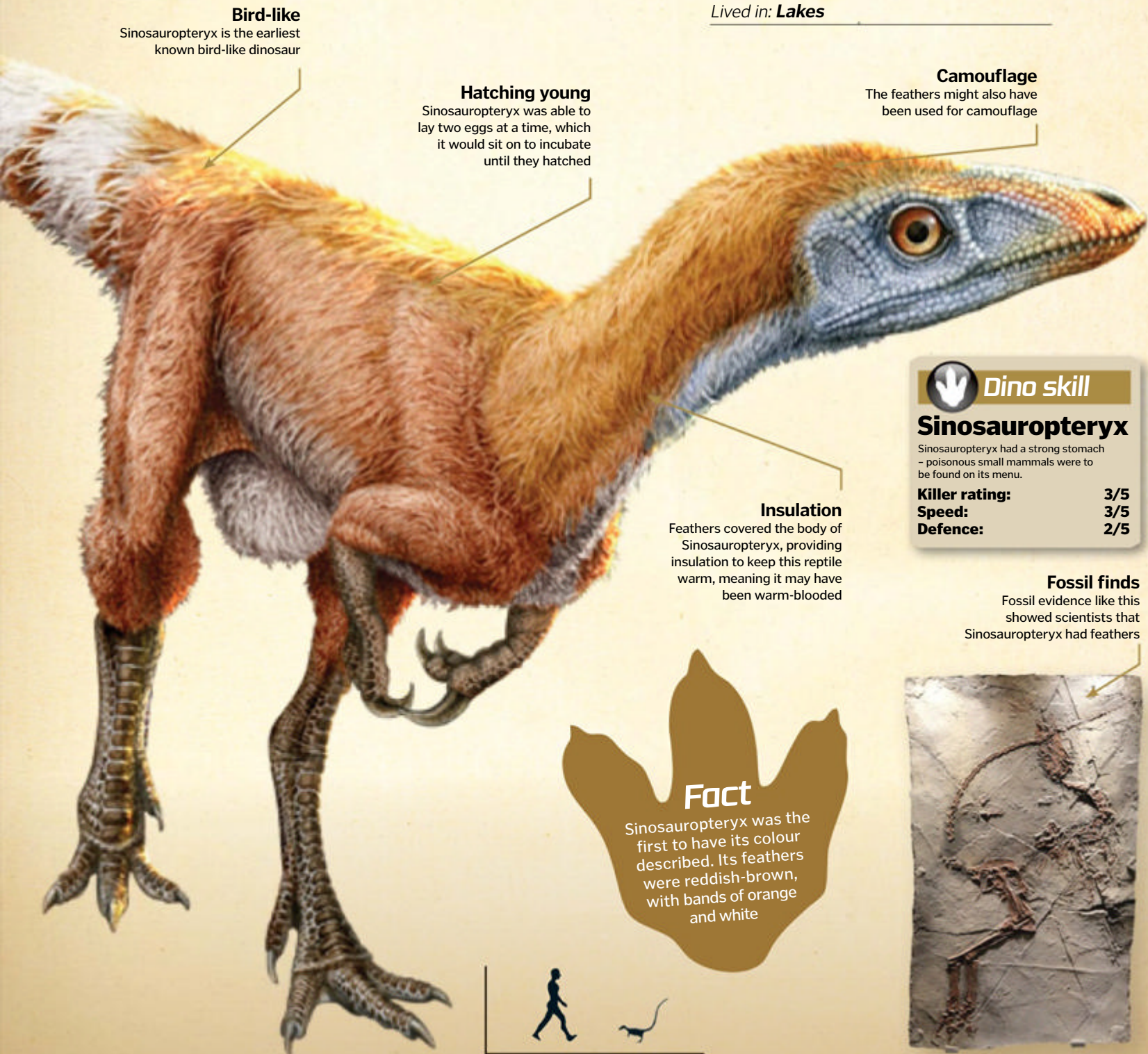
Diplodocus

An extra-long claw on its thumb allowed Diplodocus to rake through branches and vegetation for food, as well as using the claw to defend itself from predators.

Killer rating: 1/5
Speed: 3/5
Defence: 3/5



Striped tail
Feathers on its tail were bands of orange and white



Bird-like
Sinosauropteryx is the earliest known bird-like dinosaur

Hatching young
Sinosauropteryx was able to lay two eggs at a time, which it would sit on to incubate until they hatched

Camouflage
The feathers might also have been used for camouflage

Insulation
Feathers covered the body of Sinosauropteryx, providing insulation to keep this reptile warm, meaning it may have been warm-blooded

Sinosauropteryx

'Chinese lizard wing')

Carnivore

Cretaceous period, 135-120 MYA

Found in: **China**

Lived in: **Lakes**



Dino skill

Sinosauropteryx

Sinosauropteryx had a strong stomach - poisonous small mammals were to be found on its menu.

Killer rating:	3/5
Speed:	3/5
Defence:	2/5

Fossil finds

Fossil evidence like this showed scientists that Sinosauropteryx had feathers



Fact

Sinosauropteryx was the first to have its colour described. Its feathers were reddish-brown, with bands of orange and white



DID YOU KNOW? Ankylosaurus likely weighed up to four tonnes

Ankylosaurus

(‘Fused lizard’)

Herbivore

Cretaceous, 70-65 MYA

Found in: **South America**

Lived in: **Coastal plains**



Dino skill

Ankylosaurus

Its club-like tail was a vicious weapon that the Ankylosaurus could use to defend itself from attack.

Killer rating: 3/5
Speed: 3/5
Defence: 5/5

Spiky defence

Two rows of spikes ran along its body, plus there were two large horns from the back of its head that it could defend itself with

Small brained

The Ankylosaurus had a small brain

Fact

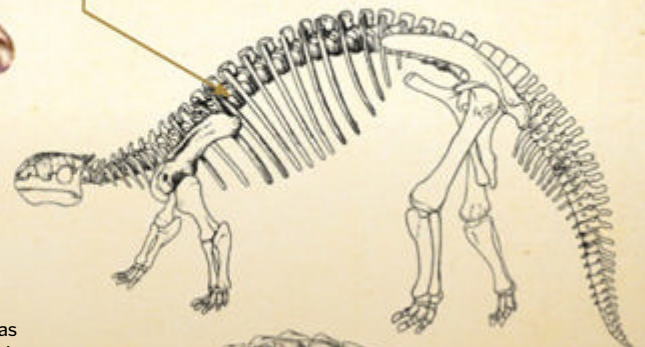
Ankylosaurus was built like a tank and had strong plates of bone fused into the skin on its back that was impenetrable to even T-rex

Breaking bones

Powerful club-tail could break an attacker's bones

Early impression

This is an old sketch of an Ankylosaur's skeleton, before the tail club was discovered



Bone head

Its entire head was covered in bony plates



Five-toed

Ankylosaurus probably had five toes on each foot

Vulnerable

The underside of its belly was the only place the Ankylosaurus was not armoured - flipping it over was the only way to kill it





Archaeopteryx

('First bird')

Carnivore

Jurassic period, 150 MYA

Found in: **Germany**

Lived in: **Subtropical islands**



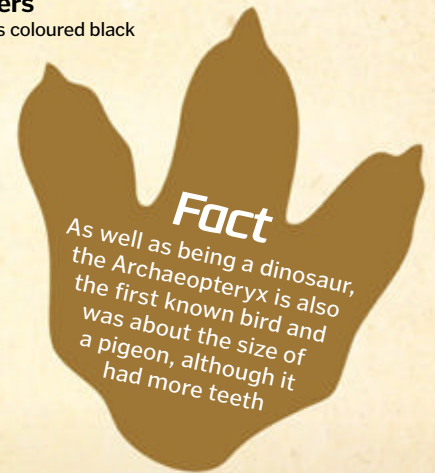
Fly or glide?

It is unclear whether Archaeopteryx was able to flap its wings and fly, or more likely whether it could just glide

Sharp teeth
Sharp teeth made Archaeopteryx an efficient predator

Dark feathers
Tips of feathers coloured black

Killer claws
Archaeopteryx had three claws on each wing, plus killing claws on its feet, with which would hunt for insects and small reptiles



Fact

As well as being a dinosaur, the Archaeopteryx is also the first known bird and was about the size of a pigeon, although it had more teeth



Dino skill

Archaeopteryx

Its wings were made for gliding only short distances - instead Archaeopteryx was well adapted to spending most of its time living in trees.

Killer rating:	2/5
Speed:	2/5
Defence:	2/5

Compsognathus

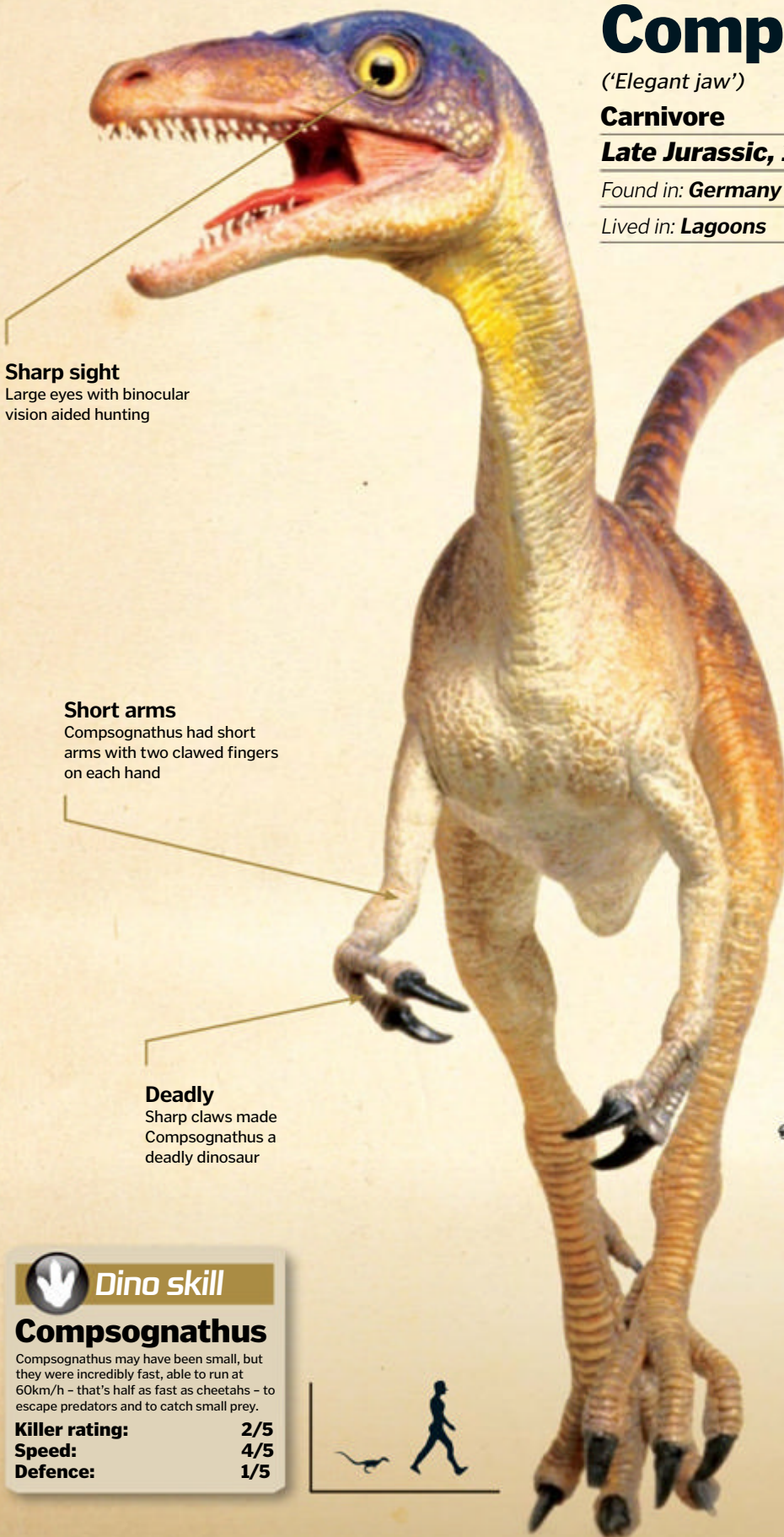
(‘Elegant jaw’)

Carnivore

Late Jurassic, 155-145 MYA

Found in: **Germany and France**

Lived in: **Lagoons**



Sharp sight

Large eyes with binocular vision aided hunting

Equilibrium

To help it run fast, its long tail helped to give the Compsognathus balance

Fact

Compsognathus had no time for chewing its food - a whole Bavarisaurus has been found in Compsognathus fossils

Short arms

Compsognathus had short arms with two clawed fingers on each hand

Pointed teeth

It had a small pointed head with sharp teeth

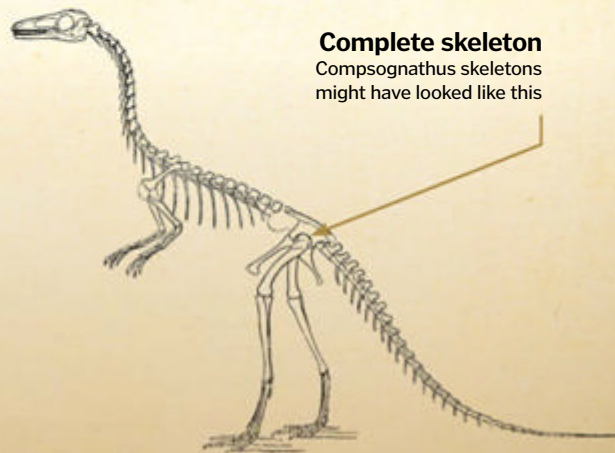
Deadly

Sharp claws made Compsognathus a deadly dinosaur



Complete skeleton

Compsognathus skeletons might have looked like this



Dino skill

Compsognathus

Compsognathus may have been small, but they were incredibly fast, able to run at 60km/h - that's half as fast as cheetahs - to escape predators and to catch small prey.

Killer rating: 2/5
Speed: 4/5
Defence: 1/5





HOW IT WORKS

MOST AMAZING DINOSAURS

Herrerasaurus

('Herrera's lizard')

Carnivore

Late Triassic, 231 MYA

Found in: **Argentina**

Lived in: **River floodplains with active volcanoes**



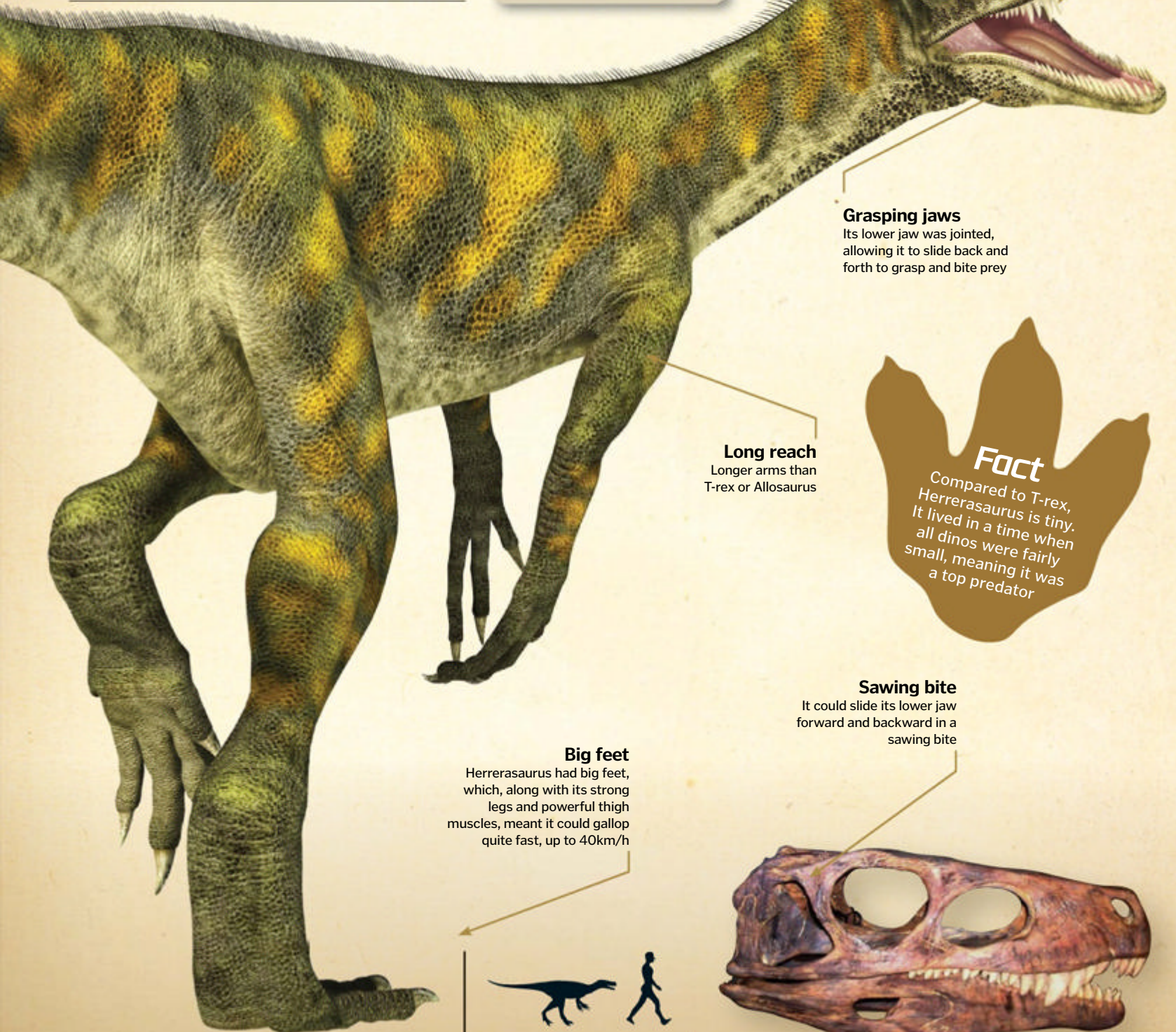
Dino skill

Herrerasaurus

One of the first dinosaurs, Herrerasaurus had an semi-opposable thumb among its claws, allowing it to grab more firmly onto its prey

Killer rating:	4/5
Speed:	4/5
Defence:	2/5

Deadly grip
Inwardly curving teeth allowed it to hang onto its prey



Grasping jaws
Its lower jaw was jointed, allowing it to slide back and forth to grasp and bite prey

Long reach
Longer arms than T-rex or Allosaurus



Fact
Compared to T-rex, Herrerasaurus is tiny. It lived in a time when all dinos were fairly small, meaning it was a top predator

Big feet
Herrerasaurus had big feet, which, along with its strong legs and powerful thigh muscles, meant it could gallop quite fast, up to 40km/h



Sawing bite
It could slide its lower jaw forward and backward in a sawing bite



Pachycephalosaur

(‘Thick-headed lizard’)

Herbivore

Late Cretaceous, 65-75 MYA

Found in: **North America, Isle of Wight, Mongolia, Madagascar**

Lived in: **Coastal regions**



Dino skill

Pachycephalosaur

Pachycephalosaur would use its domed head to ram the sides of other animals that attacked it.

Killer rating: 1/5
Speed: 2/5
Defence: 3/5



Armoured skull

Bony dome protected its small brain

Big eyes

It had large eyes compared to many other dinosaurs

Herd life

Pachycephalosaur found additional safety in numbers - they lived in herds, feeding on plants with their small, sharp teeth

Five fingers

Hands with five-fingered claws

Fighting fit

Some scientists think they used their thick skulls for fighting each other



Fact

Bow down to the royalty! Pachycephalosaur wore a crown of spikes on its head, which was armoured by a large, bony dome

Running from danger

Despite the powerful legs, Pachycephalosaur was not much of a sprinter, although its first line of defence from attackers would have been to run



Deinonychus

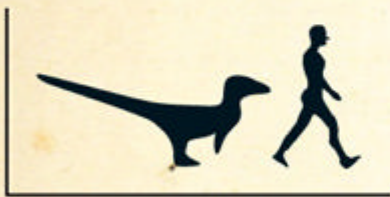
(‘Terrible claw’)

Carnivore

Early Cretaceous, 110 MYA

Found in: **North America**

Lived in: **Swamps**



Intelligent

Deinonychus had quite large brains compared to other dinosaurs, making them some of the smartest dinosaurs around

Proficient predator

A flexible neck helped it attack from all angles

Slash and tear


Large claw used for slashing prey

Bird-like

Some scientists think the legs closely resembled eagles and hawks

Pack hunter

Deinonychus were quite small so they may have hunted in packs to catch prey larger than themselves

 **Dino skill**

Deinonychus

Deinonychus is named after its large, hooked claw on the second toe of each foot, which it would use to slash at its prey.

Killer rating:	4/5
Speed:	3/5
Defence:	3/5

Fact

Birds are thought to have evolved from dinosaurs, and it was fossils of Deinonychus that first made scientists make the connection

Long fingers

They had long fingers with claws at end, the wrist bone is shown in red



DID YOU KNOW? *Liopleurodon* was the apex predator of its time and location

Liopleurodon

(‘Smooth-sided teeth’)

Carnivore

Mid-Jurassic, 160-155 MYA

Found in: **Europe**

Lived in: **The sea**

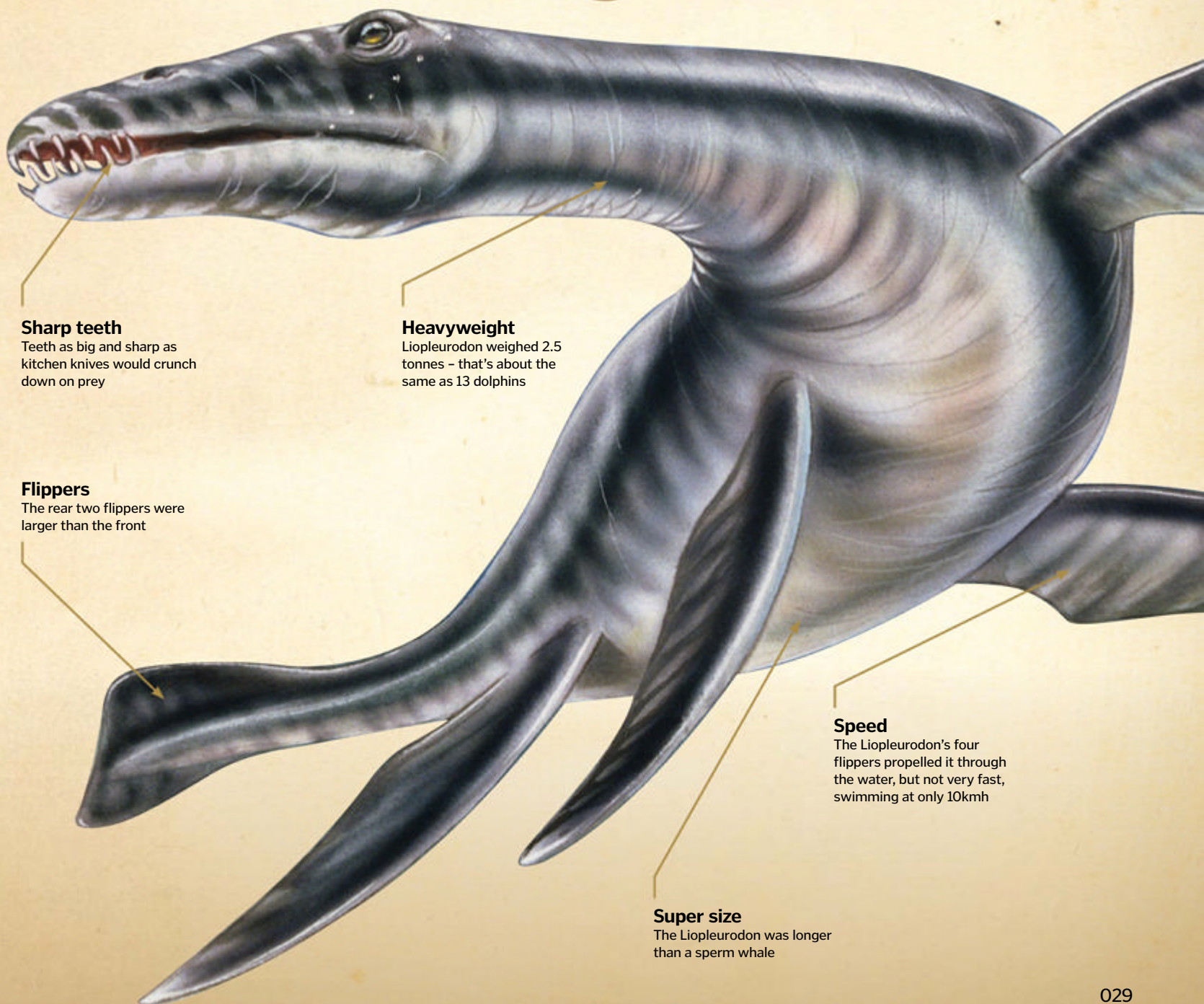


Dino skill

Liopleurodon

In the dark seas of the Jurassic era, the Liopleurodon used its keen sense of smell to sniff out prey that had the misfortune to swim past it.

Killer rating:	4/5
Speed:	3/5
Defence:	0/5



Sharp teeth

Teeth as big and sharp as kitchen knives would crunch down on prey

Heavyweight

Liopleurodon weighed 2.5 tonnes - that's about the same as 13 dolphins

Flippers

The rear two flippers were larger than the front

Speed

The Liopleurodon's four flippers propelled it through the water, but not very fast, swimming at only 10kmh

Super size

The Liopleurodon was longer than a sperm whale



Euoplocephalus

(‘Well-armed head’)

Herbivore

Late Cretaceous, 70 MYA

Found in: **North America**

Lived in: **Forests and rivers**



Weight

At 2,000kg
Euoplocephalus was
twice the weight of a
male Indian rhino



Dino skill

Euoplocephalus

Euoplocephalus would eat many types of plants and to help digest it all they had a large stomach inside a big rib cage and a barrel-shaped abdomen.

Killer rating: 1/5
Speed: 1/5
Defence: 4/5

Defence

Spikes and horns provided additional defence from jaws of carnivores like T-rex

Fact

Dinosaurs had poor eyesight and Euoplocephalus had some of the worst, - it probably bumped into things a lot



Armour plating

Euoplocephalus had armour plates that ran across their entire body, providing ample protection from the jaws of carnivores like T-rex

Bony club

It may have only eaten leaves, but its club-tail could give anyone who made it angry a life-threatening injury



DID YOU KNOW? Giganotosaurus shared its environment with Andesaurus, a massive sauropod

Giganotosaurus

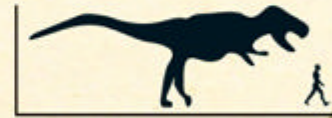
(‘Giant southern lizard’)

Carnivore

Cretaceous period, 100 MYA

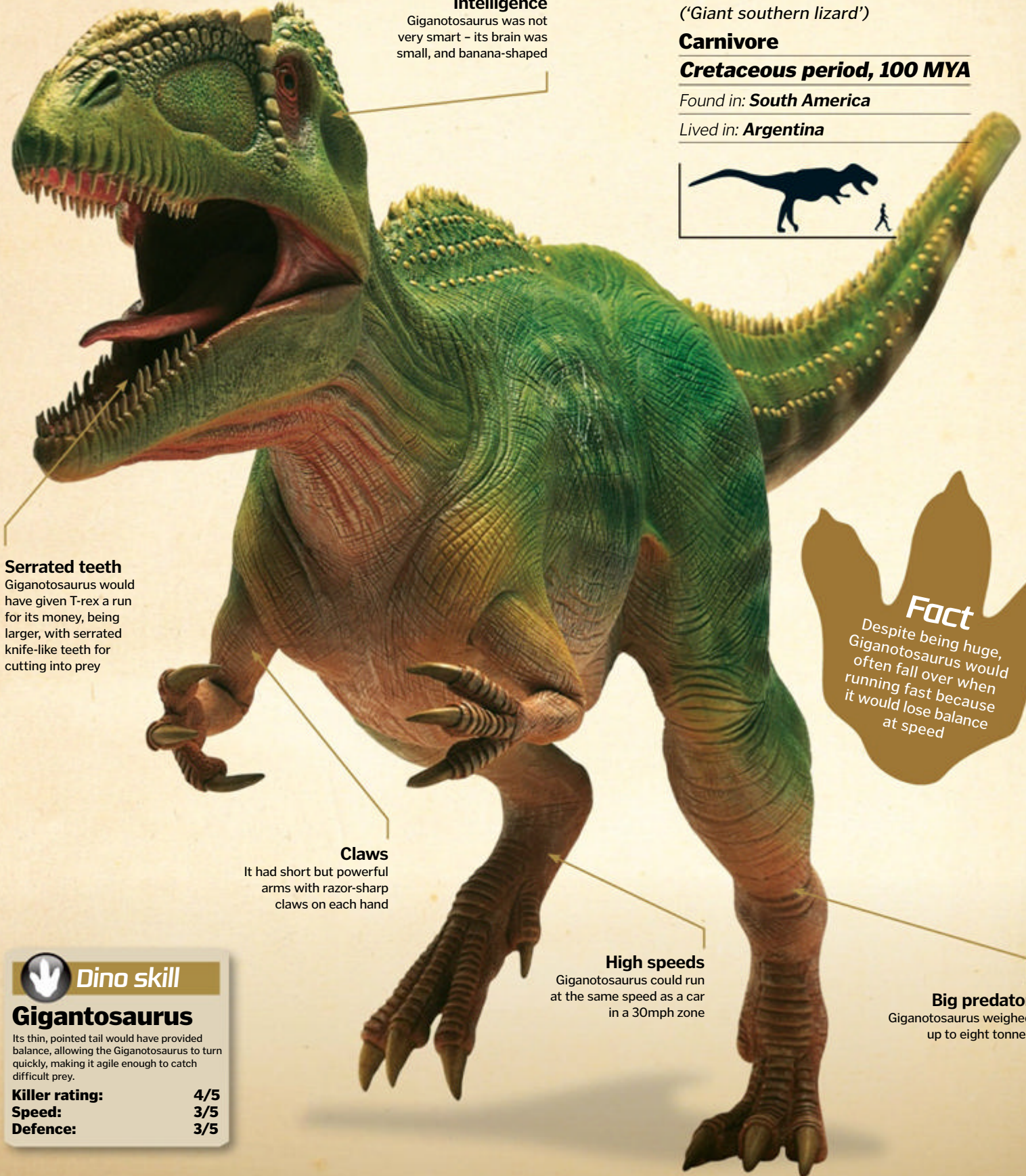
Found in: **South America**

Lived in: **Argentina**



Intelligence

Giganotosaurus was not very smart - its brain was small, and banana-shaped



Serrated teeth

Giganotosaurus would have given T-rex a run for its money, being larger, with serrated knife-like teeth for cutting into prey

Claws

It had short but powerful arms with razor-sharp claws on each hand

High speeds

Giganotosaurus could run at the same speed as a car in a 30mph zone

Fact

Despite being huge, Giganotosaurus would often fall over when running fast because it would lose balance at speed

Big predator

Giganotosaurus weighed up to eight tonnes



Dino skill

Giganotosaurus

Its thin, pointed tail would have provided balance, allowing the Giganotosaurus to turn quickly, making it agile enough to catch difficult prey.

Killer rating: 4/5
Speed: 3/5
Defence: 3/5



HOW IT WORKS

MOST AMAZING DINOSAURS

Iguanodon

('Iguana-tooth')

Herbivore

Early Cretaceous, 130 MYA

Found in: **Europe, North America,**

Africa, Asia

Lived in: **Forests, plains and rivers**

Tail

Iguanodon had a long, stiff tail



Dino skill

Iguanodon

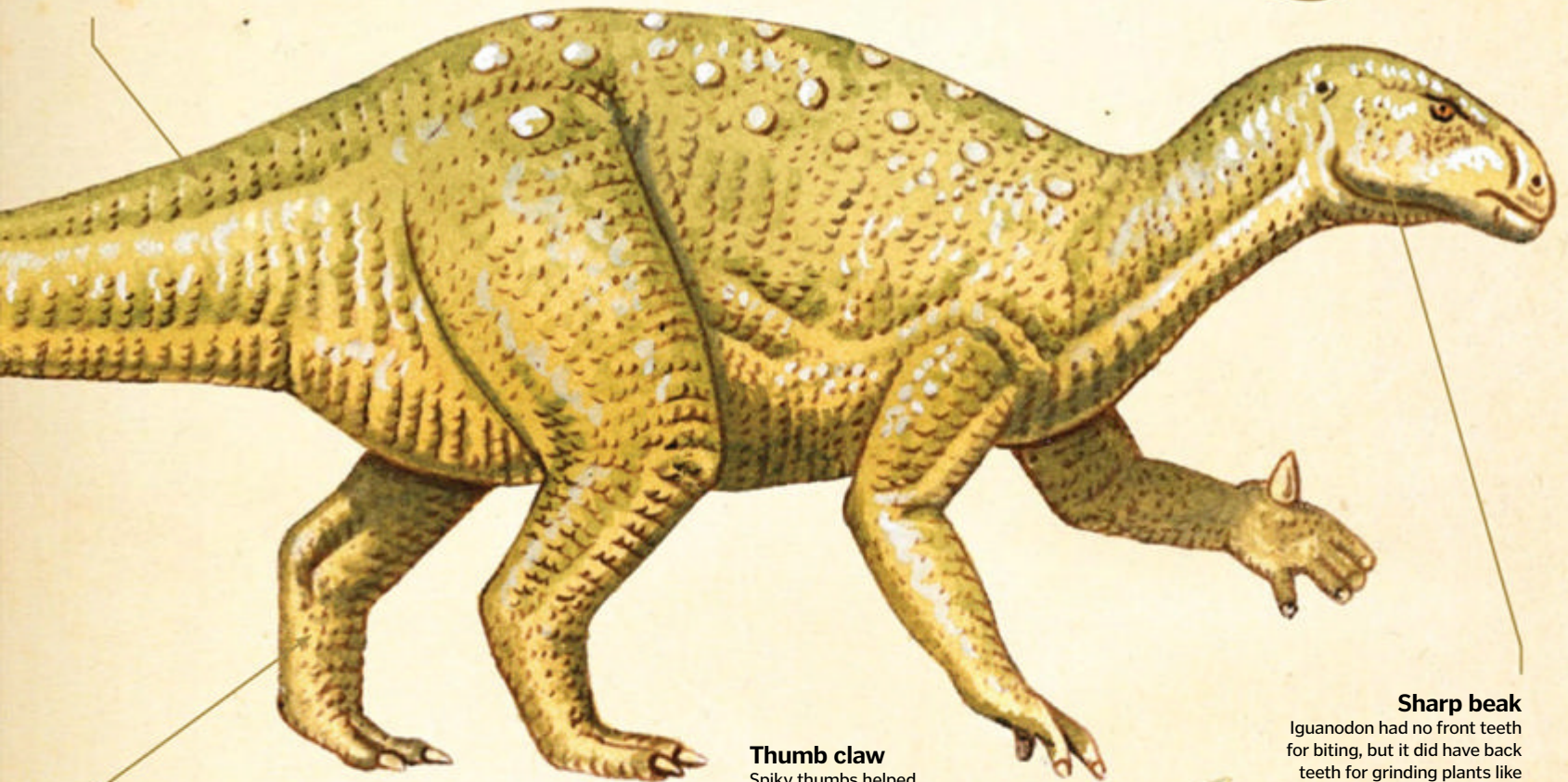
The Iguanodon's claws also had a thumb spike, which could have been used to help grab food, as well as fend off any attackers that got too close.

Killer rating:	1/5
Speed:	3/5
Defence:	2/5



Fact

Most dinosaurs stayed in one region but Iguanodons spent a lot of time moving, to all continents except Antarctica



Walk or run?

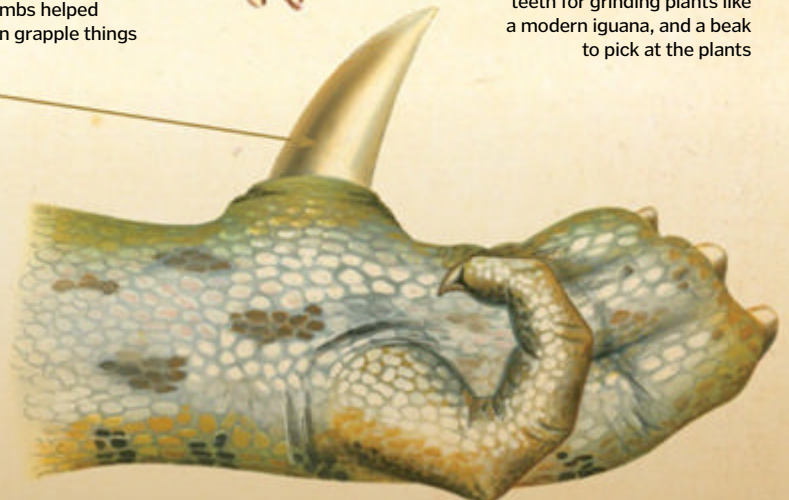
Iguanodon's legs were longer than its arms and it could walk on all fours or run on its back legs at up to 20kmh

Thumb claw

Spiky thumbs helped Iguanodon grapple things

Sharp beak

Iguanodon had no front teeth for biting, but it did have back teeth for grinding plants like a modern iguana, and a beak to pick at the plants



DID YOU KNOW? Megalosaurus was the first dinosaur to be described scientifically

Seismosaurus

('Quake lizard')

Herbivore

Late Jurassic, 156-145 MYA

Found in: **North America**

Lived in: **Forests, plains and rivers**



Dino skill

Seismosaurus

Its long neck ended in a small head armed with peg-like teeth that could strip entire woodlands of their leaves and other foliage in no time at all!

Killer rating: 1/5
Speed: 1/5
Defence: 4/5

Fact

Seismosaurus is a giant version of the Diplodocus. The ground would literally have shaken when this beast lumbered past

Long reach

A long neck allowed Seismosaurus to reach food

Herding instinct

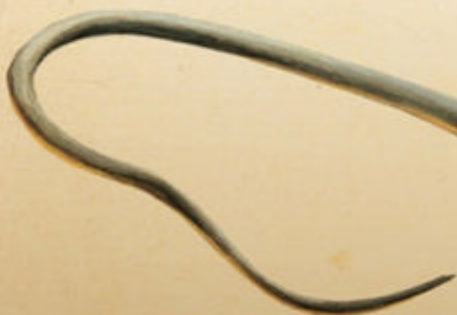
Seismosaurus travelled in grazing herds

Sturdy legs

Its enormous weight meant Seismosaurus needed very strong and sturdy legs to hold it up

Whip-like tail

Its long tail was a deadly weapon to be used against any would-be attackers





HOW IT WORKS

MOST AMAZING DINOSAURS

Ouranosaurus

('Brave lizard')

Herbivore

Early Cretaceous, 115-110 MYA

Found in: **North Africa**

Lived in: **Forests**



Intelligence

Ouranosaurus had average intelligence for a dinosaur

Sail

The distinctive spine ran across the length of Ouranosaurus' back and besides keeping the dinosaur cool, could have stored energy for the winter

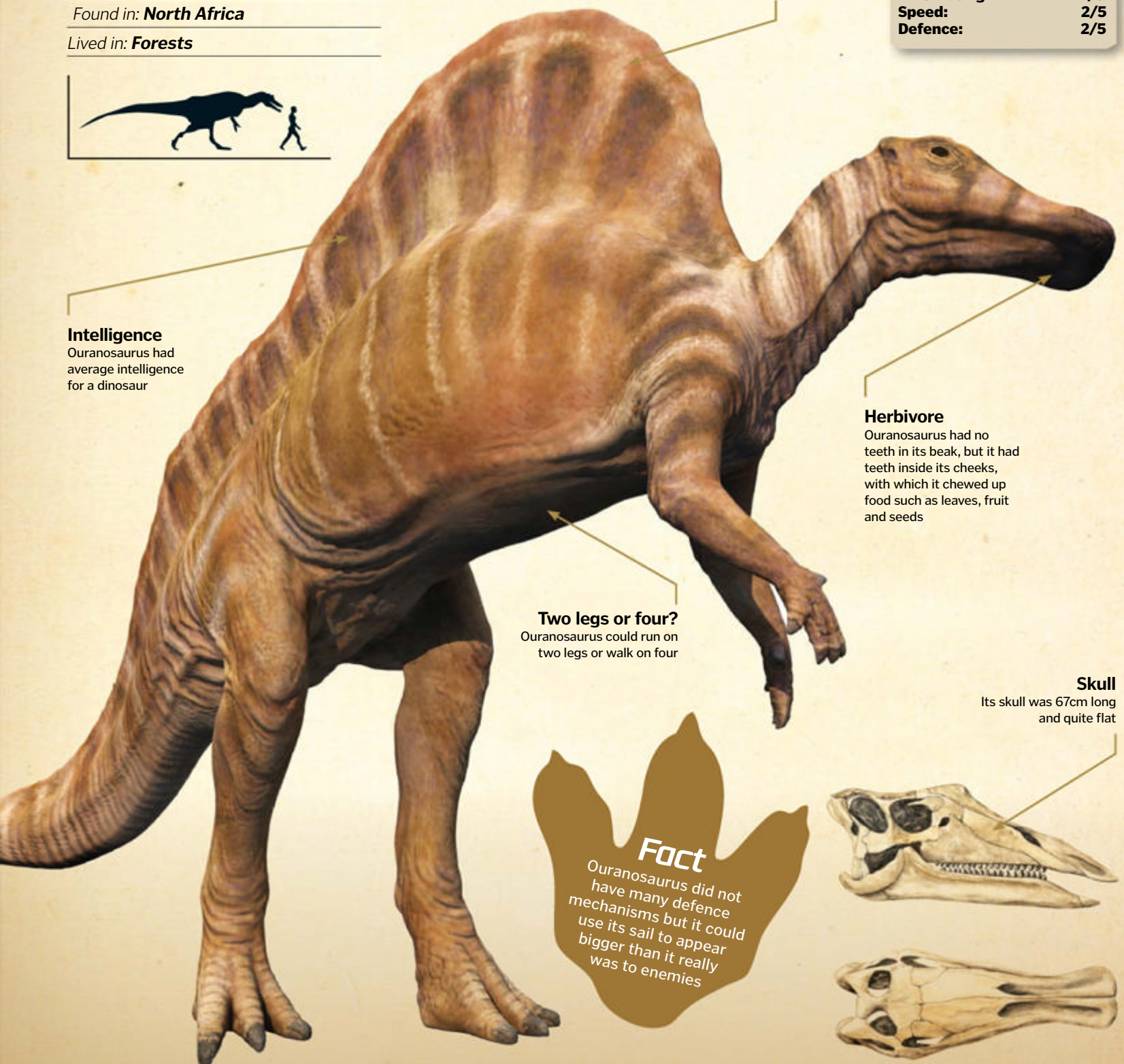


Dino skill

Ouranosaurus

Like Spinosaurus and Stegosaurus, the large sail on the spine of Ouranosaurus helped to regulate its temperature.

Killer rating:	1/5
Speed:	2/5
Defence:	2/5



Herbivore

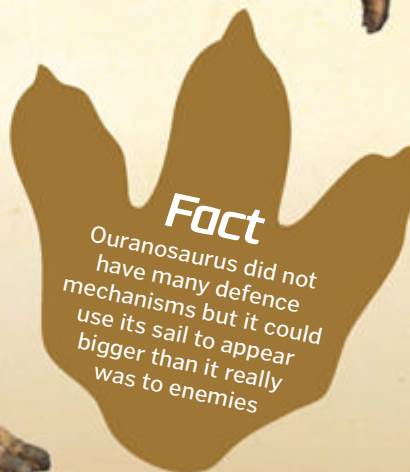
Ouranosaurus had no teeth in its beak, but it had teeth inside its cheeks, with which it chewed up food such as leaves, fruit and seeds

Two legs or four?

Ouranosaurus could run on two legs or walk on four

Skull

Its skull was 67cm long and quite flat



Fact

Ouranosaurus did not have many defence mechanisms but it could use its sail to appear bigger than it really was to enemies



DID YOU KNOW? Fossilised imprints suggest that Dilophosaurus may have had feathers

Dilophosaurus

(‘Two-crested lizard’)

Carnivore

Early Jurassic, 193 MYA

Found in: **Arizona, USA and China**

Lived in: **Close to rivers and in dry places**

Croc-like

This dinosaur had a strange bump behind its first row of teeth, making it look like a crocodile

Small predator

Dilophosaurus wasn't big enough to kill and eat large animals, so it ate smaller creatures and fish instead

Venomous?

Despite what you might have seen in the movie Jurassic Park, Dilophosaurus was unlikely to have spat out venom

Fact

Dilophosaurus had two frilly crests on the top of its head. It probably didn't have a neck frill, unlike its famous movie counterpart

Pack hunter

Dilophosaurus was very likely to have hunted in packs like wolves

Head crest

The most interesting part of its skull is this crest, used for attracting a mate



Dino skill

Dilophosaurus

Dilophosaurus was one of the largest predators of its time, during the Early Jurassic period. Fossilised footprints suggest that it hunted in packs.

Killer rating: 3/5
Speed: 2/5
Defence: 3/5



HOW IT WORKS

BOOK OF
DINOSAURS

THE PREHISTORIC WORLD



The prehistoric world

- 038** A to Z of the dinosaurs
Get to know these prehistoric beasts
- 046** What was a dinosaur?
The origins of the "terrible lizards"
- 048** When did dinosaurs rule the Earth?
How long did dinosaurs roam the Earth for?
- 050** Where did dinosaurs live?
What did the dinosaurs' habitat look like?
- 060** The dinosaurs' neighbours
Meet the creatures who lived beside the dinosaurs



041
Mass
destruction



045
Meteor
impact

054
Jurassic
swamps



042
Tyrant
lizard
king

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040
Dinosaur
communication

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056
Jurassic
ocean

© Getty Images

058
Cretaceous
plains





HOW IT
WORKS

THE PREHISTORIC WORLD

A to Z of dinosaurs



DID YOU KNOW? Dinosaurs were the dominant terrestrial vertebrates for 135 million years

A to Z of the dinosaurs

From birth to extinction, get to know these prehistoric beasts inside and out with our comprehensive A-Z guide



Dinosaurs have long sparked our imagination. From the Ancient Greeks' perception of their remains as evidence of a time when giants ruled Earth, right through to modern man's pursuit of their resurrection – be that in films like Jurassic Park or in laboratories via advanced DNA cloning techniques – dinosaurs remain a tantalisingly alien part of our world's history.

They may no longer roam the land like they did millions of years ago, but thanks to their genetic legacy and preserved remains they still remain a very real presence today.

From the fossils lying trapped in the ground through to the descendants flying above our heads, dinosaurs have unique tales to tell.

We take a closer look at this ancient world through an A-Z encyclopedia of all things dinosaur. You'll learn not just about the creatures themselves but the tools and techniques used to study them, and what Earth was like during their reign. This guide truly has it all, so strap yourself in and prepare for one wild, prehistoric ride...

Benton on a fossil dig near Albuquerque, New Mexico



Professor Mike Benton, palaeontologist Mike Benton is the Professor of Vertebrate Palaeontology at the University of Bristol, UK, and is a world-renowned dinosaur specialist. His areas of

expertise include the diversification of life through time, the origin of dinosaurs and the end-Permian mass-extinction event. He can be found working on digs in Russia and China. He offers words of wisdom throughout our dino guide, but for a more in-depth interview, head to howitworksdaily.com.



HOW IT WORKS

THE PREHISTORIC WORLD

A to Z of dinosaurs

A

Amber & dino DNA

Amber is fossilised tree resin that, due to a chemical change after burial in the ground, turns into a solid. Despite its stable state today, when the majority of the Earth's amber formed, it was far more fluid, which means many little organisms unwittingly became stuck within it – including plant matter and insects. Today these appear frozen

within the amber and have been perfectly preserved. While one or two studies in the Nineties claimed to extract DNA from these organic inclusions (as portrayed in Jurassic Park), more recent research suggests this isn't possible. Scientists at the University of Manchester using advanced DNA sequencing in 2013 were not even able to find traces of DNA in copal (a precursor to amber) only 10,000 years old, so they're very doubtful that dino DNA could have survived from millions of years ago.



C Communication in focus

Dinosaurs, much like the many species of animal alive today, communicated in very different ways. From complex dance-like movements to more obvious calls and scent markings, each dino marked their territory, warned of potential predators and relayed information regarding food in its own unique way. One of the most

interesting examples comes in the form of the hadrosaurid (above), a duck-billed dinosaur family sporting a distinctive bone crest on their heads. These crests were used as a resonating chamber for projecting their calls. Considering the hadrosaur's modest size and its wide range of predators, the ability to amplify its calls was no doubt a valuable defensive mechanism.

B

“Certain kinds of excavation and study out in the field can be for palaeoecology, trying to reconstruct food webs and modes of locomotion, or they can be about looking at patterns over time, going up metre by metre in rock formations and analysing fossil groups to see how they change”

Bone secrets

Dinosaur bones are one of a palaeontologist's greatest sources of information, supplying data about their age, anatomy, distribution and much more. The bones of dinosaurs can only be found if they went through the process of fossilisation, where the tissue of the creature dissolves and gets replaced with minerals under pressure beneath the ground. Finding and extracting these fossilised bones is a major challenge for palaeontologists, with a carefully planned out dig site essential.

Tools
Clearance is achieved with chisels, hammers and spades. The closer to the fossil the more delicate the tools

Boundary
As soon as the fossil has been confirmed, a boundary is staked, protecting the area so palaeontologists can work unhindered

Discovery
Most fossils are discovered at first only in part, with just a small fragment visible above the surface

Shooting in situ
Photography plays a crucial part of any excavation. The specimen is continuously snapped from its discovery right through to removal

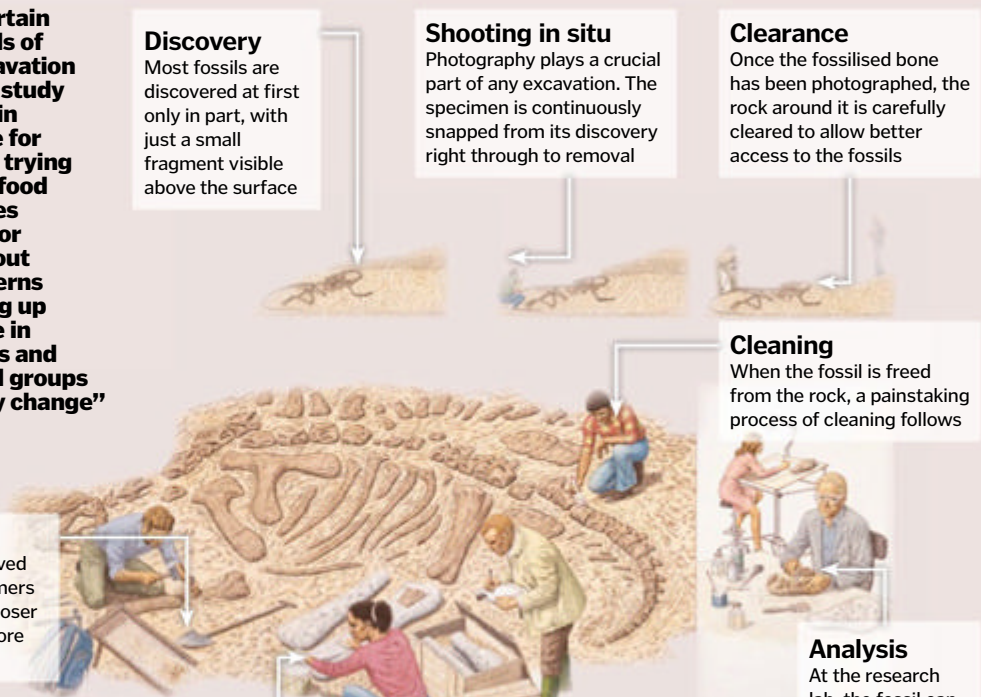
Clearance
Once the fossilised bone has been photographed, the rock around it is carefully cleared to allow better access to the fossils

Cleaning
When the fossil is freed from the rock, a painstaking process of cleaning follows

Extraction
The fossil is cut from the surrounding rock and removed piece by piece, with each one meticulously labelled

Packed up
The fragile specimens need to be transported with great care, with fossils placed in padded containers

Analysis
At the research lab, the fossil can be studied in depth, with laser scanning revealing in-depth detail about the dinosaur



DID YOU KNOW? You can see a Diplodocus skeleton in the Natural History Museum, UK

Diplodocus: a dino titan

Of all the dinosaurs that lived on Earth few can truly lay claim to be a terrestrial giant – but the Diplodocus can. Built like a suspension bridge, the Diplodocus measured over 25 metres (82 feet) long – that’s longer than five African elephants! It weighed over 12 tons, roughly 170 times more than the average human. It had an

incredibly long neck and counterweight tail, the former used to elevate its head into the foliage of trees for food, while the latter was its primary form of defence. With a typical Diplodocus estimated to have lived between 50 and 80 years, it also had one of the longest life spans of any dinosaur from the Jurassic period.



F Feathered fiends

Since palaeontologists began uncovering dinosaur remains in the 19th century, our depictions of them in the flesh have been largely coloured by a few initial artist impressions, with figures such as Charles Knight often drawing species in inaccurate postures and with factually incorrect sizes, colours and features. Based on current evidence, the lack of feathers on most species is one of the most obvious flaws in these early depictions, with half of all non-avian theropods now thought to have been partly feathered. The main cause for these misassumptions has been the lack of evidence, with feathers and soft tissues rarely preserved like fossilised bone.



“Colour in dinosaur feathers was a topic I think people thought that we would never know the answers to. But we were able to rely on a fair number of fossil

feathers that were exceptionally well preserved and deep within their internal structure we could see colour-bearing organelles. So by using some smart observations and techniques we have proved it to be possible”



E Extinction

Dinosaurs perished some 65 million years ago in what is known as the K-Pg (formerly K-T) extinction event.

This cataclysmic event at the Cretaceous-Palaeogene boundary led to 75 per cent of all species on Earth dying off. From the smallest ocean plankton to the largest land beasts, the K-Pg extinction event resulted in devastation at every level of the world’s ecosystems, with all non-avian dinosaurs eradicated. The current theory for the catalyst of this global wipeout is an asteroid impact in South America, but the real cause for such widespread carnage was not the impact itself but its knock-on effects. These include plants not being able to photosynthesise due to dust blocking out the Sun plus a series of epic tsunamis and fire storms.

G Genetic legacy

Today the study of dinosaurs is entering an exciting new age, where we can achieve an unprecedented level of accuracy through cutting-edge analysis. After a T-rex’s soft tissue was discovered within a bone sample, we can now study things like proteins, blood vessels and other micro-anatomy to help us determine how individuals lived and died, as well as how dinos evolved.



H Hunting strategies

Whether dinos hunted and scavenged alone like the T-rex or in large packs like the Deinonychus – the model for the Velociraptor in Jurassic Park – carnivorous dinosaurs were no doubt the apex predators on Earth. However, debate rages as to how co-ordinated dinosaur pack hunters were. Since first described in 1969 by palaeontologist John Ostrom, the Deinonychus has been

imprinted in the public consciousness as a highly intelligent, synchronised team hunter. However, many modern dino experts disagree with this assumption, believing that while Deinonychus did move and chase prey in groups, they did so with little co-ordination, with each individual simply acting out of self-interest rather than working together like, say, lions.



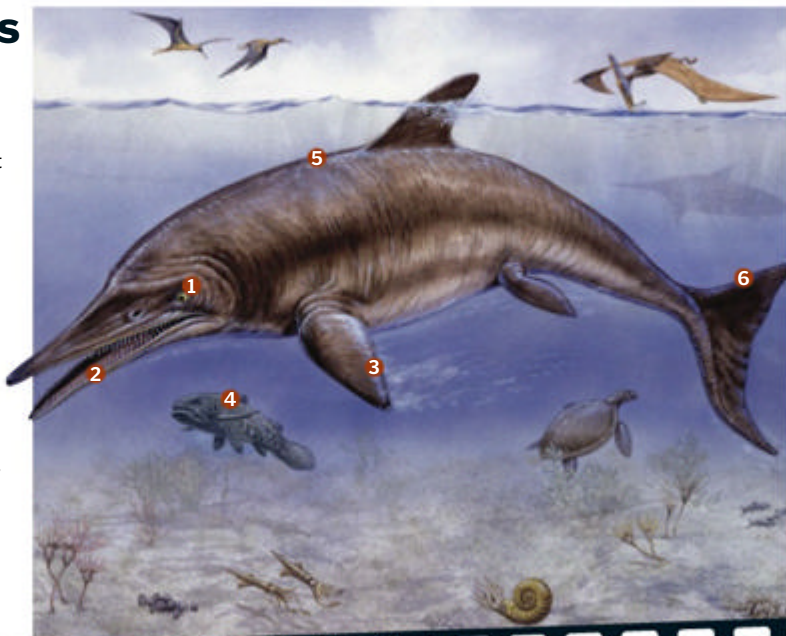
HOW IT WORKS

THE PREHISTORIC WORLD

A to Z of dinosaurs

Ichthyosaurus

Although technically not a true 'dinosaur', Ichthyosaurus, or 'fish lizard', filled the same niche in Earth's oceans and was one of the most dominant marine species of the Mesozoic era (252-65.5 Ma). Resembling today's dolphins, Ichthyosaurus measured in at roughly two metres (6.6 feet) in length and was capable of cruising through the water at around 40 kilometres (25 miles) per hour, enabling it to catch fish and squid with ease. The fact that Ichthyosaurus had a very large pair of eyes protected by a pair of bony, structural-supporting rings has led some palaeontologists to believe the species frequently hunted at great depths where pressure was very high.



1 Eyes

Large eyes were protected by rings of bone to keep them intact at great depths.

2 Teeth

The jaws were lined with rows of sharp, conical teeth, primed for shredding soft prey such as squid.

3 Fins

Stunted limb-like fins were used for stability and manoeuvring rather than propulsion.

4 Prey

Fish, squid and marine reptiles were the main food of Ichthyosaurus, but the sharp teeth could crush shellfish as well.

5 Body

Its body was streamlined, with a curved spine and no neck. By undulating its body it could alter its speed and direction.

6 Tail

A top speed of 40km/h (25mph) came courtesy of the bilobed, shark-like tail.

Jurassic lark Five factual bloopers from the famous Hollywood films

Timing problems

Jurassic Park portrayed many famous dinosaur species, including T-rex and Triceratops, but most of the animals shown actually lived in the Cretaceous period, not the Jurassic.

Out of proportion

One thing the film's producers definitely need punishing for is the depiction of the park's Velociraptors. Portrayed as being as tall as a man, in reality they barely stood 0.5m (1.6ft) off the ground.

Feather-brained

Another massive omission in Jurassic Park was the lack of any feathers. Most dinosaur species, especially sauropods, had some plumage on their bodies.

No grudge match

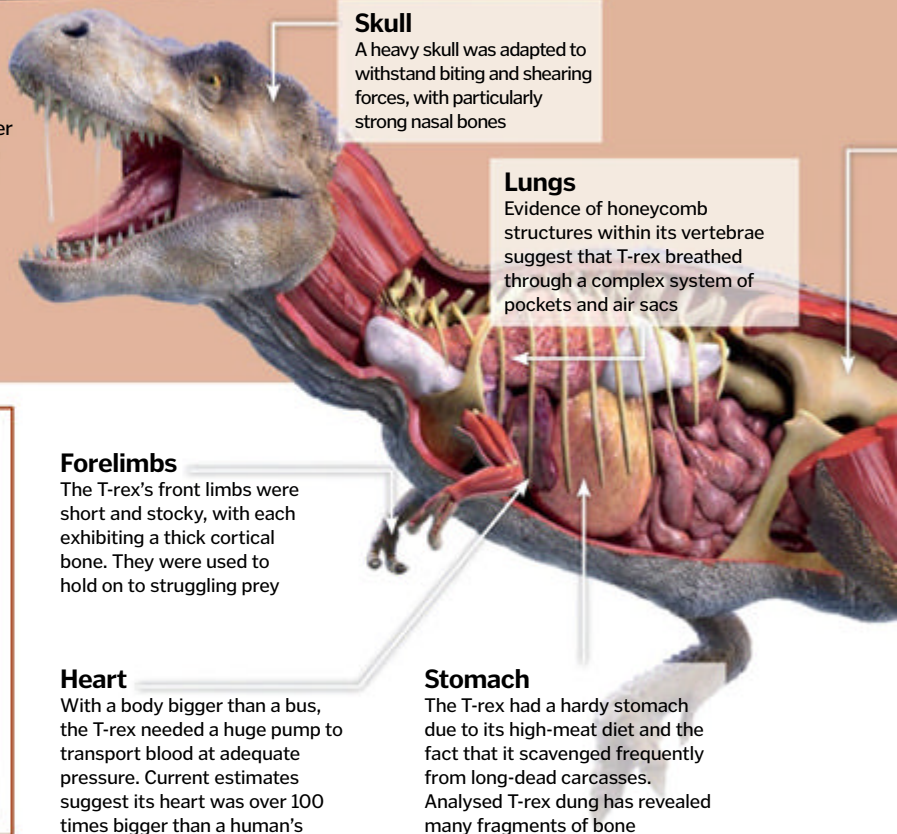
In the third film, the Spinosaurus is shown going toe-to-toe with its supposed arch-nemesis, the T-rex. In reality they never met as they lived on different continents of prehistoric Earth.

Spit on a grave

Another creative addition was Dilophosaurus's ability to spit out venom. However there is no evidence to suggest it could do this; neither did it have a frilled neck.

King of the dinosaurs

While not the biggest or smartest, the Tyrannosaurus rex was no doubt the closest to a king the dinosaurs ever had. A colossal bipedal carnivore, the T-rex measured in at over four metres (13 feet) tall and over 12 metres (39 feet) long, weighing over seven tons. It was no slowpoke either, with computer models estimating that the dino was capable of hitting a top speed of around 29 kilometres (18 miles) per hour chasing prey. When it caught up it could quickly dispatch them with a single bite that had a force of three tonnes – the equivalent weight of a fully grown African elephant. Yikes!



Skull

A heavy skull was adapted to withstand biting and shearing forces, with particularly strong nasal bones

Lungs

Evidence of honeycomb structures within its vertebrae suggest that T-rex breathed through a complex system of pockets and air sacs

Forelimbs

The T-rex's front limbs were short and stocky, with each exhibiting a thick cortical bone. They were used to hold on to struggling prey

Heart

With a body bigger than a bus, the T-rex needed a huge pump to transport blood at adequate pressure. Current estimates suggest its heart was over 100 times bigger than a human's

Stomach

The T-rex had a hardy stomach due to its high-meat diet and the fact that it scavenged frequently from long-dead carcasses. Analysed T-rex dung has revealed many fragments of bone

Lufeng: a fossil treasure trove

One of the most prolific dinosaur hotspots in the world is Lufeng in Yunnan Province, China. Since 1938, 33 species, each with its own complete fossil, have been found there. Some of the finds have been record-breaking, with many of the vertebrate fossils uncovered the oldest on record – the Lufengosaurus fossil (right) dates from 190 million years ago. Lufengosaurus was a genus of prosauropod that lived during the Early Jurassic period. Excavated finds can be seen at the Lufeng Dinosaur Museum.



DID YOU KNOW? Mesozoic means "middle life" in Greek



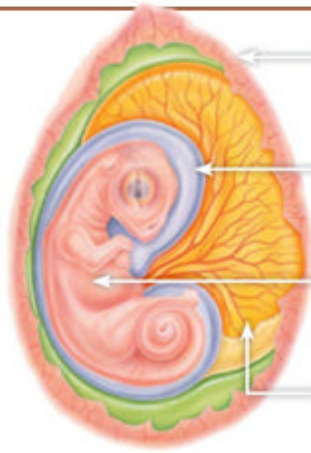
M Mesozoic world

Beginning 252.2 million years ago and coming to a close about 65 million years ago, encompassing a colossal stretch of time that includes the Triassic, Jurassic and Cretaceous periods, the Mesozoic era truly defined the age of dinosaurs. All the famous species you can think of lived within it.

The Mesozoic was generally warm with a significantly smaller temperature differential between the equatorial and polar regions – ideal conditions for the emergence and proliferation of flora and fauna. Not only was the Mesozoic famous for its domination by dinosaurs, but also for being the time period where the ancestors of today's major plant and animal groups emerged.

N Nesting & dinosaur eggs

Dinos organised their nests, laying their eggs in patterns suggesting complex social behaviours. Palaeontologists have identified two main types of egg-laying strategies – clutches and linear patterns – further divided by the shape of the nest and distribution of eggs. For example, the ornithomimid *Maiasaura* nests generally consisted of bowl-shaped excavations roughly two metres (6.6 feet) wide and 0.8 metres (2.6 feet) deep, the opening covered by loose vegetation. Each nest was spaced roughly seven metres (22 feet) apart and was used by their offspring until they were over a metre (3.3 feet) long.



Outer shell

Dinosaur eggs were elongated and had hard, brittle shells. Some of the largest found to date were 0.6m (2ft) long

Amniotic membrane

Encompassing the dinosaur was a thin membrane, helping keep the embryo hydrated during development

Embryo

At the centre lay the dinosaur embryo that, depending on the species, could take weeks or months to hatch

Yolk sac

This contained proteins and fat which served as food for the baby dino



Pelvis

The T-rex was a saurischian dinosaur, meaning it had a lizard hip arrangement. Its pubis bone pointed forward and down rather than backward and down like ornithischian species

P Palaeontology: key players

Most of our current knowledge of the dinosaur kingdom comes courtesy of palaeontologists, who dedicate their lives to uncovering the secrets of their prehistoric kingdom. From the earliest dinosaur hunters such as Othniel Marsh (pictured left), who discovered and named the *Allosaurus*, *Stegosaurus* and *Triceratops*, to 20th-century scientists who revolutionised our understanding

of the dinosaurs' legacy, such as John Ostrom who gained fame for his suggestion that birds were modern-day descendants, palaeontologists have helped provide tantalising glimpses of the prehistoric world.

One of the more contemporary palaeontologists who has helped introduce dinosaurs to the general public is Dr Philip J Currie. He is also a museum curator who helped found the prestigious Royal Tyrrell Museum of Palaeontology in Alberta, Canada.



"Weighing something like five tons yet walking bipedally makes the T-rex incredibly interesting, as it pushes the absolute limits of what is possible. I mean, you look at an elephant and think, 'Wow, that's amazing', however, an elephant has to walk on four legs and weighs roughly the same amount, so understanding how T-rex functioned is a fascinating area of research"

Body

Unlike popular depictions, it did not stand vertical on its large hind legs but leaned forward with its body approximately parallel to the ground

Tail

A muscular tail helped counterbalance the T-rex's heavy skull and aided locomotion, improving leg retraction speeds

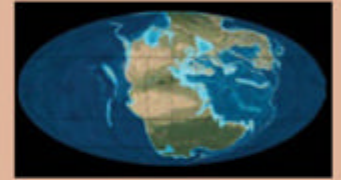
Hind legs

Powerful rear legs allowed it to hit around 29km/h (18mph). It was probably poor at turning though

Queensland

If you were to visit Queensland's more remote regions, you may very well find yourself standing face to face with one of many 100-million-year-old beasts. That's because Queensland's outback was once part of the Great Inland Sea, a huge swampy inland ocean that existed in the age of the dinosaurs. As such, hundreds of fossils have been excavated from this region and there is even an established 'Australian Dinosaur Trail' that tourists can follow.

O Oceans & continents



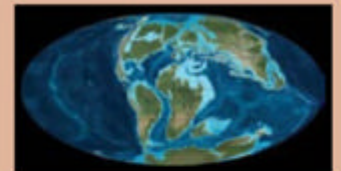
1 Triassic

At the beginning of the Mesozoic era in the Early Triassic period, all the land on Earth was joined together into the supercontinent of Pangaea, itself surrounded by the superocean Panthalassa.



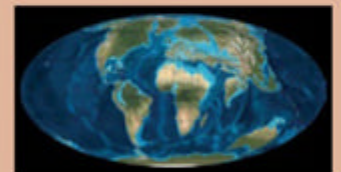
2 Jurassic

As the Mesozoic progressed and the Triassic made way for the Jurassic period, plate tectonics split Pangaea into two mega-continents: Gondwana and Laurasia, separated by the Tethys Sea.



3 Cretaceous

As the Mesozoic came to a close, Gondwana and Laurasia had split into many of the continents we know today, including North and South America and Antarctica.



4 Palaeogene

In the Palaeogene period – immediately following the K-Pg extinction – those continents continued to move to their current positions.



HOW IT WORKS

THE PREHISTORIC WORLD

A to Z of dinosaurs

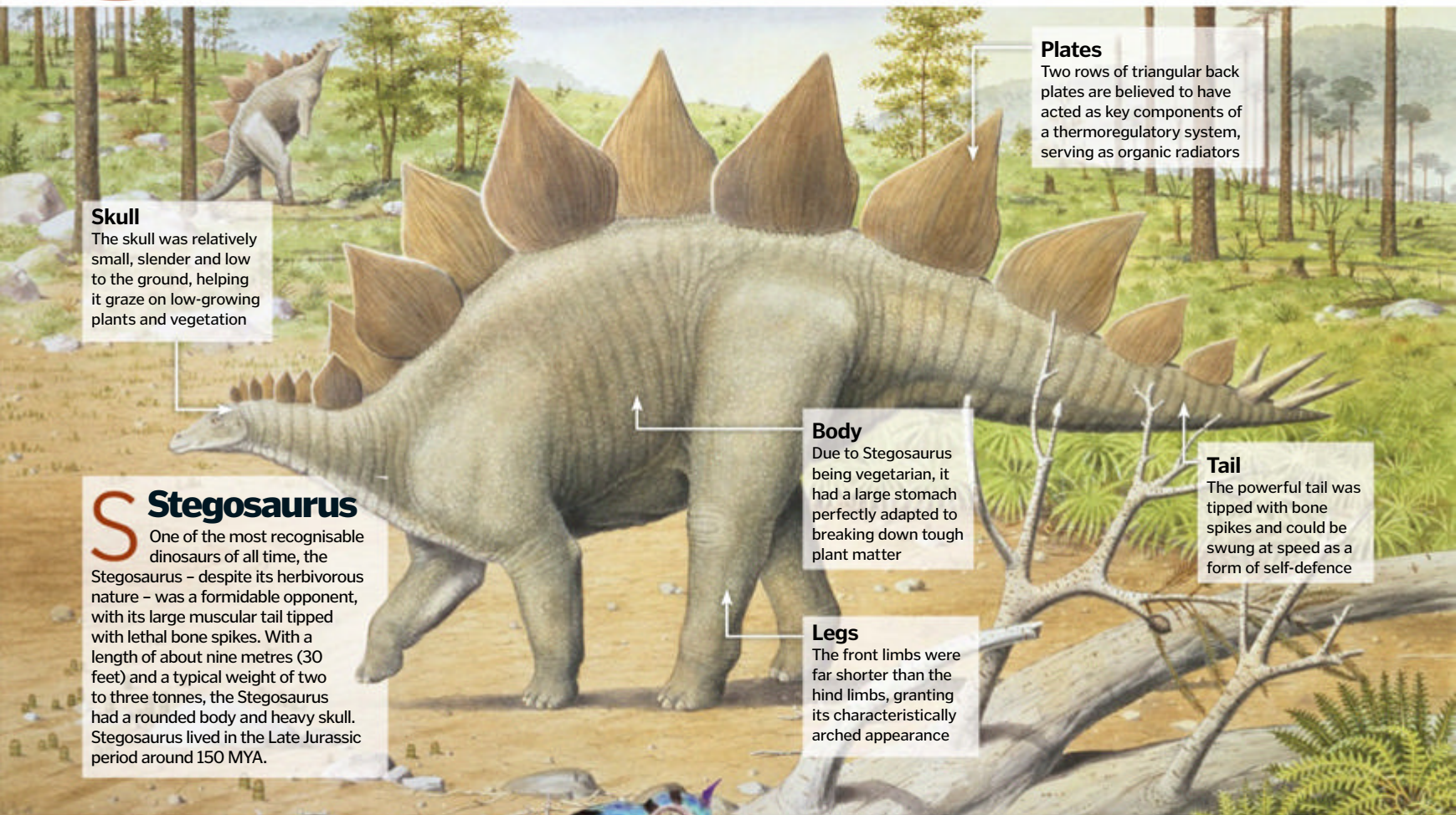


R

Relatives in the modern world

Massive scientific effort has been put into identifying which creatures today can trace their roots back to these prehistoric beasts. One of the best examples of this was the hunt for the nearest living relative of the once-mighty T-rex, undertaken by a research team at the North Carolina State University in 2007. To go about this the researchers

sequenced proteins from a 68-million-year-old T-rex tissue sample and, much to their surprise, discovered that the king of the dinosaurs' molecules showed remarkable similarity to the common chicken and that its collagen makeup was almost identical. So, at least for the time being, the humble chicken is the rightful ruler of the Earth...



Skull
The skull was relatively small, slender and low to the ground, helping it graze on low-growing plants and vegetation

S Stegosaurus
One of the most recognisable dinosaurs of all time, the Stegosaurus – despite its herbivorous nature – was a formidable opponent, with its large muscular tail tipped with lethal bone spikes. With a length of about nine metres (30 feet) and a typical weight of two to three tonnes, the Stegosaurus had a rounded body and heavy skull. Stegosaurus lived in the Late Jurassic period around 150 MYA.

Plates
Two rows of triangular back plates are believed to have acted as key components of a thermoregulatory system, serving as organic radiators

Body
Due to Stegosaurus being vegetarian, it had a large stomach perfectly adapted to breaking down tough plant matter

Legs
The front limbs were far shorter than the hind limbs, granting its characteristically arched appearance

Tail
The powerful tail was tipped with bone spikes and could be swung at speed as a form of self-defence

T Tall tails
You'll struggle to find a dinosaur without a tail. This is because the majority of dinosaurs used their tails for two important roles: the first being balance and the second being self-defence. Large animals like the T-rex and Diplodocus, thanks to their skulls or necks, were very top-heavy. They needed long and heavy tails to counterbalance this, especially when running. Smaller creatures such as Ankylosaurus (left) used its tail when under attack, evolving a large bony club at the end which could bludgeon assailants.



U Unenlagia: half bird, half dinosaur
One of the most telling links between dinosaurs and birds is the Unenlagia, a genus of theropod dinosaur from the Late Cretaceous that in almost all aspects, aside from flight, resembles a modern bird. It was discovered in 1997 and to date two species have been confirmed – U comahuensis and U paynemili – both of which share an almost identical pelvic structure to the early bird species Archaeopteryx.

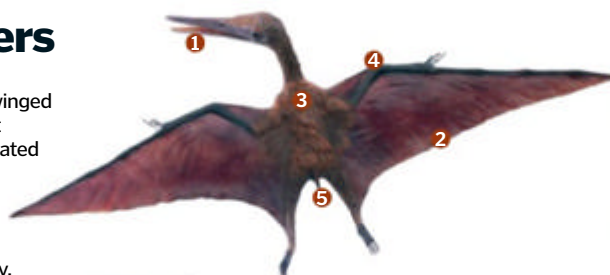
V Velociraptors debunked
Due to their appearance in the Jurassic Park films, the Velociraptor is easily one of the most recognisable of all species. Importantly though, this image of the Velociraptor is way off the mark in terms of reality. In contrast to the movie monster, research evidence suggests that the Velociraptor was actually a feathered dinosaur under 0.6 metres (two feet) in length, with colourful plumage used in mating rituals and visual displays. The species also had hollow bones, much like birds, and built large nests to protect their offspring. The Velociraptor did impress in ground speed, with it capable of hitting 39 kilometres (24 miles) per hour at top speed and boasting amazing agility, being able to change direction incredibly quickly. It used this speed to chase down prey, which largely consisted of small to medium-sized herbivores such as Protoceratops, and then kill them with its nine-centimetre (3.5-inch) retractable claws and sharp teeth. New research suggests that, while sociable compared with other carnivores, raptors were not apex pack hunters, with co-operative kills possible but infrequent.

DID YOU KNOW? *Iguanodon's thumb spike was originally thought to be a horn on the end of its nose*

Winged wonders

While not technically dinosaurs, pterosaurs were very much the winged wonders of the dinosaur era. Flying reptiles that evolved throughout the Late Triassic and dominated the skies until the Late Cretaceous, pterosaurs were the earliest vertebrates currently known to have evolved powered flight. Pterosaurs are not related to modern-day birds or bats, with the many species evolving earlier and separately.

The genus *Pterodactylus* was one of the most notable, with the species *Pterodactylus antiquus* one of the most impressive, with a toothed beak, large eyes and clawed wings. In terms of wingspan *P. antiquus* could extend its wings up to a metre (3.3 feet) and had a long, narrow skull packed with dozens of sharp, pointed teeth. It used these to snap up fish and smaller reptiles.



1 Beak

Up to 90 teeth in the long beak intermeshed when the jaw was closed, and were perfect for grabbing fast prey.

2 Wings

A wingspan of around 1m (3.3ft) was typical for *Pterodactylus*, with the wings structured in a way that indicates it would have flown like an albatross.

3 Body

Not as large as depicted in fiction, *Pterodactylus* was very lightly built with hollow bones and a long neck.

4 Limbs

Pterosaurs evolved a unique pteroid bone on the wrists of their forearms, used to support the forward wing membrane located between the wrist and shoulder.

5 Tail

Unlike some other pterosaurs, *Pterodactylus* had a relatively short, stubby tail.

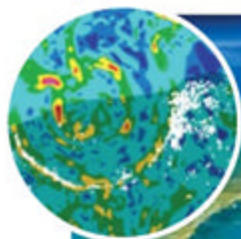


“Microraptor was a small, four-winged dinosaur... very close to the origin of birds. Its remains show it had wings on its arms and legs. It couldn't fly properly, but used its wings to glide. This shows the origin of flight in birds and their ancestors was much more complex than expected”

X X-raying prehistoric remains

X-ray scanners have become incredibly useful and important tools in the world of palaeontology as they can reveal many fossils and features that otherwise would remain hidden. For example, in November 2013, researchers in Germany used an X-ray machine to unveil the detailed structure of a fossil trapped within a plaster cast, all without ever

having to break it open and risking damage to the specimen. What's more, the researchers then made use of a 3D printer to re-create the X-ray scans in solid form, allowing palaeontologists to pick up and handle a cast of the fossil as fine and detailed as the real thing. Modern technology is set to further our understanding of dinosaurs by no bounds.



Y Yucatán impact

The colossal Chicxulub crater in the Yucatán Peninsula, Mexico, since its discovery in the Seventies, has heavily hinted as to how 75 per cent of all life on Earth was eradicated around 65.5 million years ago. The crater indicates that a space rock – probably an asteroid – at least ten kilometres (six miles) across impacted Earth. As a result of the extensive damage caused directly by the collision and consequently by tsunamis, dust storms and volcanism, it caused a total collapse in the world's ecosystems, with all non-avian dinosaurs at the top of the death list. Despite being challenged repeatedly, the impact's link to the K-Pg mass extinction has recently been reaffirmed with even more detail, with a research team linking the two events in time to within 11,000 years. That said, the researchers also highlighted that various precursory phenomena, such as dramatic climate swings, also contributed to the end of the dinosaurs post-impact.



Z Zalmoxes sized up

Zalmoxes, a genus of herbivorous dinosaur from the Late Cretaceous period, is believed by some to be one of the earliest examples of insular dwarfism – a condition whereby a species undergoes a continuous reduction in size to better suit its environment, shrinking over several generations. Fossils from at least two species of *Zalmoxes* have been found in central Europe and one of its closest ancestors is thought to be the much larger *Iguanodon*.





What was a dinosaur?

Dinosaurs were a reptile that first appeared over 230 million years ago. They lived on Earth longer than any other creature in history



Dinosaurs dominated the Earth for over 160 million years, often as the apex predators of their particular environments. Although fossilised dinosaur remains have been discovered throughout human history (early discoveries probably being the origins of mythical creatures such as

dragons and hydras), dinosaurs were only described scientifically in the early nineteenth century. It was British palaeontologist Sir Richard Owen who coined the taxon Dinosauria in 1842. The word dinosaur means "terrible lizard", but the term is somewhat misleading, as dinosaurs are not lizards but are

part of a separate group of reptiles altogether. Dinosaurs are a diverse group that began life on the super-continent of Pangaea. As continental shift progressed and Pangaea broke up into smaller landmasses, dinosaurs became strongly diversified. It's a wonder that Triceratops and T-rex share a common ancestor.

Defence

Thick skin and hard armour shells made these dinosaurs tough as nails

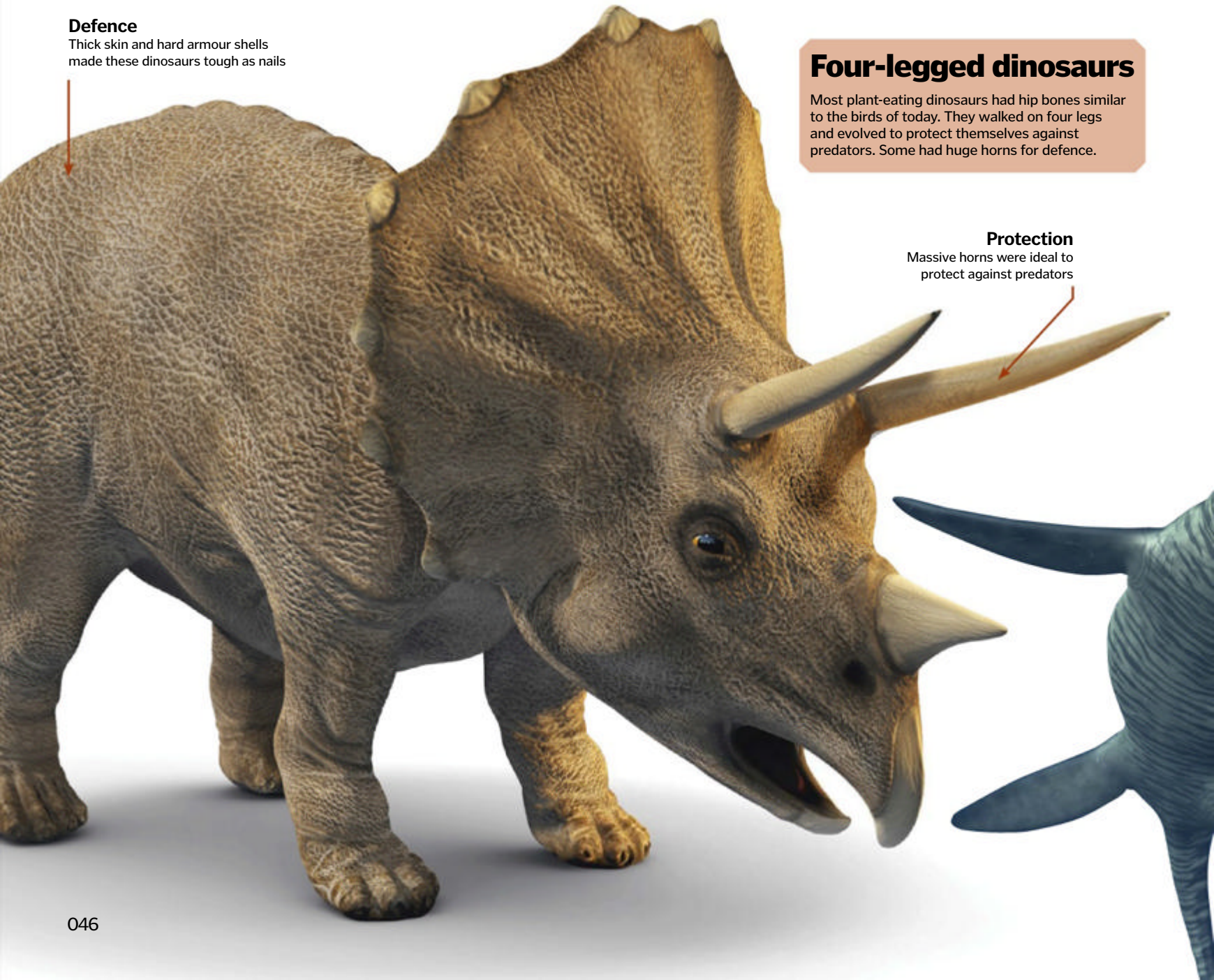


Four-legged dinosaurs

Most plant-eating dinosaurs had hip bones similar to the birds of today. They walked on four legs and evolved to protect themselves against predators. Some had huge horns for defence.

Protection

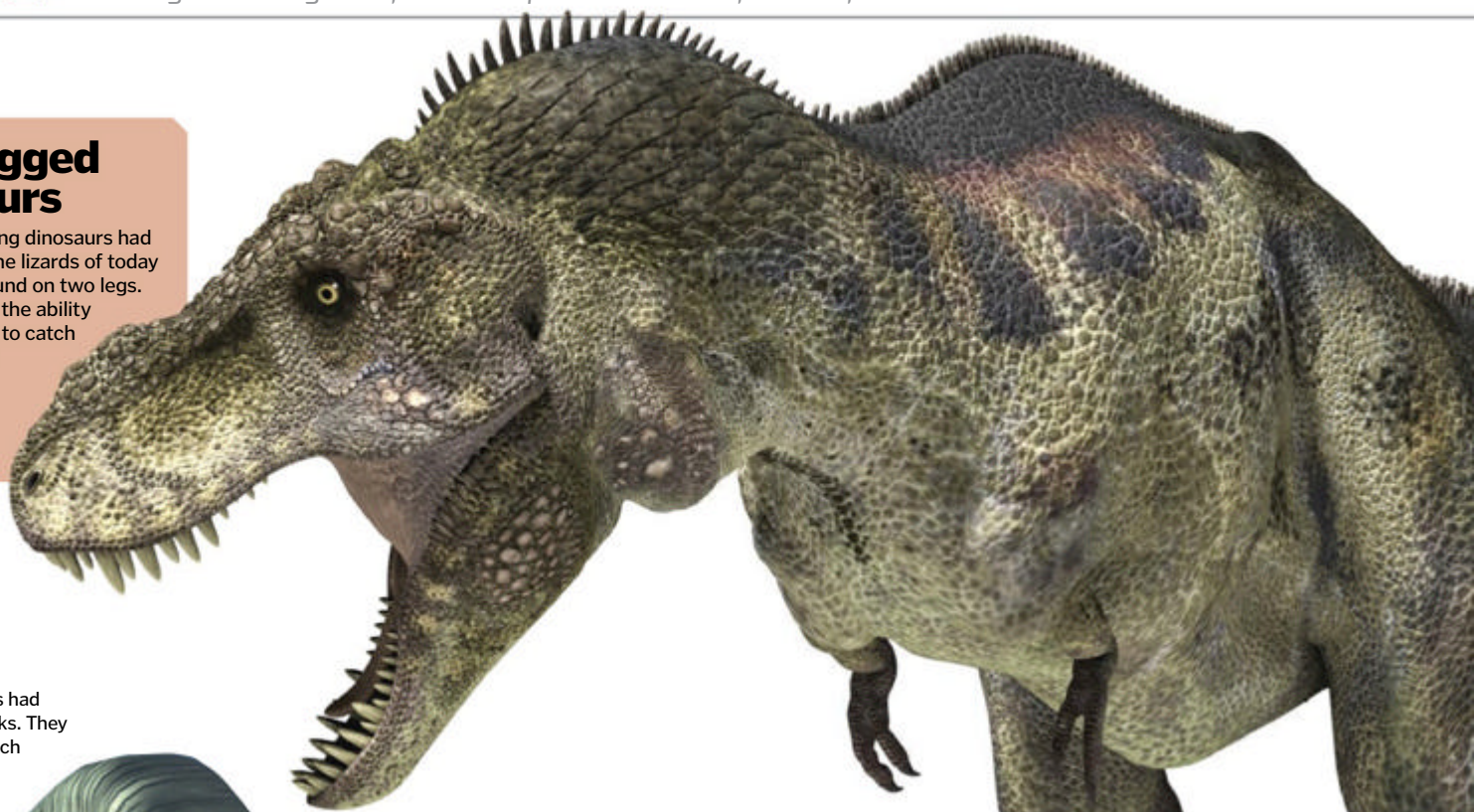
Massive horns were ideal to protect against predators



DID YOU KNOW? It's thought that only 10% of dinosaur species have been found so far

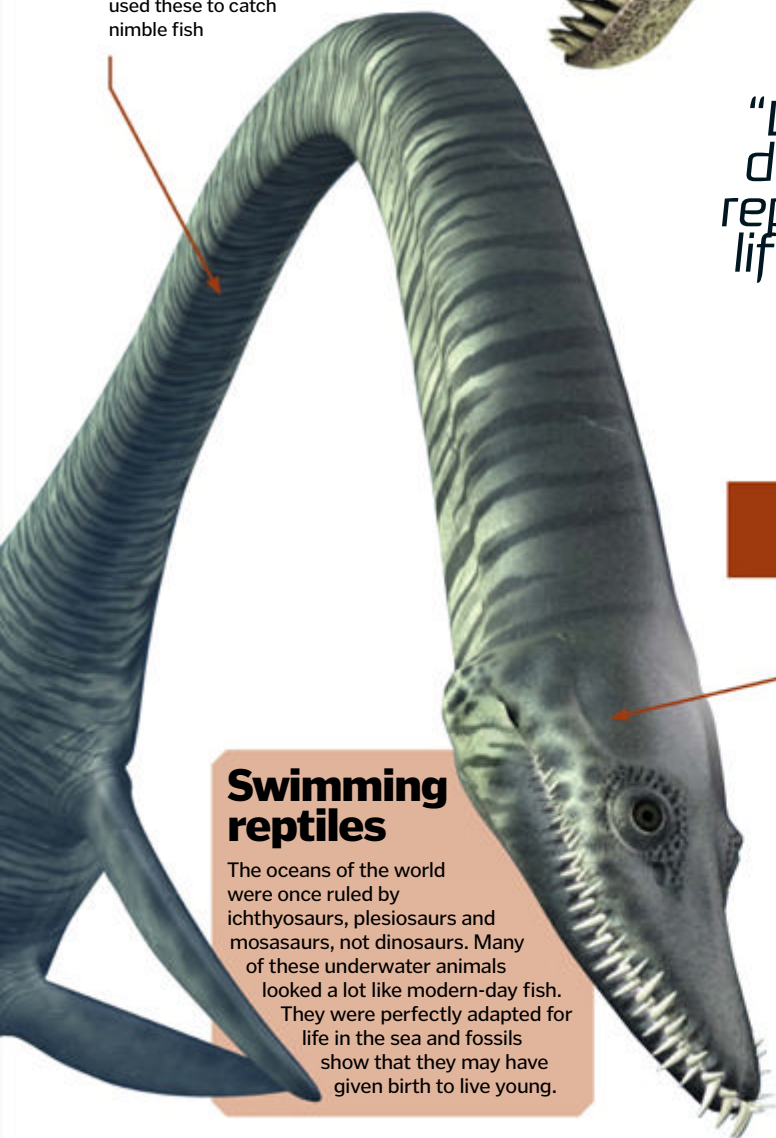
Two-legged dinosaurs

Most meat-eating dinosaurs had hip bones like the lizards of today and moved around on two legs. This gave them the ability to run very fast to catch prey. Strangely, today's birds evolved from lizard-hipped dinosaurs.



Plesiosaurs

Some plesiosaurs had long, flexible necks. They used these to catch nimble fish



"Dinosaurs are a diverse group of reptiles, beginning life on the super-continent of Pangaea"

Attack

By running on two feet, predatory dinosaurs could reach high speeds

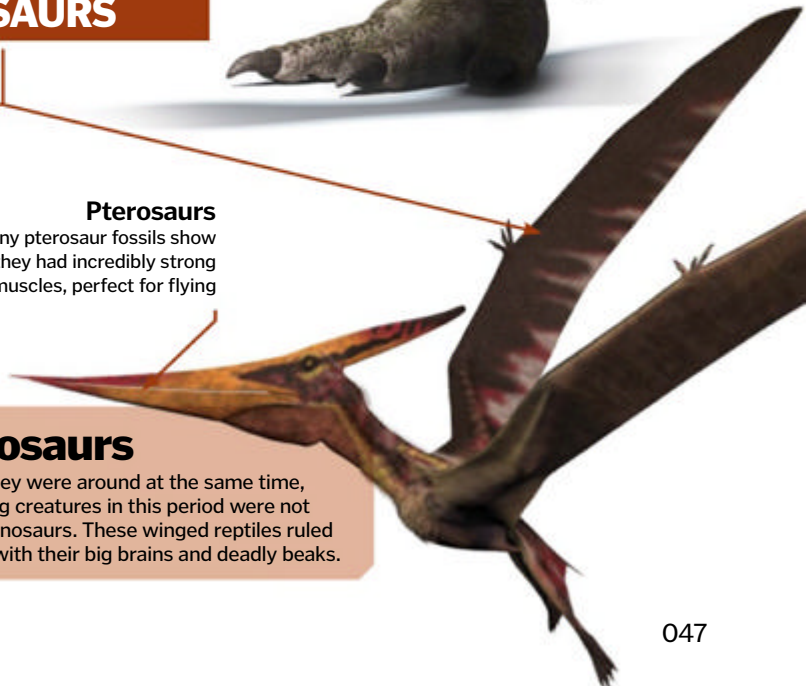
NOT ACTUALLY DINOSAURS

Pterosaurs

Many pterosaur fossils show they had incredibly strong muscles, perfect for flying

Pterosaurs

Though they were around at the same time, most flying creatures in this period were not actually dinosaurs. These winged reptiles ruled the skies with their big brains and deadly beaks.





HOW IT WORKS

THE PREHISTORIC WORLD

When dinosaurs roamed

When did dinosaurs rule the Earth?

Dinosaurs roamed Earth between 230 and 65 million years ago, when our planet was very different to today

Jurassic period

200 to 145 million years ago
The Jurassic period is called the 'Age of the Reptiles' because it was during this time that reptiles ruled the planet

The first dinosaurs
Staurikosaurus is one of the very first dinosaurs

Permian period

300 to 250 million years ago
It was extremely hot during this time. While there were oceans, the land was very much like a desert. Only reptiles would be able to thrive in this environment

Triassic period

250 to 200 million years ago
It might have been quite hot and dry, but that didn't stop the very first mammals and flying reptiles from appearing. Trees and plants also grew in the places we know today as the cold and icy south and north poles

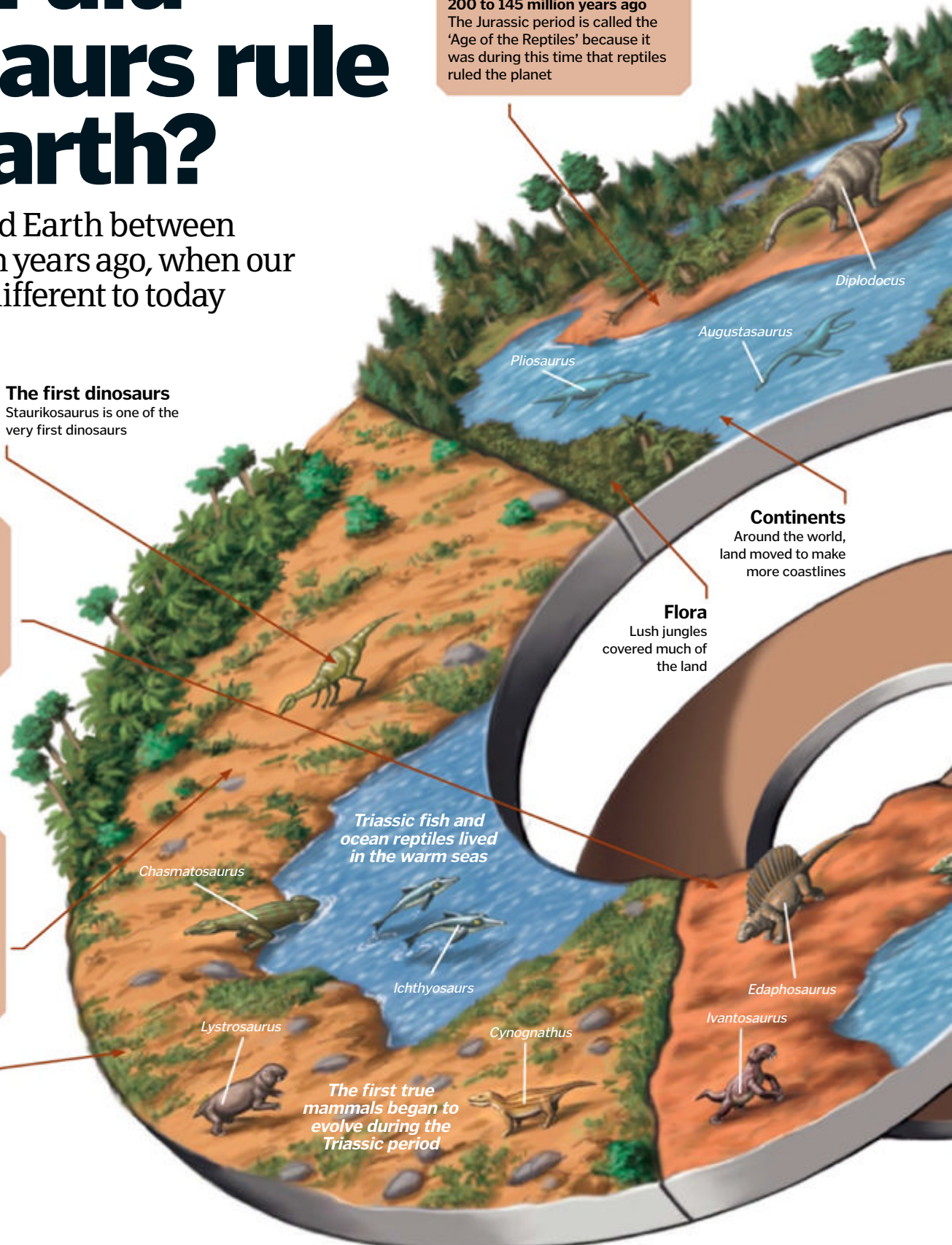
High temperatures
It might have been very hot, but some places had rain

Continents
Around the world, land moved to make more coastlines

Flora
Lush jungles covered much of the land

Triassic fish and ocean reptiles lived in the warm seas

The first true mammals began to evolve during the Triassic period



Diplodocus

Augustasaurus

Pliosaurus

Continents

Flora

Triassic fish and ocean reptiles lived in the warm seas

Edaphosaurus

Ivantosaurus

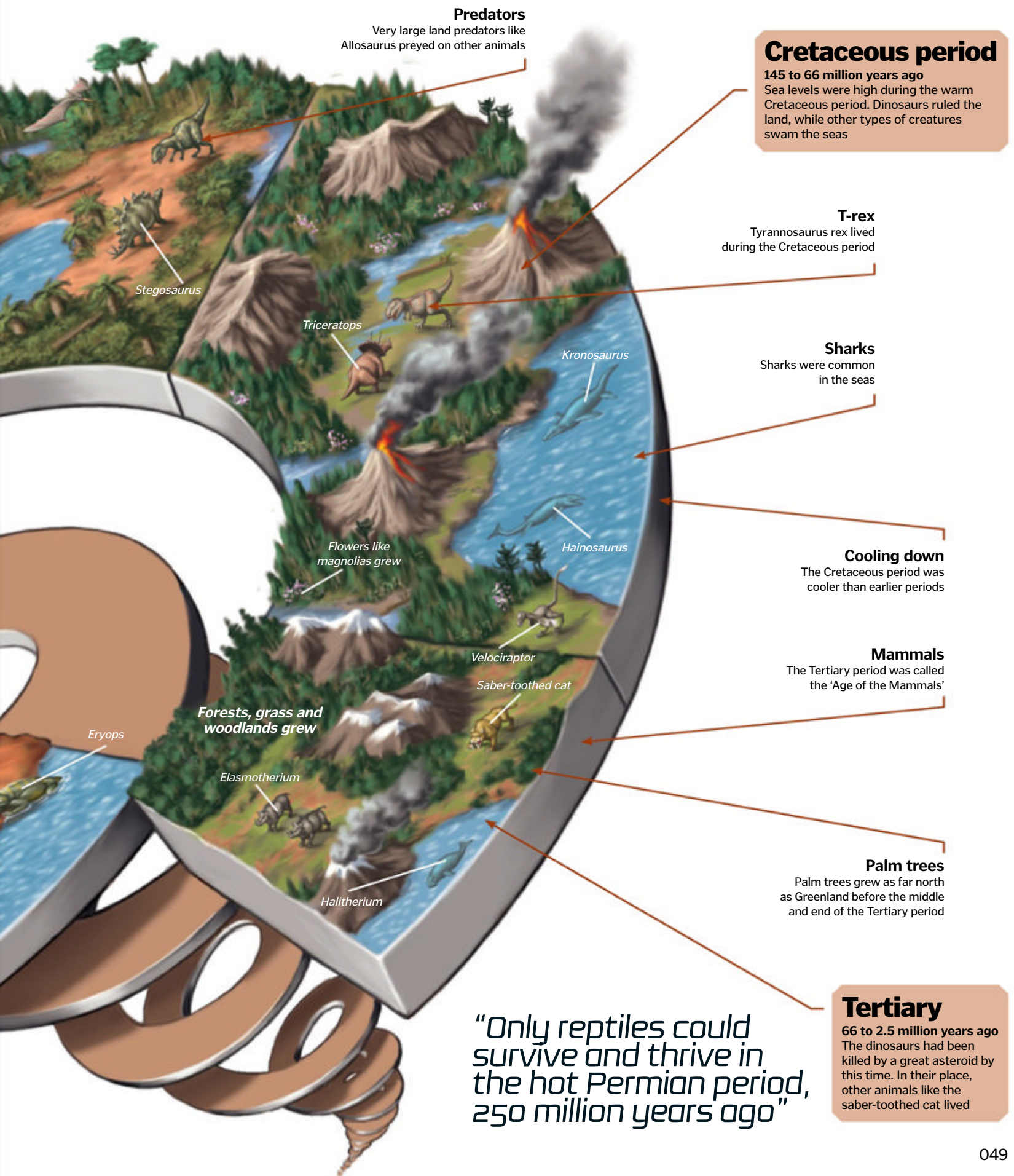
Lystrosaurus

Cynognathus

Chasmatosaurus

Ichthyosaurs

DID YOU KNOW? Lots of dinosaurs couldn't survive the 60°C heat of the Triassic period



Cretaceous period
145 to 66 million years ago
Sea levels were high during the warm Cretaceous period. Dinosaurs ruled the land, while other types of creatures swam the seas

Predators
Very large land predators like Allosaurus preyed on other animals

T-rex
Tyrannosaurus rex lived during the Cretaceous period

Sharks
Sharks were common in the seas

Cooling down
The Cretaceous period was cooler than earlier periods

Mammals
The Tertiary period was called the 'Age of the Mammals'

Palm trees
Palm trees grew as far north as Greenland before the middle and end of the Tertiary period

Tertiary
66 to 2.5 million years ago
The dinosaurs had been killed by a great asteroid by this time. In their place, other animals like the saber-toothed cat lived

"Only reptiles could survive and thrive in the hot Permian period, 250 million years ago"



HOW IT
WORKS

THE PREHISTORIC WORLD

Dinosaur habitat

Where did dinosaurs live?

Dinosaurs lived all over the world, from dry, dusty deserts to wet, sweaty swamps. Explore five different habitats that dinosaurs called home...

First dinosaurs

The Triassic weather helped dinosaurs to develop. Their bodies were much better suited to hot and dry conditions than mammals'

Plants

Only plants that could live without lots of water survived in these areas. There wasn't much for herbivores to eat

DID YOU KNOW? The extinction event that killed the dinosaurs is one of five major events to change the Earth

Triassic desert

250 to 200 million years ago

Dinosaurs first appeared during the Triassic period.
Earth was hot, dry and covered in deserts

Extinction

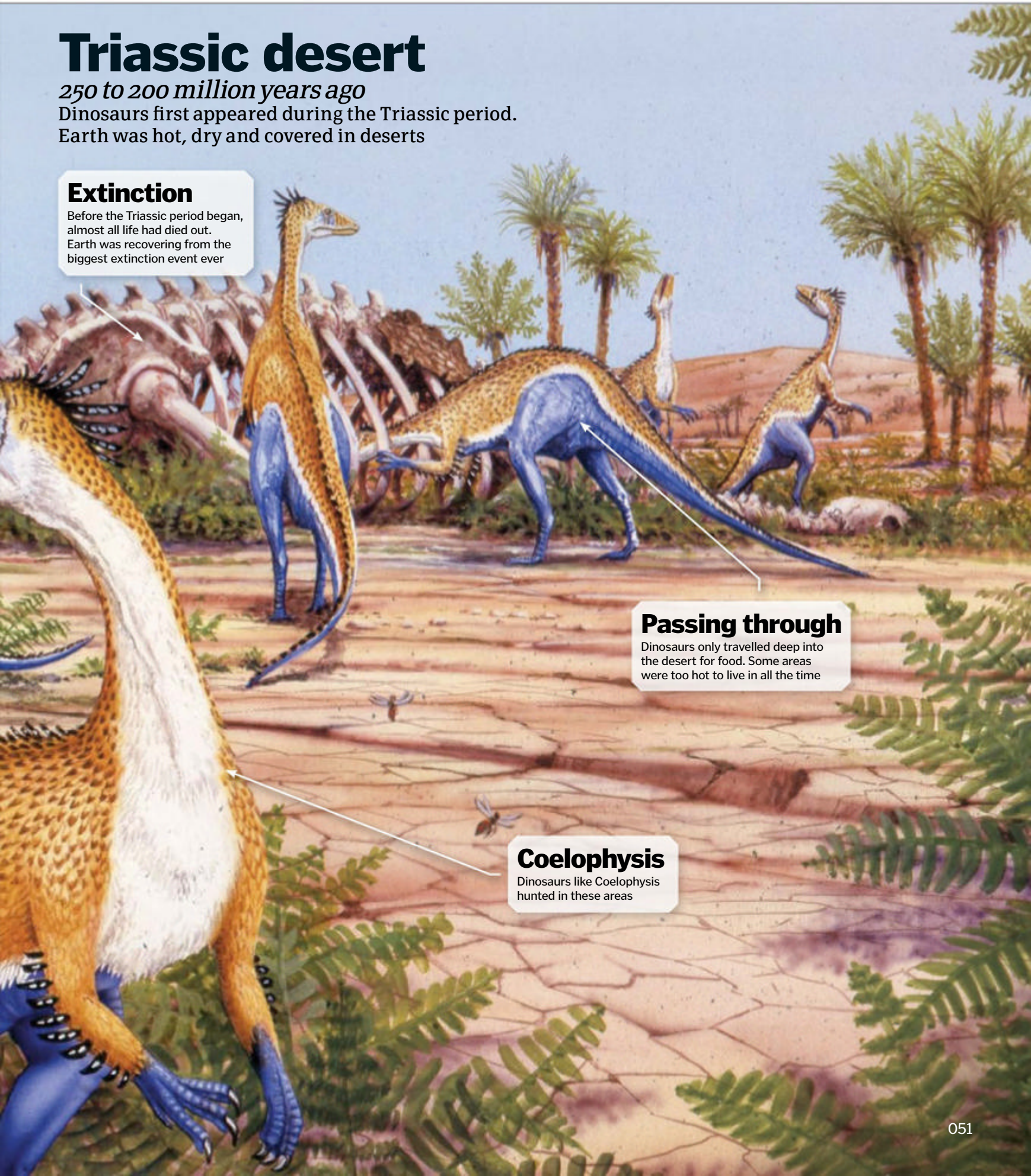
Before the Triassic period began, almost all life had died out. Earth was recovering from the biggest extinction event ever

Passing through

Dinosaurs only travelled deep into the desert for food. Some areas were too hot to live in all the time

Coelophysis

Dinosaurs like Coelophysis hunted in these areas





HOW IT WORKS

THE PREHISTORIC WORLD

Dinosaur habitat

Triassic forest

250 to 200 million years ago

The weather was milder at the north and south poles. It was drier so large forests grew

Trees

Most trees in these forests were tall with tough leaves. They were evergreens so didn't lose their leaves over winter

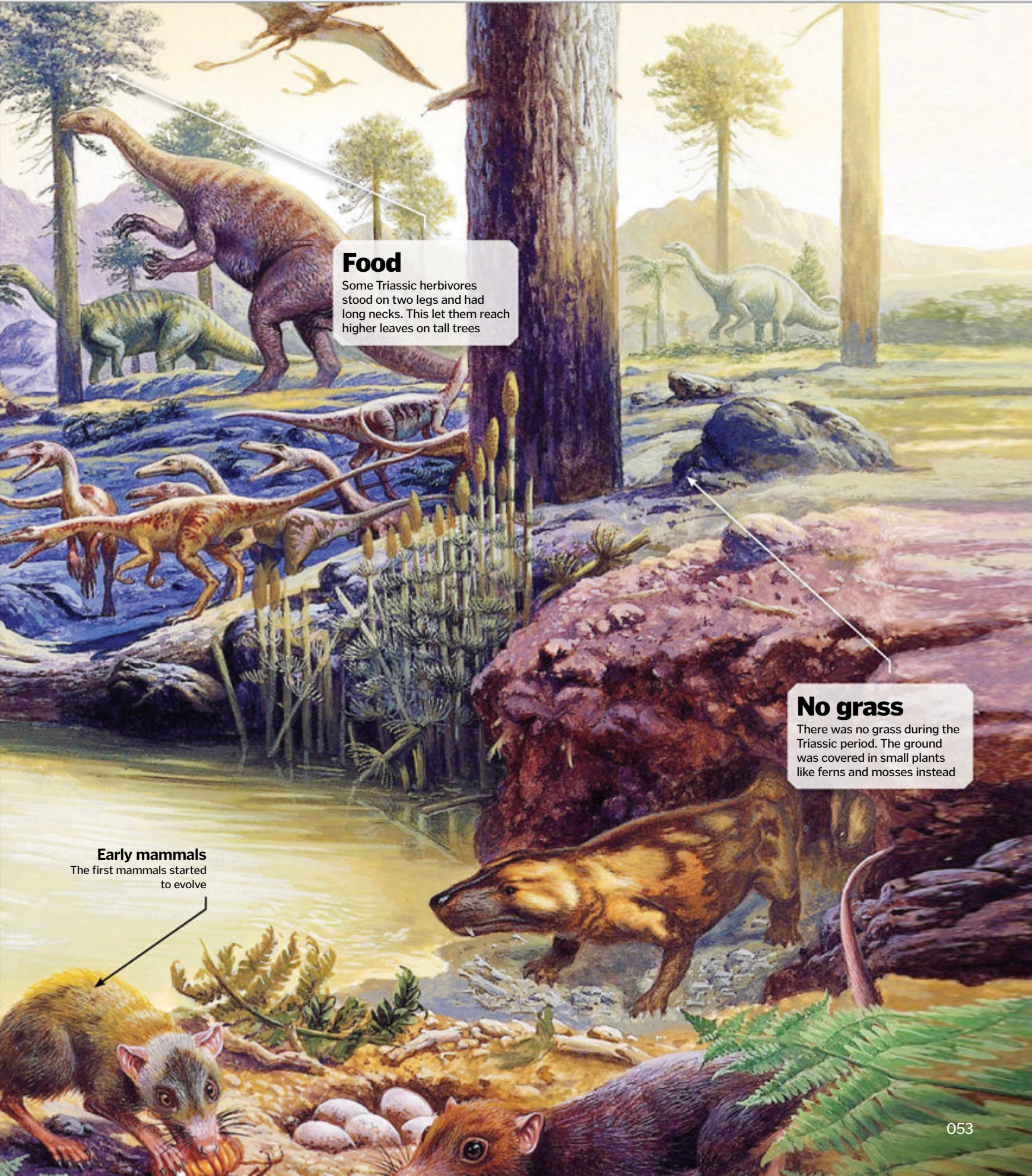
No ice caps

Even the north and south poles were warm. They weren't icy and frozen like Antarctica and the Arctic are today

Fresh water

Rivers provided fresh water to drink

DID YOU KNOW? Most of the trees in Triassic forests were conifers. They evolved 300 million years ago



Food

Some Triassic herbivores stood on two legs and had long necks. This let them reach higher leaves on tall trees

No grass

There was no grass during the Triassic period. The ground was covered in small plants like ferns and mosses instead

Early mammals

The first mammals started to evolve



HOW IT WORKS

THE PREHISTORIC WORLD

Dinosaur habitat

Jurassic swamp

200 to 145 million years ago

Sea levels were higher during the Jurassic period.

Some land got flooded, which created muddy swamps

Bigger dinosaurs

Herbivores got bigger because there were more plants for them to eat. Carnivores also grew as their prey got larger

Plants

Trees spread across Jurassic Earth. They started growing in places that were too dry for them back in the Triassic

Tree life

Small animals lived in the trees

DID YOU KNOW? Pangaea formed approximately 300 million years ago

Weather

Regular rainy seasons kept the soil damp. This watered ferns and other small ground plants that herbivores could consume

Continents moving

As Pangaea split up, the new continents had different habitats like swamps. Animals evolved quickly to survive in these new areas





HOW IT
WORKS

THE PREHISTORIC WORLD

Dinosaur habitat

Jurassic ocean

200 to 145 million years ago

Reptiles didn't just live on land. Massive prehistoric monsters ruled the Jurassic oceans as well

Oceanic predators

Plesiosaurs and Ichthyosaurs were top predators

Plenty of food

Smaller creatures like fish and molluscs were everywhere. They made easy meals for bigger beasts like reptiles, sharks and whales

DID YOU KNOW? Some types of plankton would have turned parts of the ocean red

New oceans

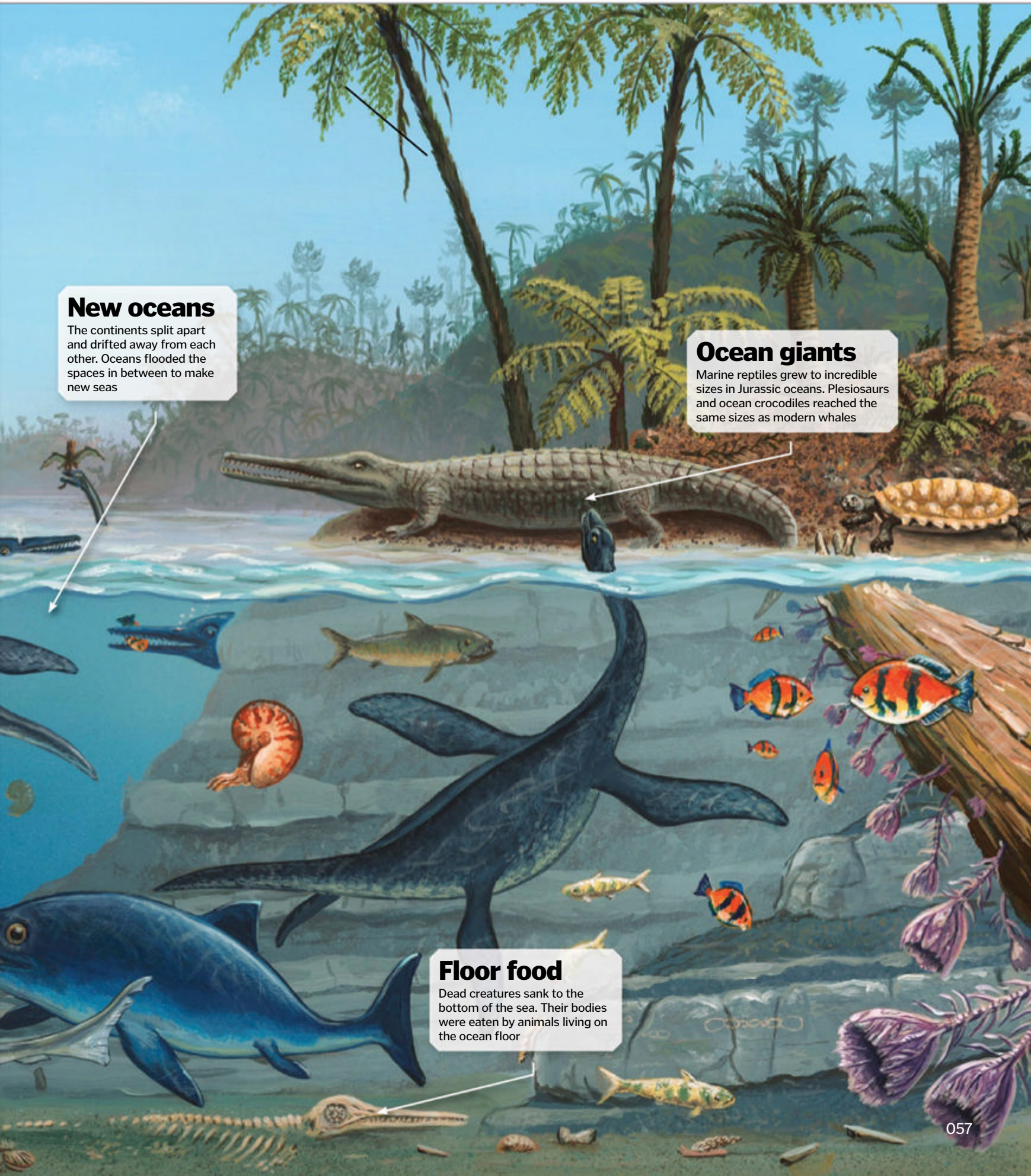
The continents split apart and drifted away from each other. Oceans flooded the spaces in between to make new seas

Ocean giants

Marine reptiles grew to incredible sizes in Jurassic oceans. Plesiosaurs and ocean crocodiles reached the same sizes as modern whales

Floor food

Dead creatures sank to the bottom of the sea. Their bodies were eaten by animals living on the ocean floor





HOW IT WORKS

THE PREHISTORIC WORLD

Dinosaur habitat

Cretaceous plains

145 to 66 million years ago

Life was not easy on the Cretaceous plains. Dinosaurs faced many changes to their habitat

Wildfires

During the Cretaceous period, lightning struck trees and started fires. Because there were plenty of plants, flames could spread quickly

Herds

Some dinosaurs survived better in groups

Flowers

Lots of different flowering plants evolved. Their pollen was spread by insects like bees. Flowers eventually outnumbered trees and shrubs

DID YOU KNOW? The phenomenon of erupting volcanoes is known as volcanism

Atmosphere

There were a lot of active volcanoes at this time. They filled the air with carbon dioxide and other gases

Climate

Continents drifted further apart. This made the ocean currents change. Currents affected the weather, making temperatures go up and down





The dinosaurs' neighbours

Tiny mammals lived alongside dinosaurs in the Mesozoic era. While many are now extinct, some of their ancestors are still alive today



Mammals evolved during the Triassic period, about the same time as the first dinosaurs appeared. Their reptilian contemporaries, the archosaurs, were the more successful creatures at the time, probably because they were better adapted to surviving the arid Triassic weather.

Early mammals are synapsids, meaning that they have an extra opening in the skull behind the eyes. This allowed strong jaws to develop.

While dinosaurs reigned, mammals never grew larger than a cat, but hardy mammals were able to grow and successfully occupy empty niches once the dinosaurs died out.

Duck-billed platypus

Cretaceous, around 120 million years ago to present
The platypus is one of the most unique mammals in the world. It lays eggs instead of giving birth and the males have venomous spurs

Palaeoryctidae

Mid-Cretaceous to early Paleogene, around 105 to 66 million years ago
These creatures looked a lot like modern-day shrews. They mainly lived in what would become North America and were very small

DID YOU KNOW? Monotremes are mammals that lay eggs, such as the platypus and echidnas

Multituberculata

Late Jurassic to early Oligocene,
160 to 35 million years ago
This group of little mammals was
around for roughly 120 million years.
It's the longest-surviving mammal
group on record

*"Mammals were
able to successfully
occupy empty
niches once the
dinosaurs died out"*

Cynognathus

Triassic, around 230 million
years ago
These creatures were also
technically mammal-like
lizards. They had many
features in common with
mammals, such as hair and
possibly even warm blood





HOW IT WORKS BOOK OF DINOSAURS

DINOSAURS

Dinosaurs

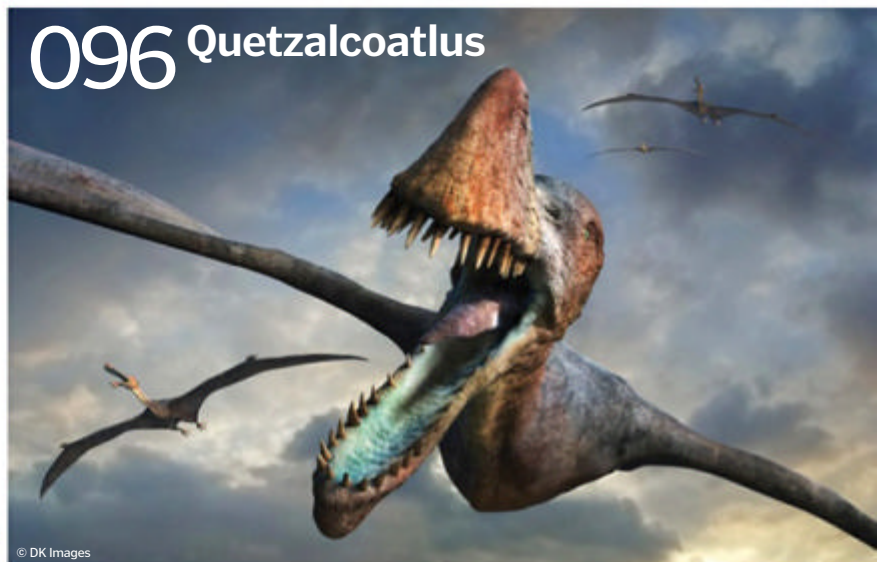
- 064** What's inside a dinosaur egg?
Take a peek underneath the shell
- 066** The world's biggest dinosaurs
The behemoths of land, sea and air
- 070** Dinosaur defence
How dinosaurs evolved to fight off predators
- 072** The cleverest dinosaur
Was Troodon really the most intelligent dino?
- 074** Diplodocus
How the mighty Diplodocus lived
- 076** Triceratops
The three-horned face dinosaur
- 078** Velociraptor
Quick death on two legs
- 080** Stegosaurus
Wielder of the spiked tail

- 082** Tyrannosaurus rex
What makes this tyrant so revered?
- 084** Brachiosaurus
A terrestrial titan of epic proportions
- 086** Ankylosaurus
The bone-breaking, club-wielding brute
- 088** Apatosaurus
Get face-to-face with the real Brontosaurus
- 090** Marine reptiles
Discover the creatures that ruled the waters
- 092** Plesiosaurus
The Early Jurassic's ferocious marine reptile
- 094** Pterosaurs
Take a look at the terrors of the skies
- 096** Quetzalcoatlus
Meet the largest flying vertebrate of all time
- 098** The deadliest dinosaurs
The fiercest, most terrifying beasts

076 Triceratops



096 Quetzalcoatlus



103 Giganotosaurus



090 Marine reptiles



074
Diplodocus



079
Velociraptor
claws



098
Deadliest
dinosaurs

101 Spinosaurus



084
Brachiosaurus

082
T-rex





What's inside a dinosaur egg?

Just like modern day baby chicks, dinosaurs grew and hatched from eggs to roam the planet a very long time ago



What came first – the dinosaur or the egg? We're not entirely sure, but what we do know is that these great reptiles laid eggs just like chickens do. Inside the shell of a hen's egg, chicks are able to grow before they're ready to hatch. That's just how the dinosaurs were born.

We know that baby dinosaurs were made this way because we have found lots of evidence. Fossilised dinosaur eggs have been found at over 200 places across the world. They tell a story about how the dinosaur made its nest, laid its eggs and how baby dinosaurs were born.

A crew of palaeontologists exploring Mongolia in 1923 were the first to scientifically recognise fossilised dinosaur eggs for what they were. Since then many dinosaur nesting sites for many different species have been uncovered all around the world. The oldest known dinosaur eggs and embryos date back to the Early Jurassic (about 190 million years ago) and come from the *Massospondylus*, a bipedal, omnivorous prosauropod.

Egg Mountain in Montana, USA is the site of one of the most famous dinosaur nest discoveries. *Maiasaura* remains were found near a nest with the remains of eggshells and babies too large to be hatchlings and this is the reason why *Maiasaura* is known as "caring mother lizard". *Maiasaura* and many other species of dinosaur, raised their young in nest colonies. This reflected the way that they herded when on the move. This amazing discovery was the first proof that dinosaurs raised and fed their young, rather than leaving hatchlings to fend for themselves like modern turtles do. Nests contained approximately 30-40 eggs and were not incubated by the parent sitting on them, but by the heat produced from rotting vegetation placed in the nest. It's thought that *Maiasaura* hatchlings left the nest after a year or two of rapid growth.

Growing up fast

The baby dinosaur grew very fast, a lot faster than any bird or animal we know of. This happened both inside the egg and out

A thick liquid

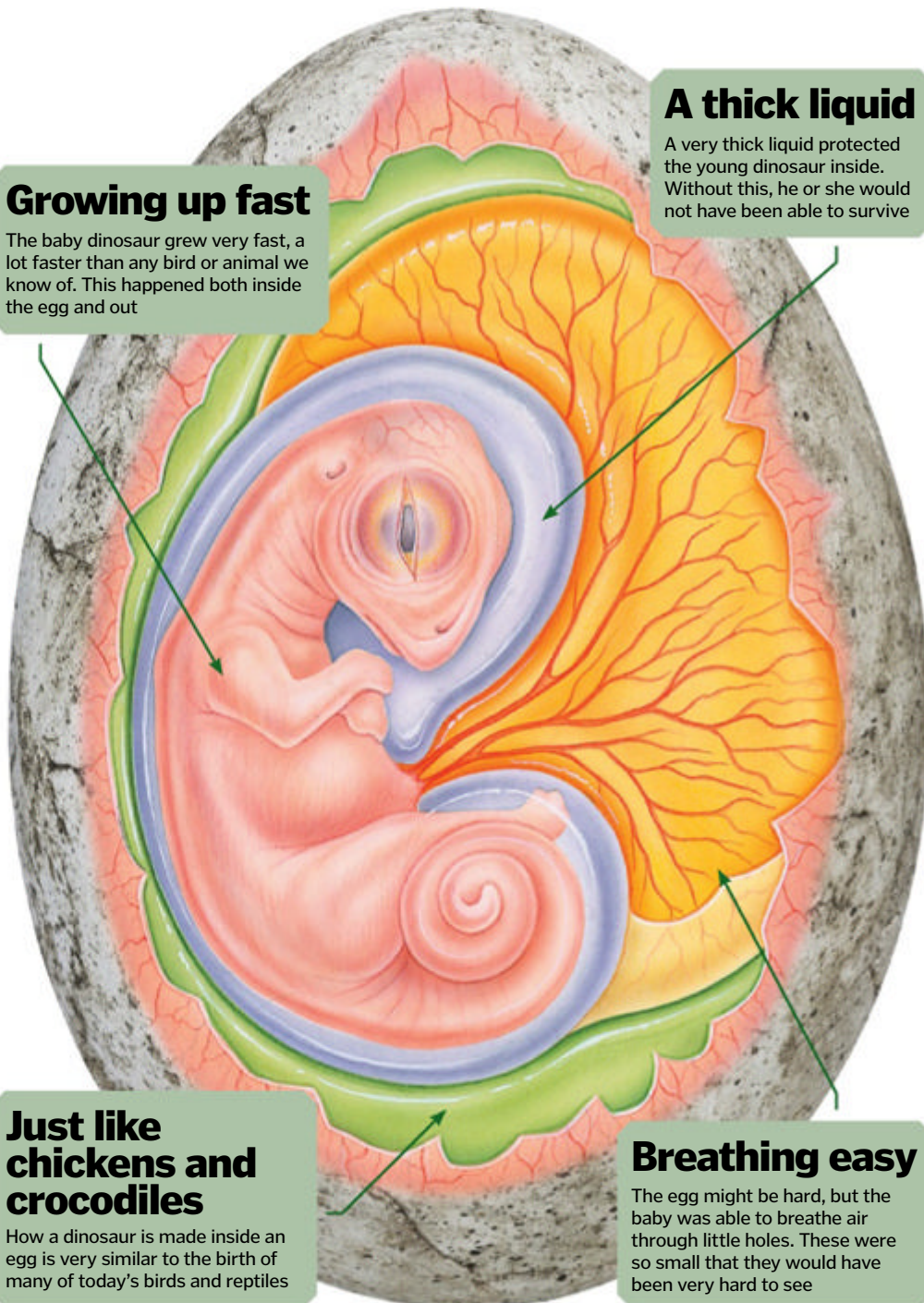
A very thick liquid protected the young dinosaur inside. Without this, he or she would not have been able to survive

Just like chickens and crocodiles

How a dinosaur is made inside an egg is very similar to the birth of many of today's birds and reptiles

Breathing easy

The egg might be hard, but the baby was able to breathe air through little holes. These were so small that they would have been very hard to see



DID YOU KNOW? Some dinosaurs were able to lay more than 30 eggs at a time

Dinosaur egg versus chicken egg

The Hypselosaurus egg is five times larger than a chicken egg

Hypselosaurus egg

Oval-shaped, 30cm tall, 25cm across

Egg discoveries

The first Hypselosaurus eggs were found in France in 1846, though they weren't recognised as dinosaur eggs until decades later. They were also the earliest dinosaur eggs ever to be discovered

"The earliest known fossilised dinosaur eggs and embryos date back to 190 million years ago"

Chicken egg

Oval-shaped, 6cm tall, 4cm across





World's biggest dinosaurs

With fossil brush in hand, we unearth the massive behemoths that ruled over land, air and sea millions of years ago

Stegosaurus

Stegosaurus was slightly larger than a shipping container, but its brain was only the size of a walnut

Brachiosaurus

The brachiosaurus used its staggering 16m (52.5 feet) height to reach tall vegetation

Flexible

Despite all this support holding the sauropod together, the design still allowed the creatures to remain surprisingly flexible

Standing

The placement of the tendon in the vertebrae allowed sauropods to hold their necks and tails upright with minimal effort

DID YOU KNOW? The biggest animal ever known to have lived on Earth, including dinosaurs, is the blue whale



Pterosaur

The hollow bones of a pterosaur ensured it remained light enough to achieve flight, even when reaching the size of a small plane



It's somewhat frightening to imagine what it must have been like to wander around the plains of Africa and Argentina 100 million years ago. Whereas today you'd be hard-pressed to encounter a beast any bigger than yourself, back then you'd be running for your life as bus-sized creatures roamed free, some remaining largely peaceful and distant, others full of aggression.

The biggest land-based animal alive today is the African bush elephant, with the largest weighing a measly 13.5 tons and measuring 10.6m (34.8ft) long and 4.2m (13.8ft) high. Argentinosaurus, the current official record-holder for largest dinosaur of them all, would have been at least four times the size. It was a sauropod, dinosaurs of the Jurassic and Cretaceous period that were mostly herbivores and known for being very large. Indeed, many other types of sauropod would have stood tall above the African bush elephant, as would raptors and pterosaurs.

Dinosaurs inhabited the Earth for much longer than any modern animal, from 251 to 65 million years ago, allowing plenty of time for certain species to develop into the giant hulks of flesh we now so revere. The biggest dinosaurs discovered to date have largely been determined to live in the Late Cretaceous period, 99.6-65.5 million years ago, before they faced extinction.

For a long time, though, palaeontologists have wondered why dinosaurs grew to be so large. While impressive, size can also be a

hindrance. Not only does a large animal need a much higher rate of metabolism, but it must also develop much stronger bones and skeletal structures to be able to hold itself upright. Many of these gigantic animals were also cumbersome and slow, leaving themselves open to attack from large predators. Why did dinosaurs continue to grow for millions of years, then?

One train of thought is that there was a huge surplus of carbon dioxide in the atmosphere during the age of the dinosaurs. This meant that vegetation flourished, and herbivores such as the sauropods simply had an over-abundance of nourishment available to eat. While somewhat of a burden in terms of manoeuvrability, their size would certainly have helped to some extent when fending off smaller carnivores. This leads to another proposal from palaeontologists, namely that some dinosaurs grew in size over millions of years as a form of self-defence.

However, others think that these giant dinosaurs were cold-blooded, which was directly responsible for their size. Indeed, warm-blooded animals simply wouldn't be able to sustain such mammoth sizes, somewhat backed up by the lack of mammals larger than a few tons today.

Huge cold-blooded sauropods, weighing in at up to 100 tons, would have been almost self-sustainable, as they could store heat throughout the day for the colder nights, maintaining a fairly unchanged body temperature and prolonging their survival.

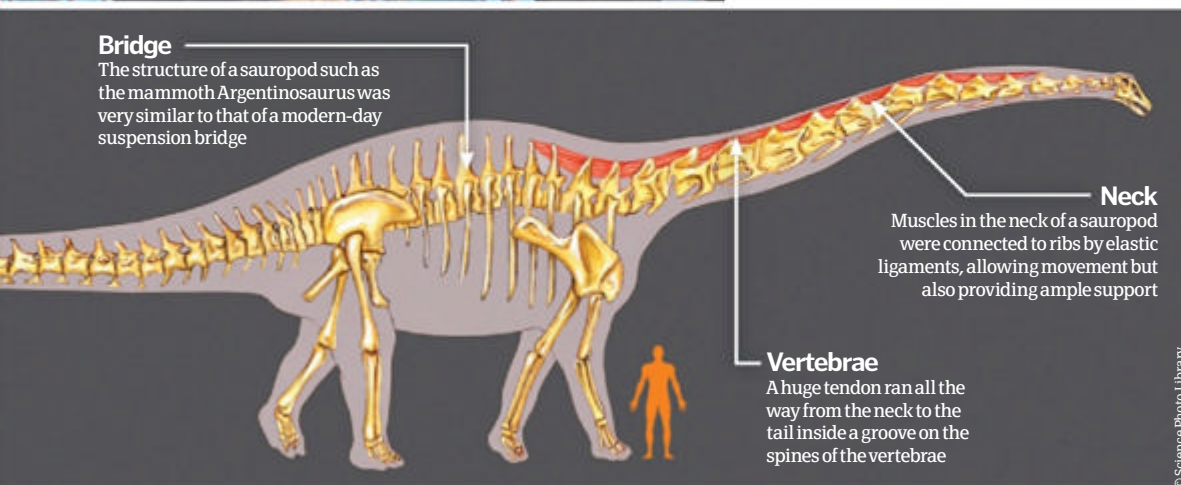
How were they supported?

We examine the anatomy of a sauropod, to see how these huge creatures were able to keep upright



Bridge

The structure of a sauropod such as the mammoth Argentinosaurus was very similar to that of a modern-day suspension bridge



Neck

Muscles in the neck of a sauropod were connected to ribs by elastic ligaments, allowing movement but also providing ample support

Vertebrae

A huge tendon ran all the way from the neck to the tail inside a groove on the spines of the vertebrae





BIGGEST OVERALL

Argentinosaurus

Argentinosaurus is the largest-known dinosaur to have ever lived, based on fossilised evidence. Weighing in at over 100 tons and measuring as much as 45 metres (148 feet) in length, this herbivore was wider and longer than a basketball court and was as heavy as a fuel-less jumbo jet.

The vertebrae of the Argentinosaurus were very broad, with small peg-and-socket articulations above the spinal cord that kept the backbones of these animals sturdy and rigid. In addition, the ribs of the Argentinosaurus were hollow, possibly allowing for greater manoeuvrability. Although the skull, neck and tail of an Argentinosaurus have never been found, measurements made from a shinbone can estimate the size of the various features of this colossal creature. Each hind limb of the Argentinosaurus would have been about 4.5 metres (15 feet) long.

The statistics...

Argentinosaurus
Weight: >100 tonnes
Length: <45m (148ft)
Height: 21m (70ft)
Date: Late Cretaceous (99.6-65.6 Ma)
Group: Sauropodomorphs
Bigger than: A basketball court



Tail
The spinosaur's tail was incredibly strong, with huge muscles at its base allowing it to be potentially used as a weapon

BIGGEST CARNIVORE

Spinosaurus

The Spinosaurus is often overlooked as the largest carnivorous dinosaur in favour of its more famous cousin, the Tyrannosaurus rex. However, the Spinosaurus would have dwarfed the popular movie star, measuring 16m (52ft) in length compared to 12m (39ft) for a T-rex. That being said, the characteristic features of the Spinosaurus – namely its fin-like spinal protrusion – make it one of the most recognisable theropods. In the late-Cretaceous period, this 12-tonne creature would have been fairly common, with its sail-like spine adding to a fearsome display and possibly helping to regulate its body temperature.

Sail
Tall bony spines growing upwards from the vertebrae of the Spinosaur supported its characteristic sail-like structure

Teeth
Within its crocodile-like snout, an unusual feature for a theropod, were rows of conical teeth for hunting and killing fish and average-sized land-based dinosaurs

Feet
At the base of the strong hind legs of the Spinosaur were three long, forward-facing claws

The statistics...

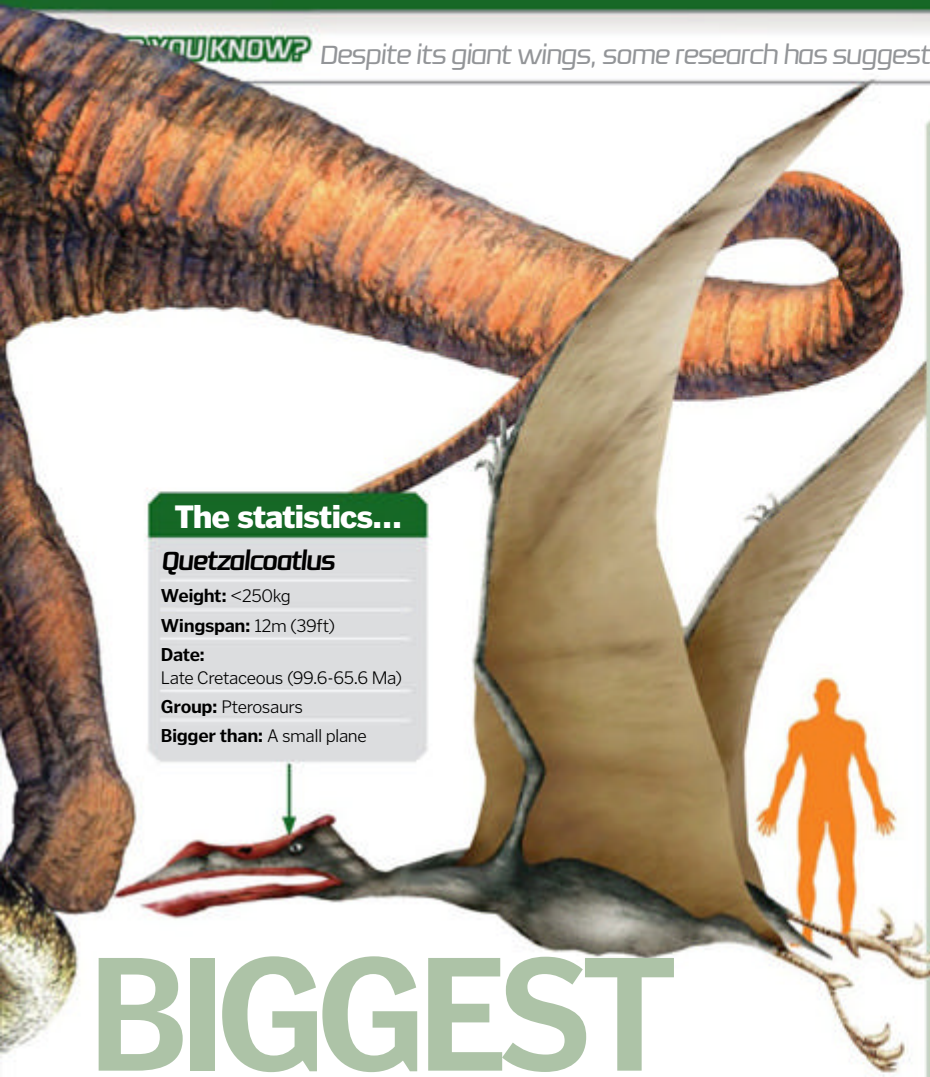
Spinosaurus
Weight: 12 tonnes
Length: 16m (52ft)
Date: Late Cretaceous (99.6-65.6 Ma)
Group: Theropods
Bigger than: A double-decker bus

The other contenders

There is some contention among paleontologists as to what the largest dinosaur of all time was. Currently the official record-holder is the 100-tonne behemoth that is Argentinosaurus. However, there have been several other claims to the throne over the years. In the late-19th Century, a paleontologist known as Edward Cope claimed to have found part of a vertebra that suggested he had unearthed a sauropod dinosaur (known as 'amphicoelias') measuring a humongous 62m (203ft). Mysteriously, however, this bone 'disappeared' shortly afterwards, leading some to believe he had falsified the claim to get one over on his chief paleontological rival at the time, Othniel Marsh. It will be interesting to see if any more evidence of this giant creature is unearthed in future. Another contender that little is known about is Bruhathkayosaurus, which may possibly be the heaviest dinosaur ever discovered, coming in at up to a gigantic 220 tonnes.



DO YOU KNOW? Despite its giant wings, some research has suggested that Quetzalcoatlus was unable to fly



The statistics...

Quetzalcoatlus

Weight: <250kg

Wingspan: 12m (39ft)

Date:
Late Cretaceous (99.6-65.6 Ma)

Group: Pterosaurs

Bigger than: A small plane

BIGGEST PTEROSAUR

Quetzalcoatlus

Although not technically regarded as 'dinosaurs', pterosaurs were around at a similar time and are often (somewhat incorrectly) referred to as 'flying dinosaurs', much to the ire of some palaeontologists. Nevertheless they were impressive creatures, and none more so than Quetzalcoatlus, the largest flying animal of all time. Its huge 2.5m (8ft) skull housed an elongated mouth that was used to hunt land animals including dinosaurs and other vertebrates. Despite its size Quetzalcoatlus was comparatively light as its bones were comprised of a series of air sacs, a useful feature for such a colossal creature aiming to take to the skies. While most other pterosaurs fed on fish, Quetzalcoatlus was somewhat unique in its hunting of land animals, no doubt useful nutrition to fuel its giant metabolic needs.



Dinosaur identification



We spoke to Mike Benton, Professor of Vertebrate Palaeontology in the School of Earth Science at the University of Bristol, UK, to find out how palaeontologists can estimate the size of a dinosaur from fossils and more

How It Works: Can you describe your current role within the world of palaeontology?

Mike Benton: I work in a 50:50 teaching and research position – I teach undergraduates, both geologists and keen palaeontologists, and especially I teach Masters and PhD students. Every year, some 20-25 new Masters students and four-five new PhD students come from all parts of the world to work with us, and I really enjoy working with them to help them develop their careers. In research, I work on several topics by myself, on others with my students, and on others with collaborators around the world.

Could you briefly summarise the key methods and techniques used in the identification of prehistoric creatures?

Palaeontologists identify fossils based on the existing knowledge of living and extinct forms. The fossils are often incomplete, and usually show only the hard parts, such as shells and bones. But, if there is a living relative, these parts can be identified, and a fair attempt made to identify what the fossil is. Usually, palaeontologists have many fossils of the same animal or plant to work with, and they can compare these.

Can you describe some of the challenges involved in identifying a dinosaur?

Dinosaurs are all extinct, and their closest living relatives, the birds, are so different that it is hard to make useful comparisons in many cases. But, when complete skeletons are known, all the bones can be identified from knowledge of living forms, and the skeleton can be reconstructed. This usually shows basic things, such as whether the animal walked on all fours or on its hind limbs only, what it ate (are the teeth sharp or not?), and

whether it could have used its hands for grasping things.

How are paleontologists able to discern how large a dinosaur is, and how can they estimate a dinosaur's diet?

The dinosaur skeleton will itself be large or small. The best guide to body weight for a fossil form is to measure the leg bones. The femur (thigh bone) is particularly useful – because weight (= mass) is a three-dimensional measure, we look for something that increases and decreases in proportion to mass, and that is the diameter of the femur. So you get a good relationship between femur head diameter and body mass from living birds, crocodiles and mammals, and dinosaur body weights can then be estimated from this regular relationship. Diet is determined from overall tooth shape – curved and pointy for meat-eating, and broader for plant-eating. It's hard to be more precise, because we don't have the data set of comparative information to tell exact plant food from wear marks and scratches on the tooth enamel (used for determining the exact diet of mammals).


What, in your opinion, are the most important discoveries made in the past 50 years?

Well, first, the realisation that dinosaurs were active and dynamic animals, dating from the work of John Ostrom in 1969 on Deinonychus, and Bob Bakker in the Seventies on dinosaur warm-bloodedness. Second, the paper by Luis Alvarez and colleagues in 1980 that showed the first evidence that the Earth had been hit by an asteroid 65 million years ago. This has been much confirmed since then, and even the crater has been identified, all showing the key role of this in causing the extinction of the dinosaurs.



How did dinosaurs defend themselves?

Dinosaurs evolved spikes, horns and even thick armoured skin to protect themselves. They needed to be able to fight off predators or risk getting eaten

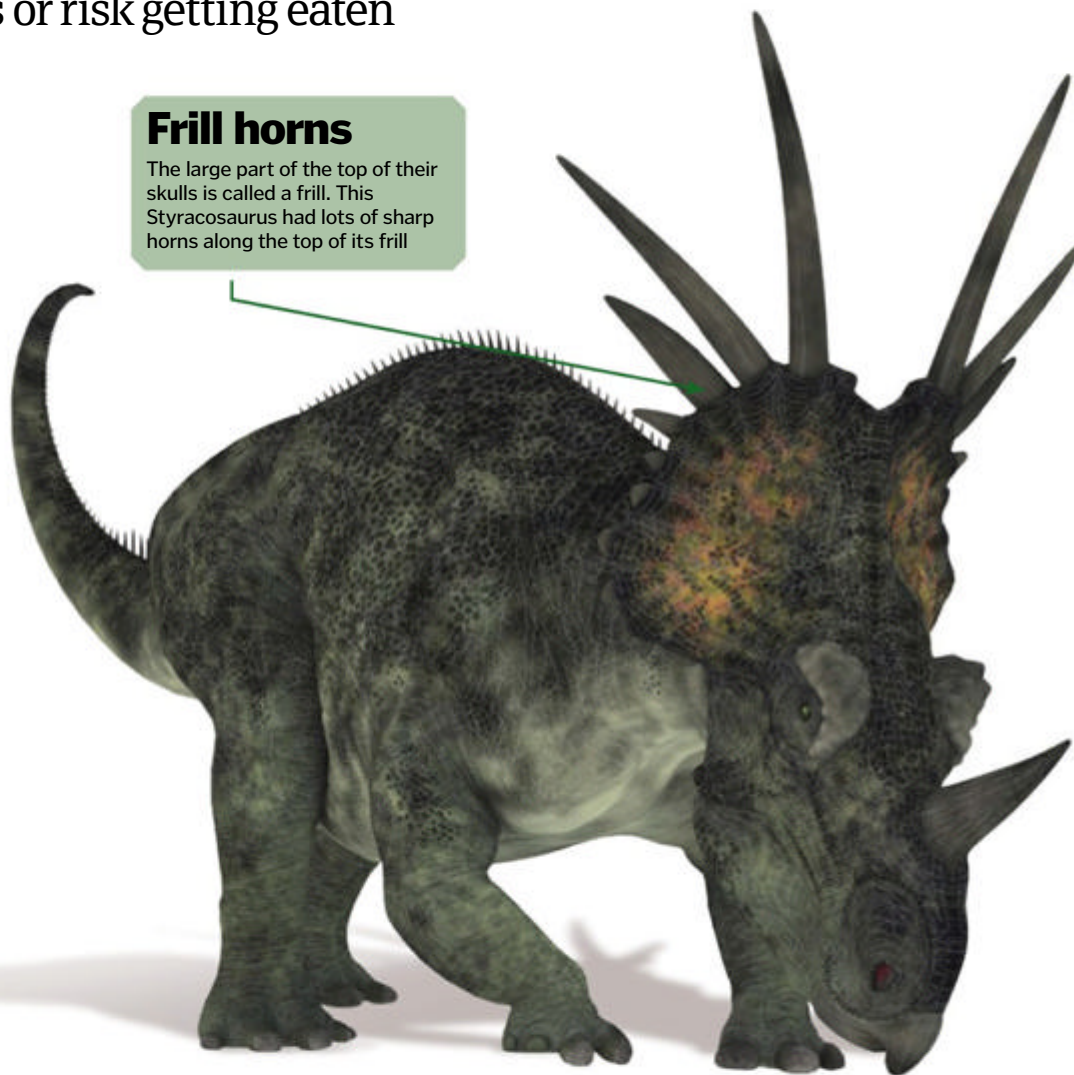
 Herbivorous dinosaurs developed built-in weapons to defend against carnivores. This gave them a better chance of surviving a fight against predators. It also gave them a better chance at defending vulnerable young against predation. Some dinosaurs had sharp claws on their hands, like Iguanodons, which could have been used as a tool and as a weapon. Dinosaurs like Triceratops had horns as long as a human arm that pointed forwards so that the Triceratops could take on its enemy head on. Both these defences could have been used to stab attacking predators.

Other dinosaurs used their tails as weapons. The Ankylosaurus had a heavy, bony hammer at the end of its tail. They could use this to smash into an attacking dinosaur and they were strong enough to crush skulls and break bones. Some dinosaurs were covered in tough scales like a thick coat of armour. Stegosaurus had a row of bony plates running along its spine that are thought to be used for temperature control, though it's certainly possible that they were also used for defence. The bony plates ended along the tail but Stegosaurus remained well defended by the sharp spikes at the end of its tail. Powerful muscles could propel those spikes into an oncoming attacker. Indeed, Allosaurus remains have been found with wounds that line up perfectly with the dimensions of a Stegosaurus's tail spikes

Larger herbivores used their size as a defence. Dinosaurs like the Diplodocus were so massive that carnivores couldn't attack them easily. For smaller dinosaurs, running away was usually the best defence. They developed lighter bones so they could run faster. They needed to escape quickly to avoid fighting altogether.

Frill horns

The large part of the top of their skulls is called a frill. This *Styracosaurus* had lots of sharp horns along the top of its frill



Tail spikes

Tail spikes could be used as weapons because they were hard and sharp. They also made dinosaurs much harder to eat.



Whip

Dinosaurs like *Diplodocus* had long tails that they could use like whips. It's possible that they snapped faster than the speed of sound.



Tail club

Tail clubs were swung around just like a hammer. They were smashed into predators' legs and could crush bones.



DID YOU KNOW? *Styracosaurus* means "spiked lizard" for the large horns on its nose and frill

Armour plating

The Scolosaurus had a body built for defence - from a bony club at the end of its tail to thick scales covering its body

"Triceratops had pointed horns on its face as long as a human arm"

Thick scales

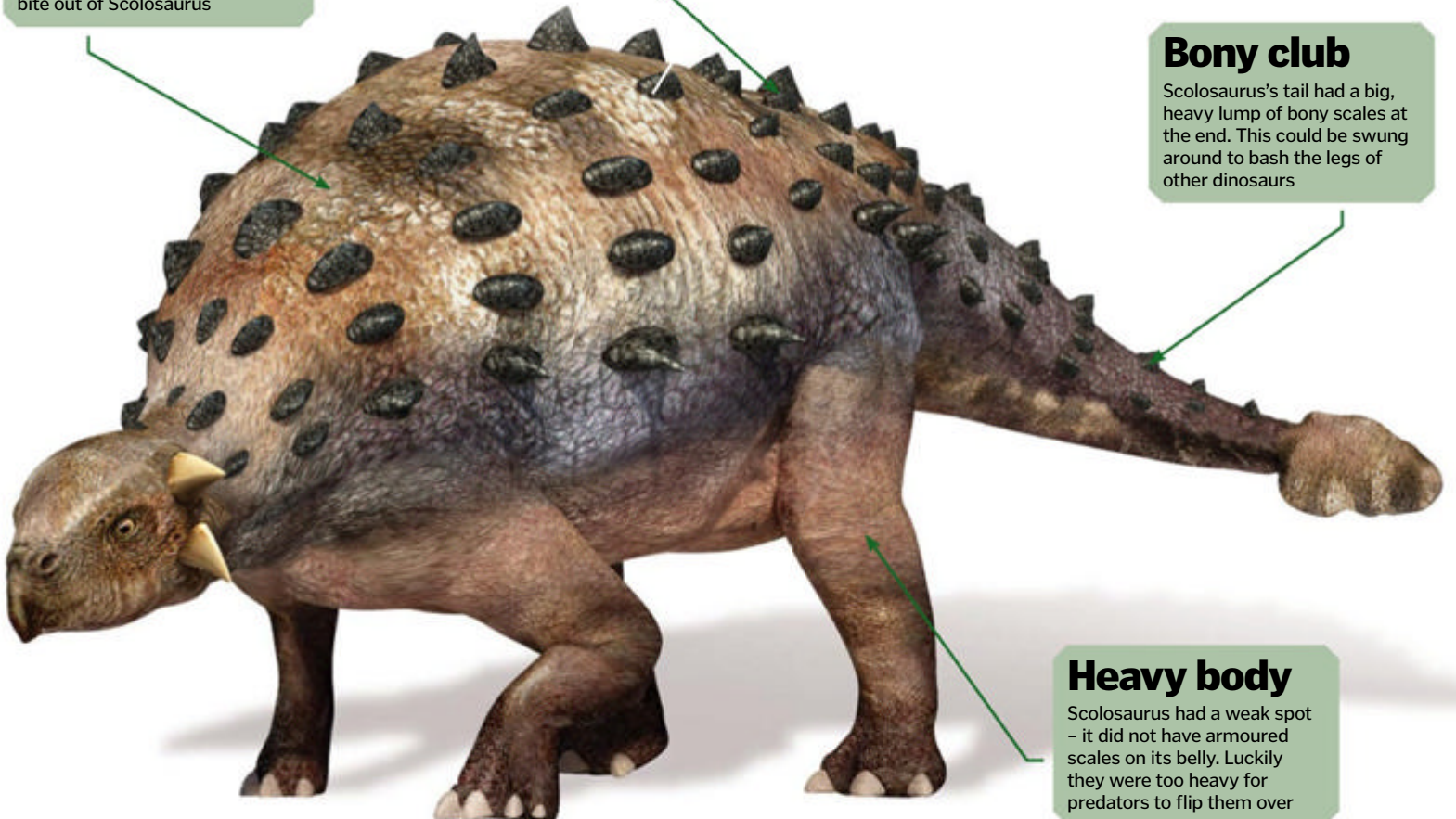
Scolosaurus's bodies were covered in extra-thick scales that were as hard as bone. Predators had a tough time trying to take a bite out of Scolosaurus

Bony spikes

All along their backs and the tail club were sharp spikes. They could do a lot of damage to any carnivores that got too close

Bony club

Scolosaurus's tail had a big, heavy lump of bony scales at the end. This could be swung around to bash the legs of other dinosaurs



Heavy body

Scolosaurus had a weak spot - it did not have armoured scales on its belly. Luckily they were too heavy for predators to flip them over

Horns

Horned dinosaurs might have charged towards predators to try and scare them away. Their horns could have ripped through skin.



Crest

Head crests were used for communication. Dinosaurs could make warning calls to each other if they saw a predator nearby.



Headbutt

Some dinosaurs, like Stegoceras, could smash skulls with predators. Their heads were protected by extra layers of bone for shock-absorption.





HOW IT
WORKS

DINOSAURS

Dinosaur intelligence

What was the cleverest dinosaur?

The Troodon was about the same size as a human, but their brain was much bigger than the other dinosaurs'. This made them very dangerous hunters



Dinosaurs were not a brainy bunch, but the Troodon was unusually smart. Its brain was much larger than other dinosaurs and it was ferocious predator. They were clever enough to hunt in packs so they could catch much larger prey. There was no escape from a Troodon.

The bird-like dinosaur was very good at running, with its long legs and curved claws that would deliver the killer blow to prey. It is thought that a Troodon's teeth were as sharp as knives and that their big eyes gave them great night vision, so they weren't limited to hunting in daylight.

Thumbs up

Troodons were the most human of all the dinosaurs. They had opposable thumbs and they could walk upright on two legs

DID YOU KNOW? Troodon could run after its prey at 30kmh



A smarter dinosaur

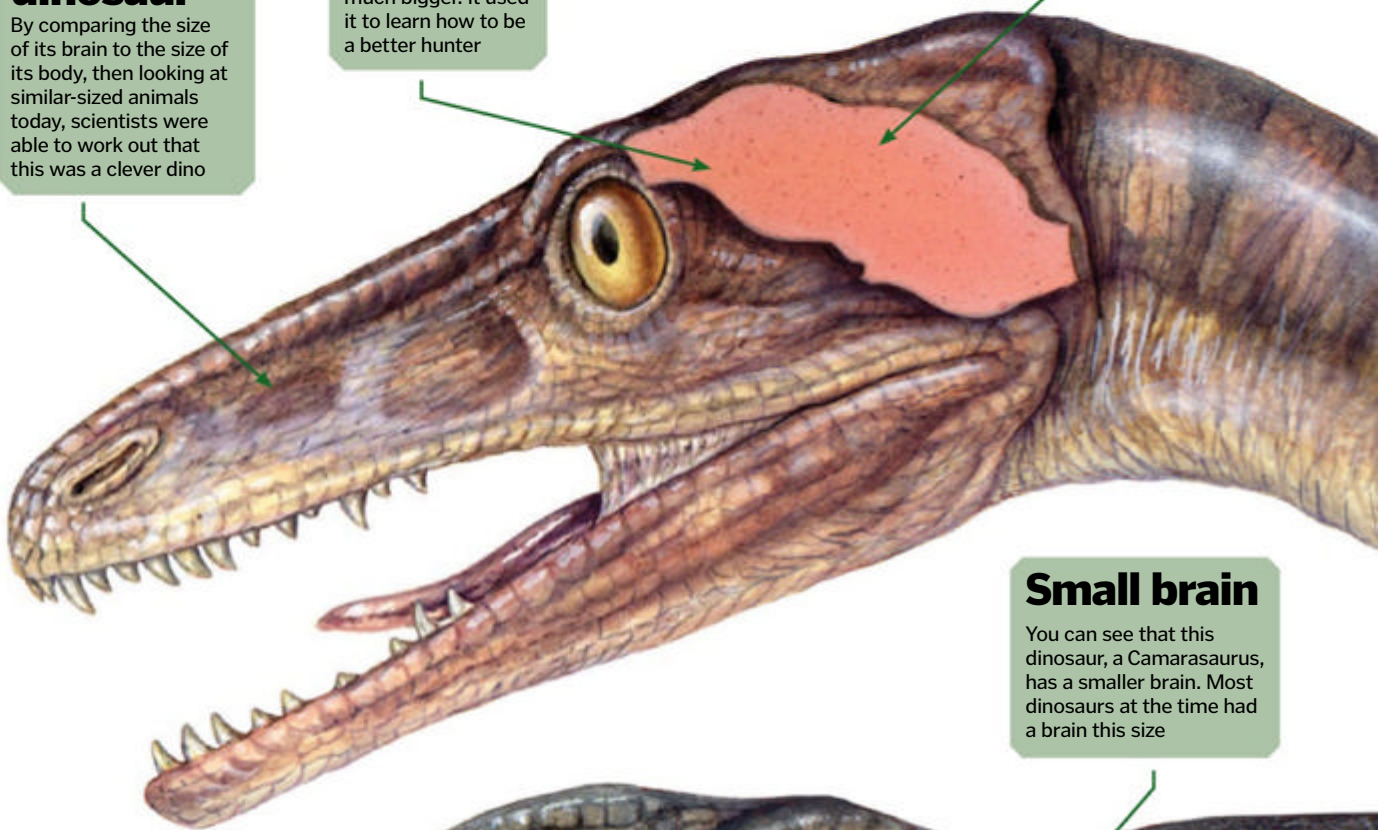
By comparing the size of its brain to the size of its body, then looking at similar-sized animals today, scientists were able to work out that this was a clever dino

Big brain

Most dinosaur brains were as small as walnuts, but the Troodon's was much bigger. It used it to learn how to be a better hunter

Cooperation

A bigger brain meant that Troodons could communicate with each other and hunt together in efficient packs

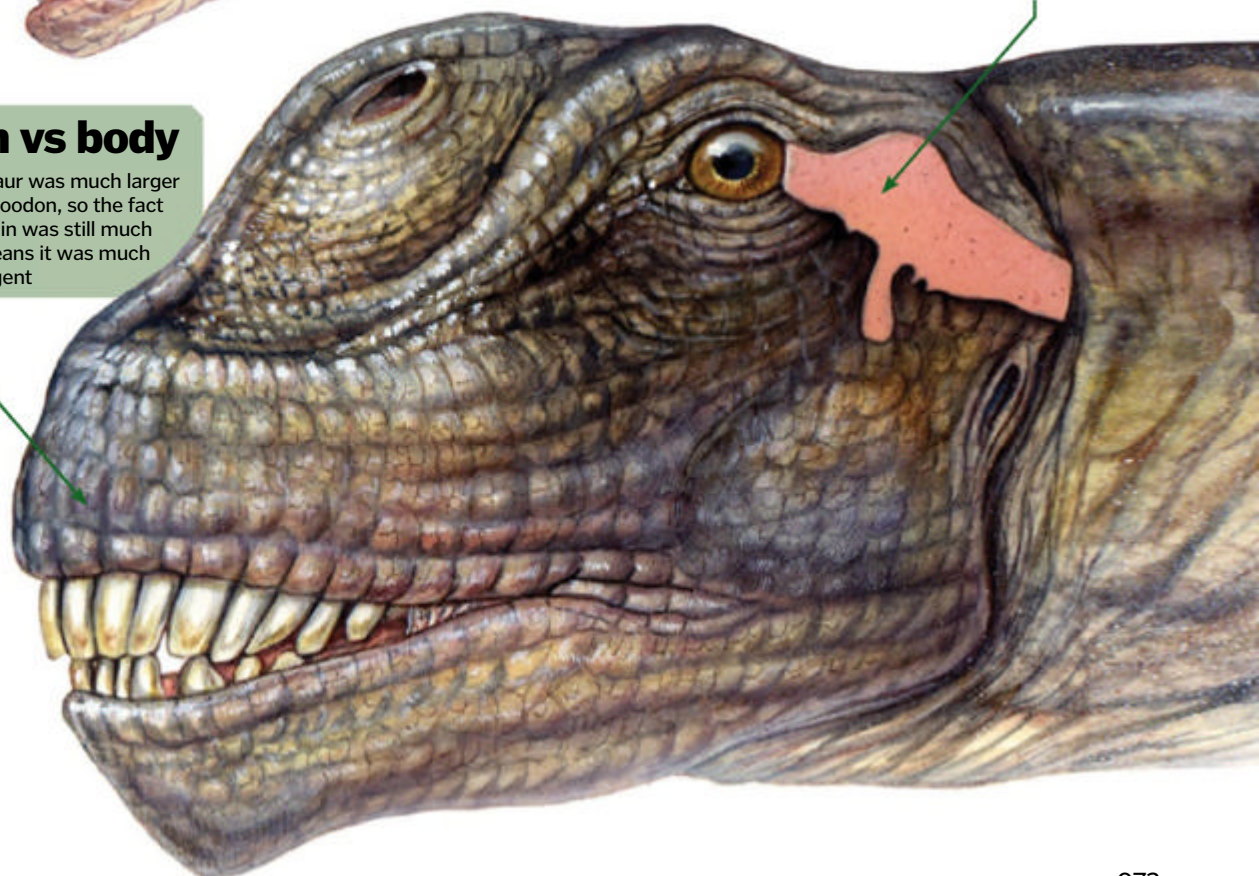


Small brain

You can see that this dinosaur, a Camarasaurus, has a smaller brain. Most dinosaurs at the time had a brain this size

Brain vs body

This dinosaur was much larger than the Troodon, so the fact that its brain was still much smaller means it was much less intelligent





Diplodocus

We find out how this mighty dinosaur once lived



Diplodocus is one of the most famous dinosaurs. It belonged to the group known as the sauropodomorphs and was around in the Late Jurassic period – specifically the Kimmeridgian and Tithonian eras roughly 154-150 million years ago. It reached sizes of up to 25 metres (82 feet) in length and was found in what is now North America. There were four species of Diplodocus, with the largest of these being *Seismosaurus*, which translates to ‘ground shaker’.

Diplodocus was part of the diplodocid family, sharing the same characteristic of having 15 neck vertebrae, short forelimbs compared to the rest of its body and a whip-like tail. Its giant neck made up a large proportion of its body, but there is still some contention as to whether it held its neck vertically or horizontally. Its rectangular skull contained huge eye sockets and nasal chambers. Studies of its teeth suggest that Diplodocus fed using what is known as branch stripping, where the branch of a tree is grasped in a creature’s jaw and then pulled sharply up or down, tearing off foliage.

Diplodocus was the largest dinosaur around. It was later eclipsed by other sauropods, but it roamed the tallest for at least a few million years. Numerous bones have been found and studied by palaeontologists, providing an insight into how these giant dinosaurs were able to support themselves and how they lived.

Spine

Running along its back, like other sauropods, were triangular spines on its vertebrae

Vertebrae

There were as many as 80 caudal vertebrae in the tail of the Diplodocus

Tail

It’s highly likely that it was able to crack its whip-like tail at supersonic speeds, using it as a primary form of attack or defence

Diplodocus feet are believed to have been fleshy and cushioned by thick pads, much like those of elephants



© Bearrice Murch

DID YOU KNOW? The name *Diplodocus* means 'double beam', a reference to the V-shaped bones in the vertebrae of the tail

Head

Compared to the rest of its body, the *Diplodocus* had a very small head

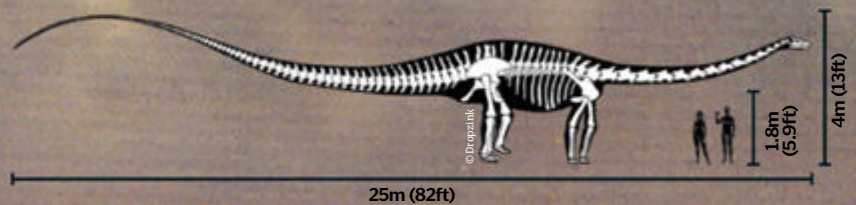
Teeth

The teeth of *Diplodocus* were peg-like, allowing it to strip foliage from branches

Stability

The outstretched tail counterbalanced the neck of the *Diplodocus*, allowing the huge creature to remain stable

"Its giant neck made up a large proportion of its body, but there is still some contention as to whether it held its neck vertically or horizontally"



Legs

Diplodocus could weigh up to 15 tonnes. It therefore needed huge, trunk-like legs to support its immense body weight



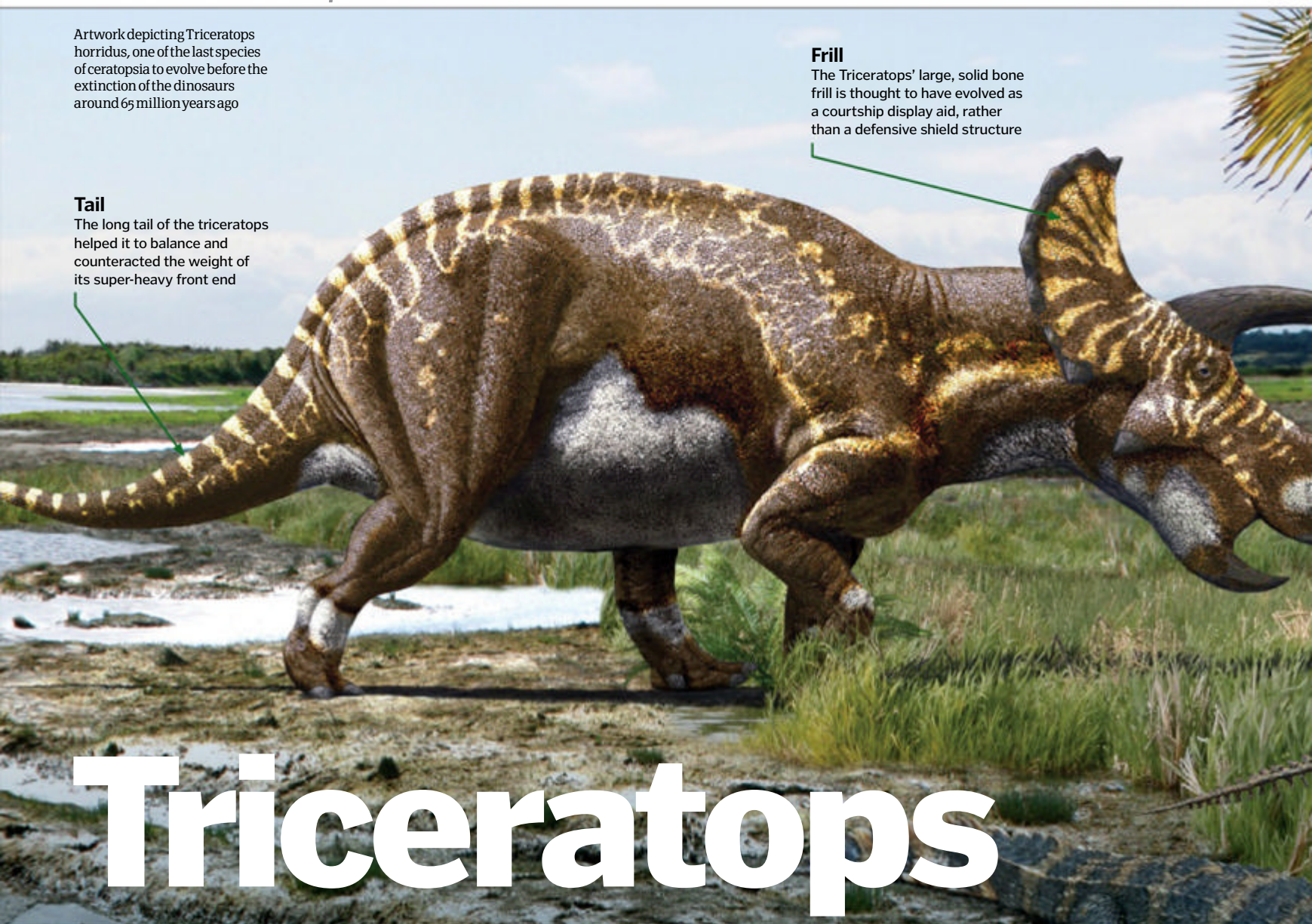
Artwork depicting *Triceratops horridus*, one of the last species of ceratopsia to evolve before the extinction of the dinosaurs around 65 million years ago

Tail

The long tail of the triceratops helped it to balance and counteracted the weight of its super-heavy front end

Frill

The Triceratops' large, solid bone frill is thought to have evolved as a courtship display aid, rather than a defensive shield structure



Triceratops

One of the most well-known dinosaurs, the Triceratops was a herbivorous titan that was very well equipped for a fight



Triceratops is a genus of herbivorous dinosaur that comprises two validated species – *Triceratops horridus* and *Triceratops prorsus*, both of which roamed Earth during the Late Cretaceous period (68–65 Ma) before being eradicated in the K-T mass-extinction event that wiped out all dinosaurs.

Triceratops were large, rhinoceros-like animals that weighed many tonnes – a fully grown adult would be expected to weigh in the region of seven tonnes. They were heavily armoured with reinforced bone horns, which could exceed 70 centimetres (28 inches) and a solid bone frill, and hugely powerful thanks to their sturdy frame. These traits, combined, made both species of *Triceratops* a fearsome foe to potential predators, capable of puncturing flesh and shattering bone with their sharp horns when charging.

In terms of anatomy (for a comprehensive rundown, see the 'Triceratops anatomy' illustration), the *Triceratops* genus is incredibly interesting, not least because many of its parts' functions are still debated today in the field of palaeontology. A good example of this can be seen by analysing a typical *Triceratops* skull, which – aside from typically measuring a whopping two metres (6.6 feet) in length – sported three horns as well as a fluted, extravagant rear frill.

The horns, from which the genus gets its name, and frill have been successfully argued by palaeontologists to have been used for self-defence against predators, with close examination of unearthed specimens revealing battle scars, cuts, punctures and cracks. However, modern scholars also postulate that both skull features, along with the elongated nature of the skull itself, most likely

also evolved as courtship aids, with potential mates selected on the size and shape of these features. It has also been suggested that the frill may have helped *Triceratops* regulate their body temperature in a similar manner to the plate-laden *Stegosaurus* (whose name translates as roof, or covered, lizard).

Other anatomical areas of interest lie in this dinosaur's large bird-like beak and hips. Indeed, it is because of these particular features that this genus has been used as a reference point in the definition of all dinosaurs – ie all dinosaurs are descendants of the most recent common ancestor of *Triceratops* and, as such, this common ancestor is also that of birds prevalent throughout the world today. It's important to note here that modern birds did not descend from triceratops directly, but rather from its common ancestor with all other dinosaurs; today's birds in fact originate from saurischian dinosaurs.

Triceratops anatomy

We examine the skeleton of this powerful plant-eater to see its basic anatomy



Pelvis

Triceratops had a gently arched back leading down towards a strong pelvic structure, both factors that generated more power when charging

Brow horns

Considerably larger than the nose horn, the brow horns commonly stretched out beyond the animal's snout and were sharp-tipped

Nose horn

With both species of Triceratops, the nose horn is very short and squat, elevated from the upper jaw on a bone arch

Chest cavity

The chest cavity was massive, holding the animal's vital organs at the front and upper stomach to the rear

Neck

The head of the Triceratops was joined at the neck by a ball-and-socket joint located behind the large frill

Beak

A tough, horny, toothless beak at the front of the Triceratops' snout aided in foraging activities

The statistics...

Triceratops

Length: 8m (26ft)

Height: 2.9m (9.5ft)

Weight: 6,350kg (14,000lb)

Diet: Herbivore

Discovered: Colorado, USA

Front legs

Both validated species of Triceratops have extremely sturdy front legs to ensure support for its heavy head and chest cavity

Skull

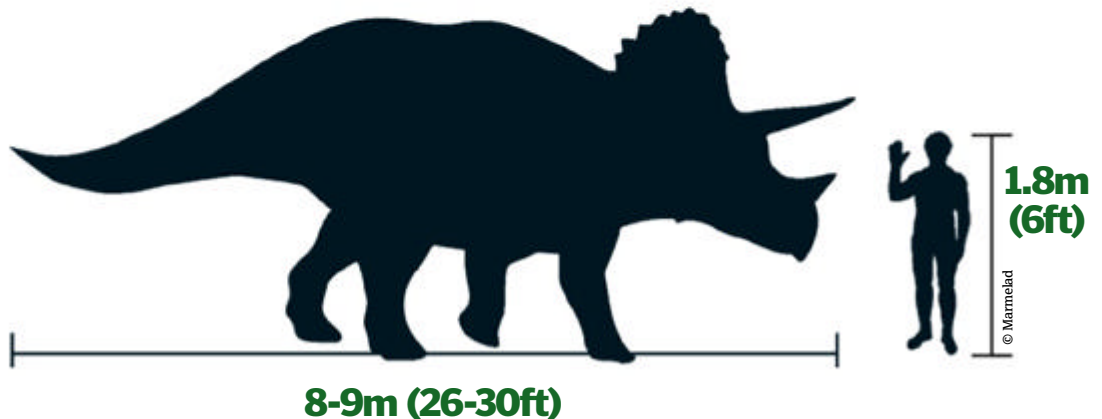
Over 50 complete Triceratops skulls have been found today, each confirming that they were incredibly heavy and solid

Jaw

The Triceratops' teeth were arranged in groups of 36-40 columns in each side of the jaw, with three to five stacked teeth per column

The fundamental diet of the Triceratops was largely dictated by – and most likely co-evolved with – its low-slung posture and head position, which was located close to the ground. As a consequence of these factors, as well as its deep and narrow beak and sharp teeth batteries, both species of Triceratops most likely consumed large amounts of low-growth ferns, palms and cycads, plucking the plants with their beaks and then shredding the fibrous material with their teeth.

The Triceratops' main potential predators were carnivorous theropod dinosaurs such as the Tyrannosaurus rex. However, while modern-day depictions of these two prehistoric titans are often far-fetched, Triceratops specimens have been discovered with T-rex bite marks and even one where the herbivore had had one of its brow horns snapped off entirely.





“Velociraptor hunting techniques revolved largely around their speed and agility”

Velociraptors

One of the most deadly dinosaurs, the Velociraptor was an adept predator and scavenger, but not quite the creature Hollywood would have us believe...



Velociraptors have been ingrained in public consciousness since the 1993 movie *Jurassic Park* showcased them as the most fearsome of apex predators. Smart, lethal and bloodthirsty, the Velociraptors of the film arguably stole the show. However, the movie was famed for its indulgence of artistic licence, with palaeontologists bemoaning the lack of historical accuracy.

So what were these dinosaurs really like? Velociraptor, of which there are two verified species – *V. mongoliensis* and *V. osmolskae*, was a genus of dromaeosaurid (“running lizard”) theropod dinosaur that lived in the Late Cretaceous period, about 75-71 million years ago. They were two metres (6.6 feet) long, just under a metre (three feet) high, feathered and bipedal, running on two of their three toes per foot. Velociraptors were native to modern-day central Asia most notably Mongolia, where they

built large, ground-based nests to protect their vulnerable young.

Velociraptors, though often living in close proximity to one another, were largely solitary and, while certain finds suggest they could have teamed up while chasing their quarry, they were not pack hunters, with evidence showing they would fight among themselves for feeding rights. In addition, their staple diet consisted of animals of equal size and weight to themselves or those smaller than them, with very little evidence suggesting they would attempt to bring down larger dinosaurs, such as the *Tyrannosaurus rex* at *la Jurassic Park*.

Velociraptor hunting techniques revolved largely around their speed and agility. They could accelerate up to 64 kilometres (40 miles) per hour and pounce long distances, as well as grip prey firmly with their unique, sickle-shaped claws (notably

their enlarged ‘killing claw’). These traits were partnered with a tendency to ambush prey, rather than tackle their victims face on or from long range (see the ‘Slash or subdue?’ boxout for more). Interestingly, however, while there’s no doubt that Velociraptors hunted live prey, unearthed fossilised evidence suggests they were also incredibly active scavengers, with the species frequently feeding on carrion (pterosaur bones have been found in velociraptor guts, for instance) and carcasses left over by other predators.

Velociraptors died out along with the remaining species of dromaeosauridae in the run up to, and as a result of, the Cretaceous-Tertiary mass-extinction event that occurred approximately 65.5 million years ago. Despite this, elements of their anatomy and appearance can still be seen today – albeit in heavily evolved forms – in many species of bird.

The statistics...

Velociraptor

Length: 2m (6.6ft)

Height: 0.8m (2.5ft)

Weight: 113kg (200lb)

Diet: Carnivore

Discovered: Mongolia



This is an accurate representation of a Velociraptor, being covered in feathers and attacking prey smaller than itself

Slash or subdue?

Did Velociraptors use their sickle-shaped claws to disembowel prey or for some other purpose?

The majority of non-avian theropod dinosaurs are characterised by razor-sharp serrated teeth and talon-like recurved claws, the Velociraptor being no exception. Armed with a bounty of claws on both its hands and feet, the Velociraptor at first glance seems to be the perfect killing machine, capable of rapidly chasing down prey before shredding their flesh with one of their knife-like tools. Well, that was at least the commonly accepted theory among palaeontologists until late in 2011, before a new study by a team of international dinosaur experts suggested an entirely different use for them.

The study suggested that far from their claws – specifically the Velociraptor’s much-touted ‘killing claws’ – being used to shred and slice prey in order to kill them prior to consumption, they were far more likely to be used in a similar way to the talons of modern-day hawks and eagles. This entails the birds using their talons as a gripping tool, snaring prey of a lesser body size, pinning them down with their own body weight and then often consuming them live with their beaks.

This theory is seemingly backed up by the Velociraptor’s feet showing morphology consistent with a grasping function, supporting a prey immobilisation model rather than the originally assumed combative one.



A fossilised claw from a Velociraptor. Recent evidence has emerged that has challenged the idea that this was used as a slashing weapon

Anatomy of a Velociraptor

What physiological features made this dinosaur a natural-born killer?



Spine

The Velociraptor’s spine was S-shaped and very flexible, allowing it to shift position and direction with great agility. It also enabled it to jump to a great height, so it could pounce on targets from afar

Tail

Long bony projections under the vertebrae, in partnership with ossified (semi-bone) tendons, granted the Velociraptor a stiffened tail structure. This helped it to keep balance and turn at speed

Legs

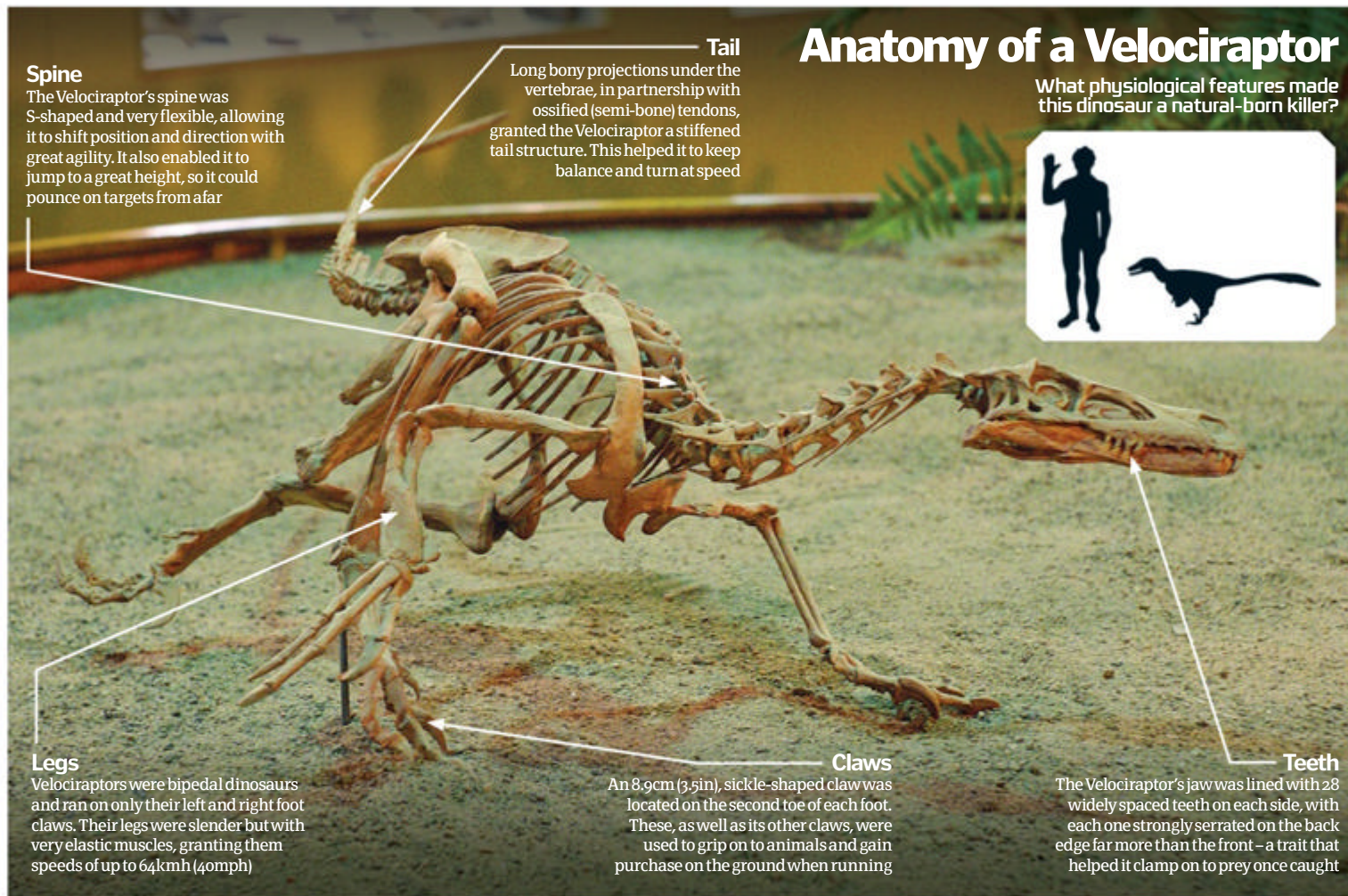
Velociraptors were bipedal dinosaurs and ran on only their left and right foot claws. Their legs were slender but with very elastic muscles, granting them speeds of up to 64kmh (40mph)

Claws

An 8.9cm (3.5in), sickle-shaped claw was located on the second toe of each foot. These, as well as its other claws, were used to grip on to animals and gain purchase on the ground when running

Teeth

The Velociraptor’s jaw was lined with 28 widely spaced teeth on each side, with each one strongly serrated on the back edge far more than the front – a trait that helped it clamp on to prey once caught





Stegosaurus

The bony plates along the Stegosaurus's back were probably used for display rather than as a form of defence



The statistics...

Stegosaurus

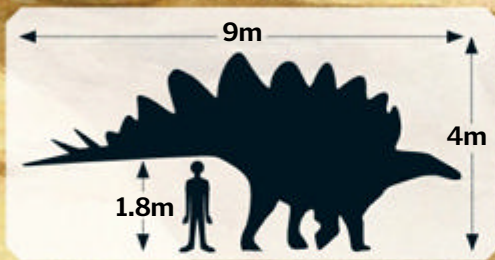
Length: 8-9m (26.2-29.5ft)

Height: 2.8-4m (9.2-13.1ft)

Weight: 3,100kg (6,800lb)

Diet: Herbivore

Discovered: Colorado, USA



Stegosaurus

One of the most well known of the dinosaurs, the Stegosaurus boasted a series of diamond-shaped bone plates and a tail that could kill

Skull

Despite its large scale, the Stegosaurus's head was very narrow and it had a tiny brain capacity



Maybe the most iconic genus of dinosaurs ever excavated, the *Stegosaurus* was a herbivorous titan, capable of consuming huge quantities of low-level foliage while protecting itself from predators with its vast armoured frame and potentially lethal spiked tail.

The first example of *Stegosaurus* – from which its family name, *Stegosauridae*, derived – was unearthed in 1877 and since then four confirmed species of the dinosaur have been officially identified. Each species demonstrates a similar structure and feature set, with each animal epitomising a large quadruped, sporting a series of diamond-shaped plates along its back. These large creatures were over eight metres (26 feet) long and were heavily built at over 3,000 kilograms (6,614 pounds).

Interestingly, it's these plates that palaeontologists and academics know the least about, with a variety of arrangements, structures and uses suggested. When first unearthed it was speculated that they were used as a form of armoured defence against carnivorous predators. However, their positioning along the back and apparent bluntness has led to this theory being largely dismissed today. Instead, academics suggest that the plates were used as a decorative feature – perhaps in mating displays or to ward off *Stegosaurus* rivals in territory disputes.

The field of palaeobiology reveals almost everything else about this genus. Studying fossilised evidence it is clear that due to *Stegosaurus's* very small and narrow skull, they had a tiny brain and so were not very intelligent – something seemingly confirmed by their primitive and mundane feeding habits. The low level of the animal's neck, short but bulky forelegs and raised pelvis/elongated hind legs indicate that *Stegosaurus* spent much of its daily routine consuming large quantities of low-lying foliage (such as ferns, cycads and conifers). This is confirmed by the shape and formation of its teeth and a low bite force.

Upon closer inspection of the dinosaur's legs it is also clear that it could not move very quickly. This is apparent as the discrepancy in size between the front and hind legs is so great that, if the creature ran at over eight kilometres (five miles) per hour, its longer back legs would cross over the forelegs leading it to fall.

Despite these shortcomings, *Stegosaurus* wasn't totally defenceless, as it boasted a flexible, armour-plated and spiked tail. Taking *Stegosaurus stenops* as an example, the dinosaur had four dermal tail spikes of approximately 75 centimetres (29.5 inches) in length each, which extended out from the tail slightly off the horizontal plane. These spikes enabled the *Stegosaurus* to whip its tail and puncture the flesh of any attackers.

Forelegs

The forelegs were very bulky and powerful. They were relatively short, however, granting easy access to the ground

Stegosaurus anatomy

Understand the biological structure of this distinctive dino from the inside out

Plates

The *Stegosaurus's* plates were made from bone and covered with either skin or toughened horn

Pelvis

Due to its great weight – over 3,000kg (6,614lb) – the *Stegosaurus* had a huge pelvis to support a vast ribcage and spine

Tail

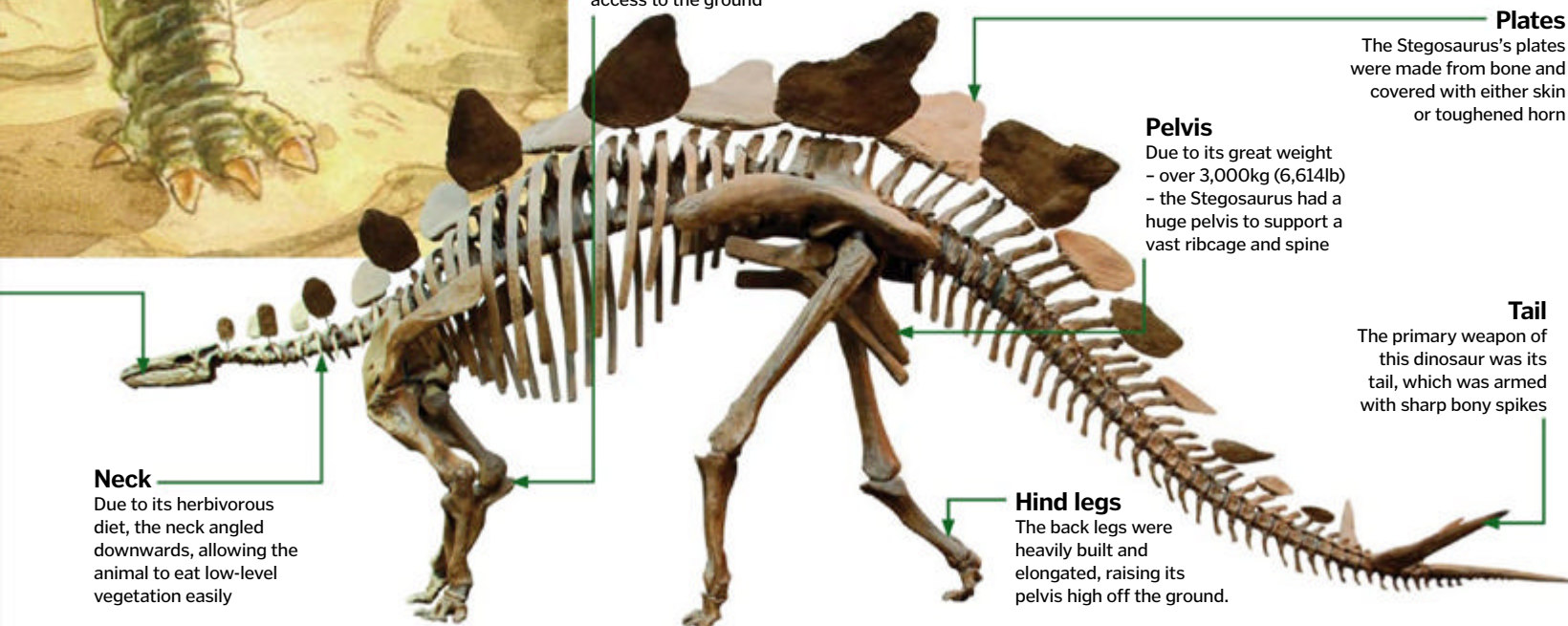
The primary weapon of this dinosaur was its tail, which was armed with sharp bony spikes

Neck

Due to its herbivorous diet, the neck angled downwards, allowing the animal to eat low-level vegetation easily

Hind legs

The back legs were heavily built and elongated, raising its pelvis high off the ground.





The statistics...

Tyrannosaurus rex

Length: 12-13m (40-43ft)

Height: 4m (13ft)

Weight: 6-9 tonnes

Diet: Carnivore

Discovered: Colorado, USA

Tyrannosaurus rex

Learn about the lizard king's physiology and how it presided over the prehistoric jungle



Tyrannosaurus rex was a species of Theropoda dinosaur in the Late Cretaceous period. Like other tyrannosaurids – such as Tarbosaurus and Gorgosaurus – the T-rex was a bipedal carnivore and apex predator and scavenger, preying on smaller dinosaurs directly or out-muscling them for their kills. Typical prey included hadrosaurs and ceratopsians.

Tyrannosaurus rex's name translates as "tyrant lizard king" – something that was historically attributed due to its immense size. Indeed, the Tyrannosaurus rex is one of the largest species ever excavated by palaeontologists, with specimens averaging over 12 metres (40 feet) in length and four metres (13 feet) in height, but it wasn't the biggest carnivorous dino. It was incredibly heavy with fully grown adults weighing up to nine tonnes; this figure was suggested in 2011 after an in-depth study which made digital 3D models of five T-rex skeletons.

Due to their considerable size, the Tyrannosaurus rex had very few, if any, predators – a fact that enabled it to remain unchallenged as the Late Cretaceous era's apex predator on land and to live for lengthy periods. Estimates taken from excavated specimens – of which there are now more than 30 confirmed around the world – indicate that the T-rex's life span was roughly 30 years, with the majority of growth taking place in the first 16 years before tailing off rapidly. This suggests that the Tyrannosaurus rex would have reached adulthood at approximately 20 years of age.

As with almost all species of Dinosauria, the Tyrannosaurus was wiped out 65.5 million years ago in the Cretaceous-Palaeogene (K-Pg) extinction event. At the time it was one of the last widespread non-avian dinosaurs, as evidenced by the discovery of many specimens throughout North America.



T-rex mythbuster

Due to a variety of films depicting the T-rex in their own unique way, an accurate view of the species has been clouded. For example, despite being a prominent star of all the Jurassic Park films, Tyrannosaurus rex did not exist in the Jurassic period (199-145 MYA). In fact, it lived millions of years later during the Late Cretaceous (100-65.5 MYA). Further, for decades T-rex has been depicted as having green scaly skin. However, recent evidence suggests its skin colour was varied and, during the early years of its life, it probably sported insulative feathers. The T-rex has also been commonly lauded as the biggest carnivorous dinosaur of them all. This isn't strictly true, with palaeontological evidence suggesting the species Spinosaurus outsize it by over three metres (9.9 feet) in length. And finally, another myth perpetuated in Jurassic Park is that the Tyrannosaurus could run at high speed (ie keep up with a car), but it could probably only manage about 40 kilometres (25 miles) per hour due to its relatively small strides.

Anatomy of the lizard king

We analyse a Tyrannosaurus rex's skeleton to see what made it such a deadly predator

Tail
Crucial for maintaining balance – especially as modern evidence suggests T-rex had a near-horizontal spinal position – the dinosaur's large tail was essential for chasing prey

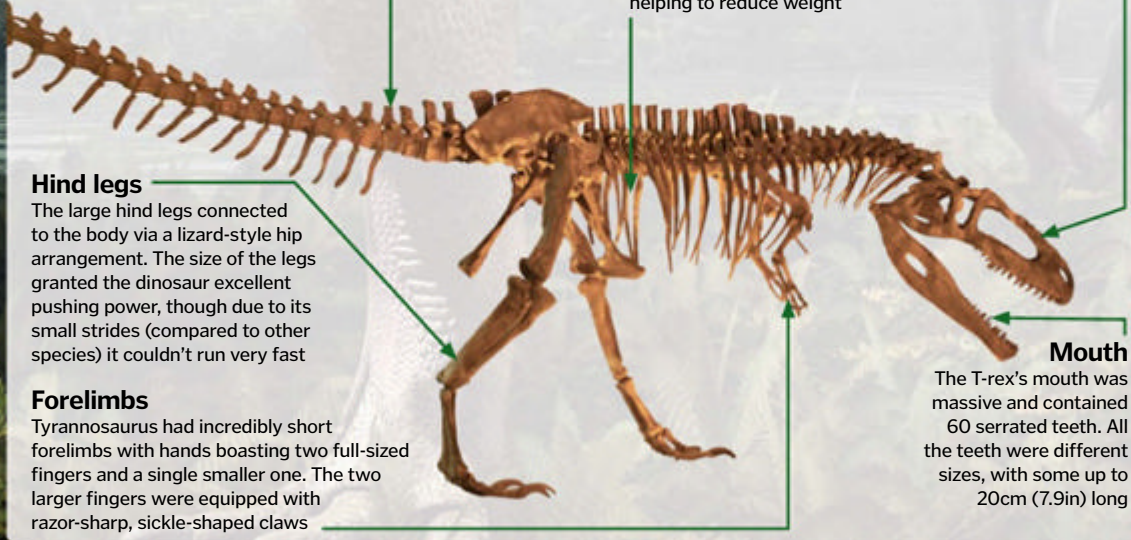
Body cavity
The Tyrannosaurus rex had an incredibly heavy body structure and a wide body cavity. To improve mobility, some of the dinosaur's vertebrae had holes – helping to reduce weight

Hind legs
The large hind legs connected to the body via a lizard-style hip arrangement. The size of the legs granted the dinosaur excellent pushing power, though due to its small strides (compared to other species) it couldn't run very fast

Forelimbs
Tyrannosaurus had incredibly short forelimbs with hands boasting two full-sized fingers and a single smaller one. The two larger fingers were equipped with razor-sharp, sickle-shaped claws

Skull
Tyrannosaurus's skull was huge and its snout and lower jaw were very deep. The eye sockets faced forward to a greater degree than most dinosaurs, indicating it had acute binocular vision

Mouth
The T-rex's mouth was massive and contained 60 serrated teeth. All the teeth were different sizes, with some up to 20cm (7.9in) long





The giant Brachiosaurus

Three times longer and two times taller than a double-decker bus, Brachiosaurus truly was a terrestrial titan of epic proportions



Brachiosaurus was a genus of sauropod dinosaur that roamed the Earth during the Late Jurassic period (circa 155-140 million years ago). They are characterised, like many sauropods of the time, by their huge necks and comparatively tiny skulls and brains. Currently only one species has been officially confirmed – *B altithorax* – though others have been suggested.

Interestingly, like other sauropods, these creatures – despite weighing an estimated 60 tons and measuring up to 30 metres (98 feet)

long – were actually colossal vegetarians, with their diet comprising solely foliage.

Their evolution of such a long neck (see 'The high life' boxout for more details) seems to be intrinsically linked to their diet, with the elevated head position enabling them to access leaves unavailable to shorter species.

This dominion over a food source is also a major factor behind their generally massive proportions, with millions of years of domination allowing them to grow to sizes far in excess of rival creatures from the same era.

The epic size of Brachiosaurus was also its primary form of defence when it came to predators. Once fully grown, their legs would have resembled tree trunks and these – partnered with a heavy, stocky tail – made them extremely difficult to tackle.

While their size and domination granted many benefits, it was also a contributor to Brachiosaurus's eventual demise, with resource depletion and climate change leading to their background extinction around 145 million years ago.

Anatomy of a titan

Take a look inside this lofty member of the dino family

Skin

Brachiosaurus's skin was leathery and tougher around limb joints. Its colour varied depending on age and species

Torso

The torso was massive and accounted for up to 70 per cent of the creature's total volume. Its huge organs were protected by a robust ribcage

Heart

Due to its immense size this dinosaur needed a large, powerful heart to pump blood to its brain and around its body. Estimates place the creature's blood pressure at three to four times that of humans

Tail

A long, stiff tail acted as a counterbalance to the sauropod's long neck, especially when it was brought down towards the horizontal. While combat was rare, the tail could also be used as a weapon

Lungs

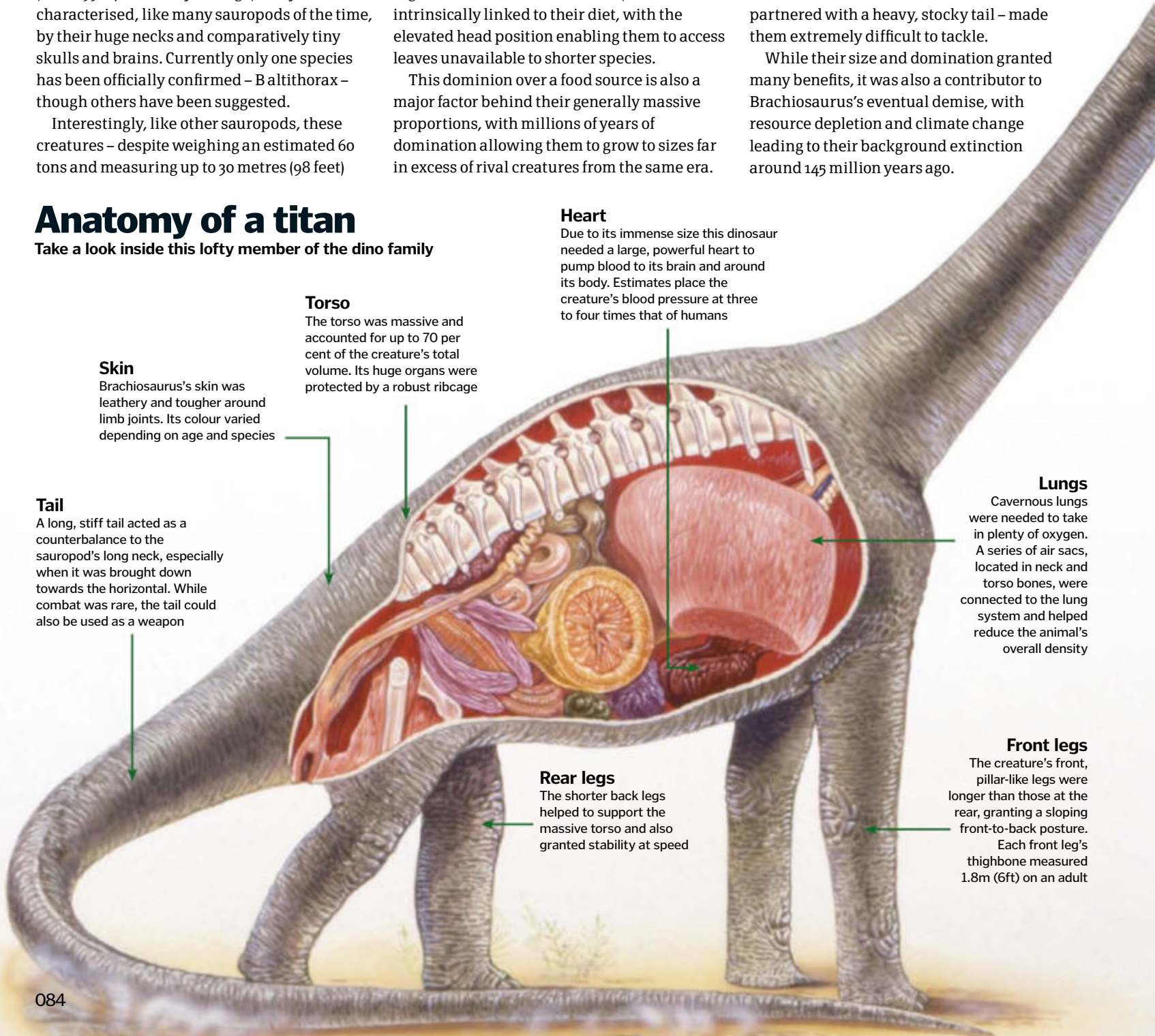
Cavernous lungs were needed to take in plenty of oxygen. A series of air sacs, located in neck and torso bones, were connected to the lung system and helped reduce the animal's overall density

Rear legs

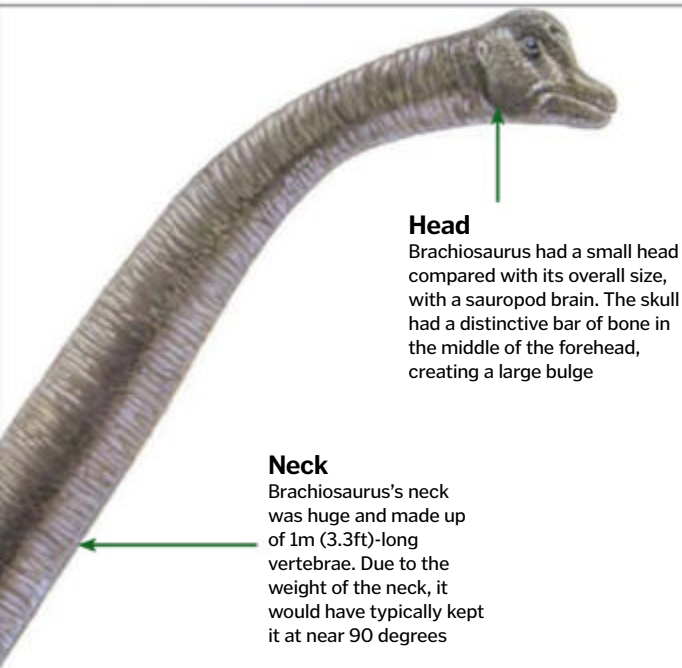
The shorter back legs helped to support the massive torso and also granted stability at speed

Front legs

The creature's front, pillar-like legs were longer than those at the rear, granting a sloping front-to-back posture. Each front leg's thighbone measured 1.8m (6ft) on an adult



DID YOU KNOW? Brachiosaurus could not rear up on its hind limbs as depicted in Jurassic Park



Head

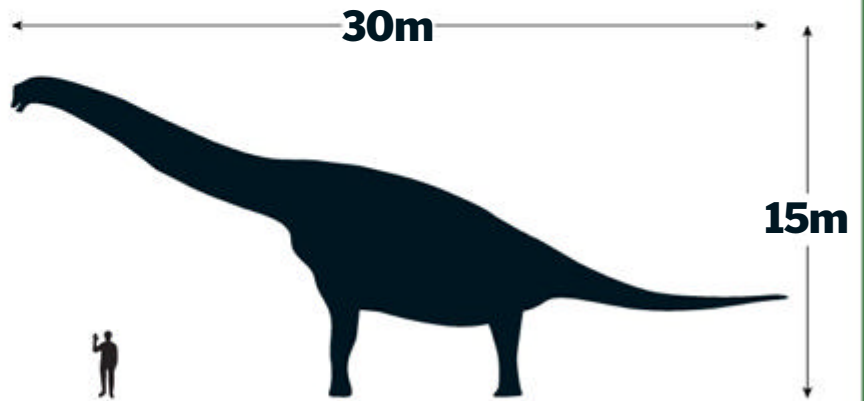
Brachiosaurus had a small head compared with its overall size, with a sauropod brain. The skull had a distinctive bar of bone in the middle of the forehead, creating a large bulge

Neck

Brachiosaurus's neck was huge and made up of 1m (3.3ft)-long vertebrae. Due to the weight of the neck, it would have typically kept it at near 90 degrees

Brachiosaurus vs human

How does this mega-dino size up to your average Homo sapien?



The statistics...

Brachiosaurus

Length: 25-30m (82-98ft)

Height: 15m (49ft)

Weight: 60 tons

Diet: Herbivore

Discovered: Colorado, USA

The high life

Each vertebra in the neck of Brachiosaurus was approximately one metre (3.3 feet) in length, which is absolutely colossal compared with the largest animals around today. Combined, these vertebrae formed an extensive, snake-like neck that enabled the Brachiosaurus to reach up into tall trees and other plants with ease to feed on foliage – of which it needed vast quantities to survive.

Importantly, despite the long neck giving Brachiosaurus a keen browsing advantage when compared with other smaller dinosaurs, as a payoff it would have needed a near-vertical neck posture most of the time in order to prevent injury.

Unlike the popular 20th-century view that Brachiosaurus would raise and lower its head to access different tiers of foliage, it is now generally thought that only the immediate level around its head height would have been eaten, with lower tiers of leaves only consumed by juveniles.

Its name translates as 'arm lizard' because unusually for dinosaurs its front legs were longer than its hind legs



Ankylosaurus

A club-wielding brute of a creature, this tough dino had the power to break bones



Ankylosaurus was one of the largest ankylosaurs, a genus of armoured dinosaurs that lived throughout North America between 75 and 65.5 million years ago. Famous for both its brutal tail-mounted club and its immense bone plate armour, the Ankylosaurus was a defensive titan, capable of fending off rivals many times its size.

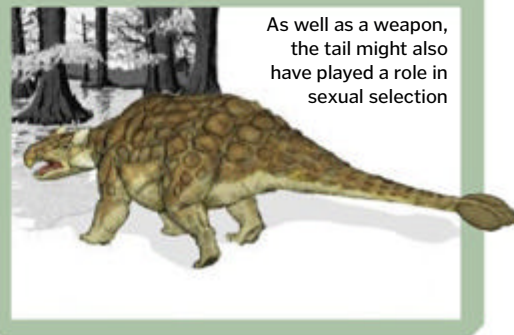
Ankylosaurus's focus on defence was born out of its herbivorous nature, with its entire body geared towards the consumption of foliage. From its low-slung body, rows of leaf-shaped cropping teeth, short front legs, wide feet and cavernous stomach, the Ankylosaurus was the consummate browser,

devouring vegetation whole with little shredding or chewing. Indeed, studies have indicated that the skull and jaw of the Ankylosaurus were structurally tougher than many similar, contemporary dinosaurs.

In fact, evidence suggests that Ankylosaurus – and ankylosaurs in general – were adept survivors. But despite their impressive armour, weaponry and sustainable diet, they could not cope with the Cretaceous-Tertiary extinction event that wiped out all terrestrial dinosaurs approximately 65.5 million years ago. Only a few fossils of this prehistoric herbivore have been excavated to date – most coming from the Hell Creek Formation in Montana, USA.

Club members only

The well-known tail club of the Ankylosaurus was one of the most lethal weapons sported by any dinosaur. The club was made from several large bone plates called osteoderms that were fused into the last few vertebrae of the animal's tail. Behind these vertebrae several others lined with thick, partially ossified tendons completed the club's handle, resulting in a structure that, when swung, was capable of dealing out a lot of damage. Indeed, a study in 2009 suggested that the tail clubs of fully grown ankylosaurs could easily crush and break bone with a force capable of caving in an assailant's skull. Whether or not the animal purposely aimed the club to cause damage remains unclear at this point.



As well as a weapon, the tail might also have played a role in sexual selection

Ankylosaurus anatomy

Get to know the key biology of this tank-like dino

Osteoderm

Covering much of the body Ankylosaurus sported a series of bony plates called osteoderms embedded in the skin

Head

The Ankylosaurus's head was square, flat and broader than it was long. The jaws featured curved rows of irregularly edged, leaf-shaped teeth for tearing vegetation

Neck

The dinosaur's head sat at the end of a very short and stocky neck. This helped support its bulky head and also acted as a bracing mechanism when charging

Front leg

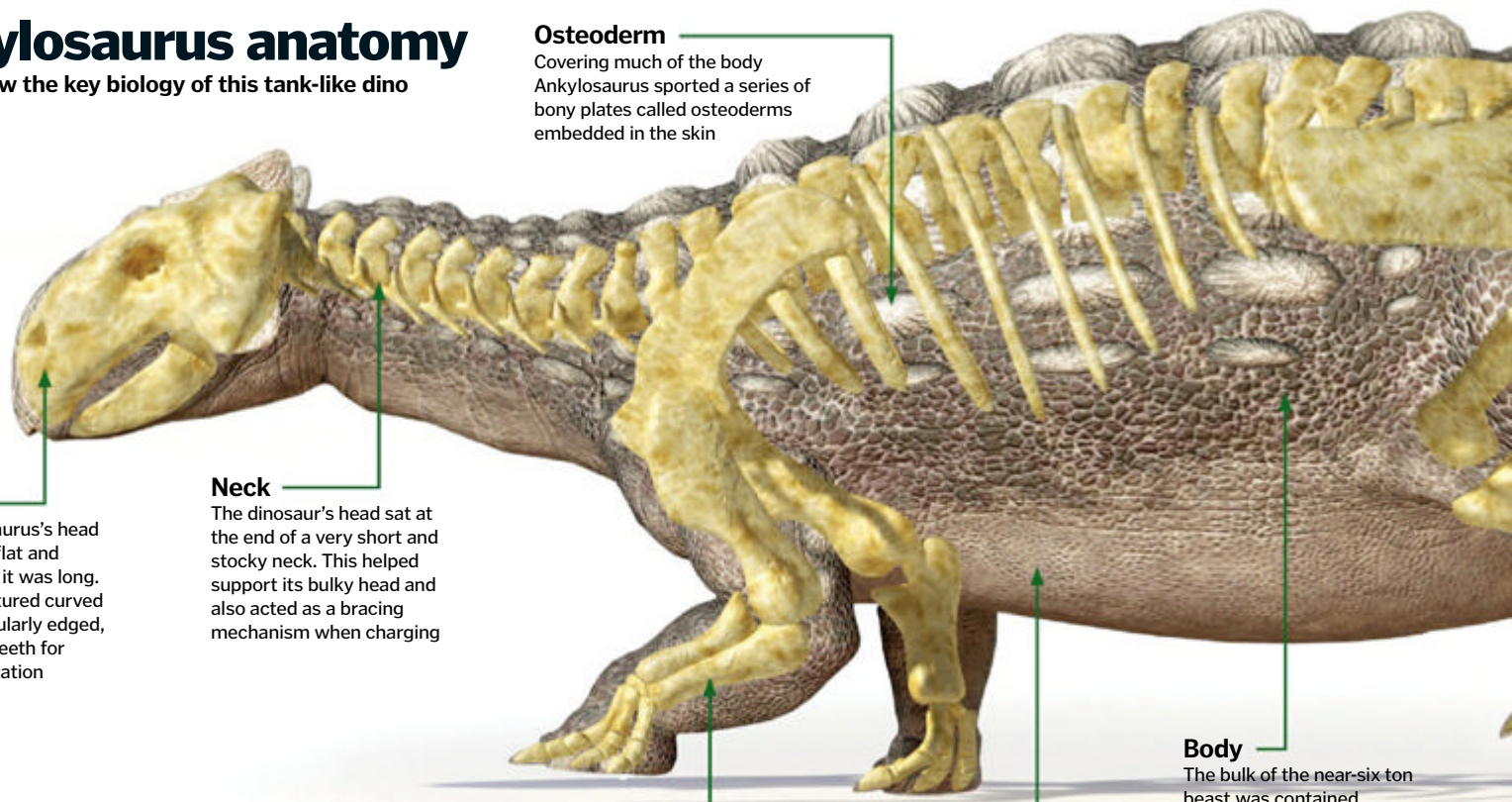
Powerful but short legs supported the front half of the animal. The wide foot area of these forelegs granted good traction and stability

Stomach

The only part of the dinosaur that was unarmoured, the underbelly hung low to the ground. Predators would try to tip Ankylosaurus over to access this weak point

Body

The bulk of the near-six ton beast was contained within its low-slung body. This was covered with armoured bone plating and topped with spines

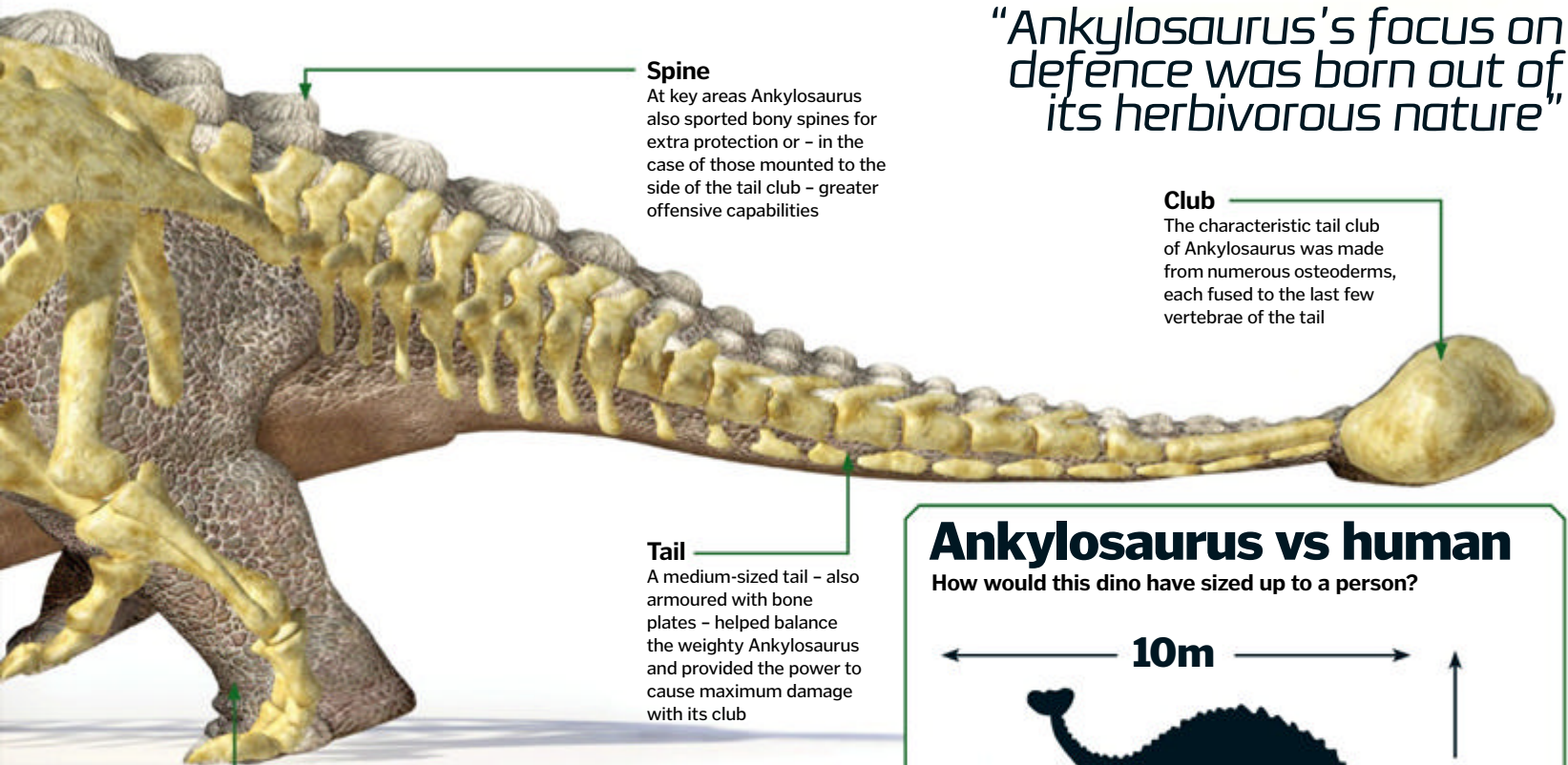
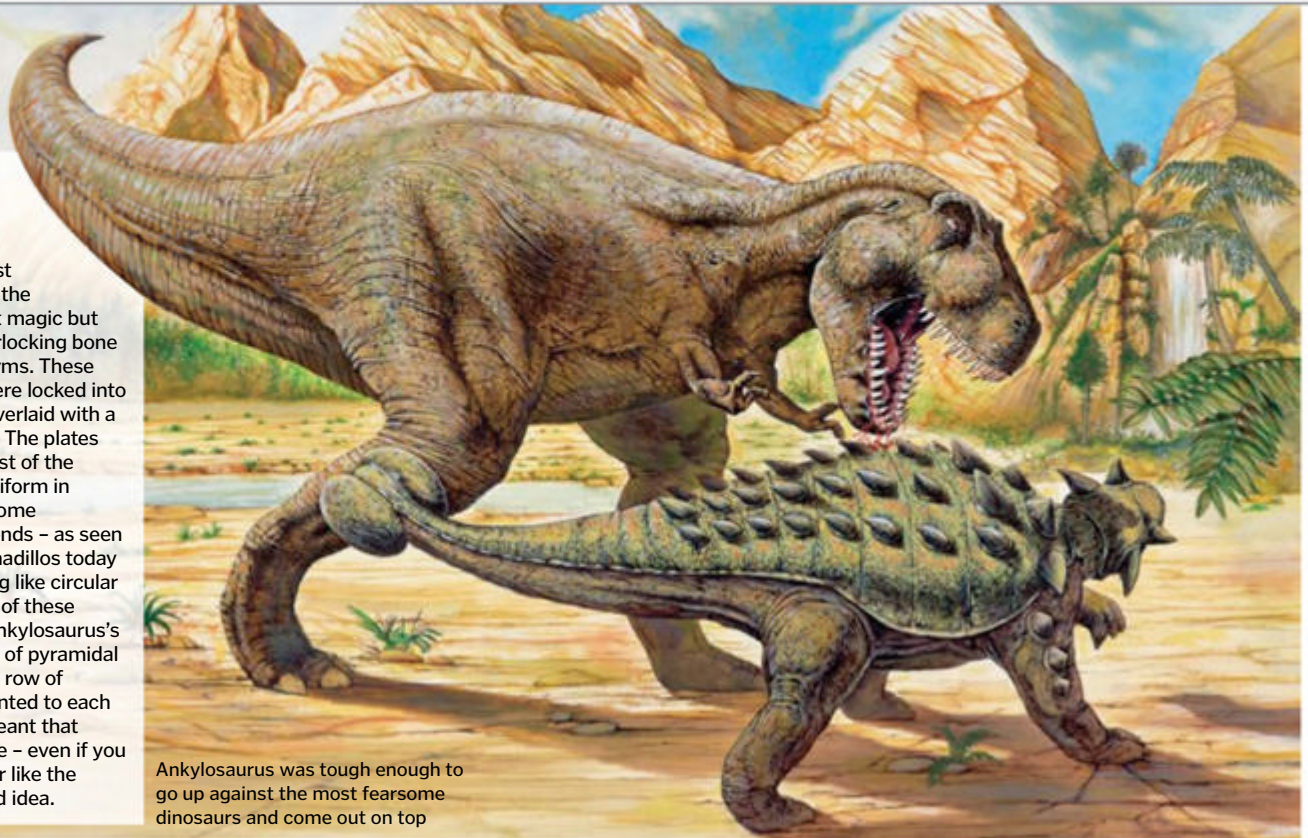


DID YOU KNOW? Interestingly the earliest specimens of ankylosaurs we have found did not possess a tail club

You shall not pass!

The impressive, almost bulletproof armour of the Ankylosaurus was not magic but rather a series of interlocking bone plates called osteoderms. These bone plates, which were locked into the skin, were bone overlaid with a tough layer of keratin. The plates were located over most of the body, but were not uniform in shape nor size, with some resembling flat diamonds – as seen on crocodiles and armadillos today – and others appearing like circular nodules. The addition of these plates on top of the Ankylosaurus's head, along with a set of pyramidal horns to its rear and a row of triangular spikes mounted to each side of the tail club meant that attacking this creature – even if you were an apex predator like the T-rex – was not a good idea.

Ankylosaurus was tough enough to go up against the most fearsome dinosaurs and come out on top



Spine

At key areas Ankylosaurus also sported bony spines for extra protection or – in the case of those mounted to the side of the tail club – greater offensive capabilities

Club

The characteristic tail club of Ankylosaurus was made from numerous osteoderms, each fused to the last few vertebrae of the tail

Tail

A medium-sized tail – also armoured with bone plates – helped balance the weighty Ankylosaurus and provided the power to cause maximum damage with its club

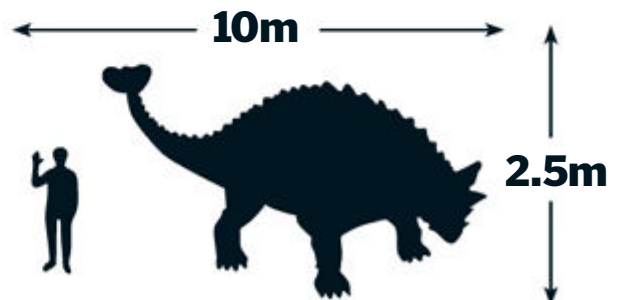
Rear leg

Equally powerful – if not more so – but longer than the Ankylosaurus's forelegs, the rear legs reached up to about 1.7m (5.6ft) at the hip

“Ankylosaurus's focus on defence was born out of its herbivorous nature”

Ankylosaurus vs human

How would this dino have sized up to a person?





Head

Apatosaurus had a deep, slender skull filled with long peg-like teeth. These broad, rounded teeth were excellent at stripping off leaves from branches

Neck

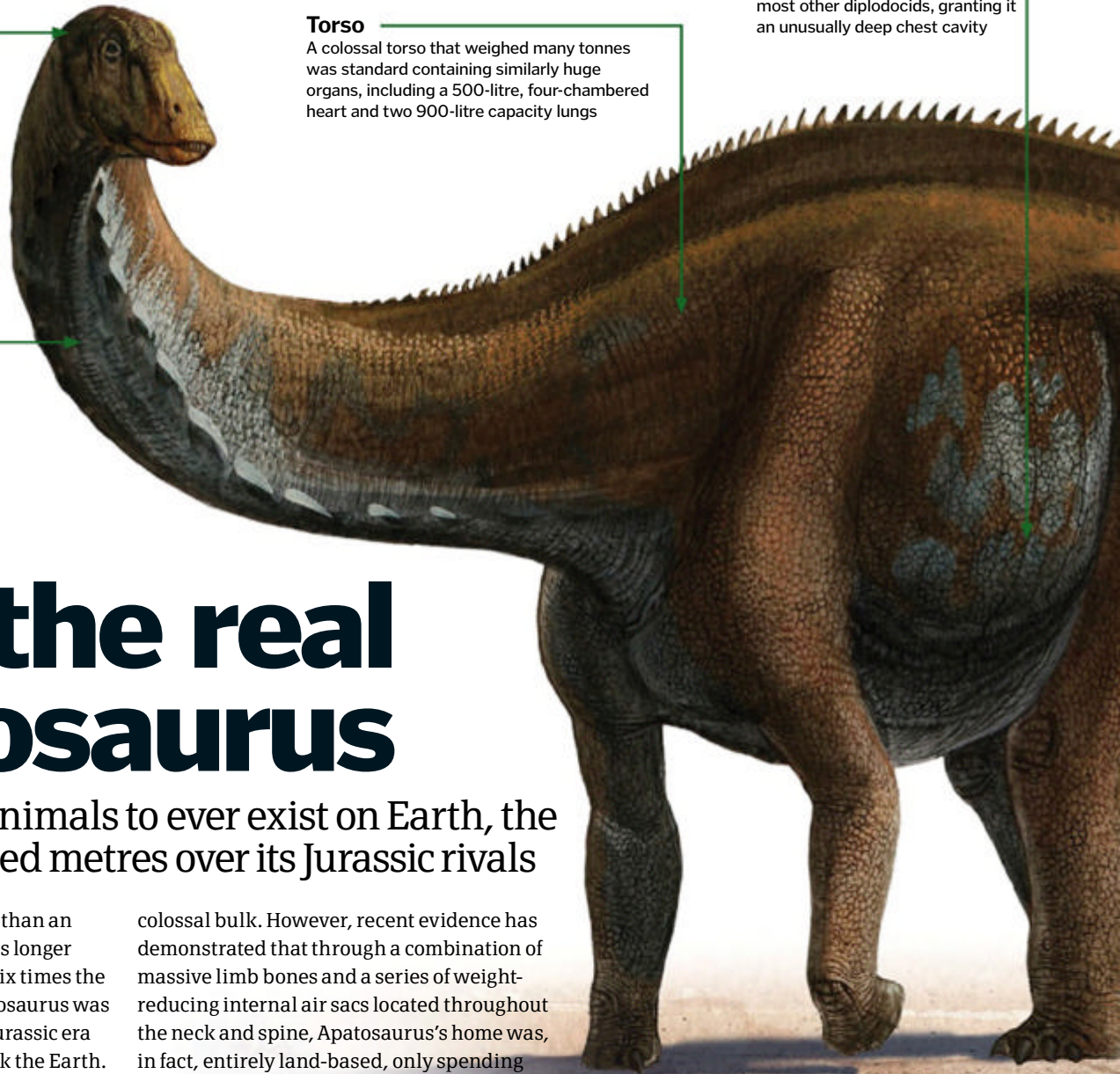
As with other sauropods, the Apatosaurus's neck vertebrae were deeply bifurcated, carrying paired spines. The neck was also filled with many weight-saving air sacs

Torso

A colossal torso that weighed many tonnes was standard containing similarly huge organs, including a 500-litre, four-chambered heart and two 900-litre capacity lungs

Ribs

Apatosaurus possessed incredibly long, robust ribs compared to most other diplodocids, granting it an unusually deep chest cavity



Meet the real Brontosaurus

One of the largest animals to ever exist on Earth, the Apatosaurus towered metres over its Jurassic rivals



Around four times heavier than an African elephant, five times longer than your car and almost six times the height of a full-grown human, Apatosaurus was one of the largest dinosaurs of the Jurassic era and one of the most gigantic to ever walk the Earth.

As is typical with large dinosaurs of this period, Apatosaurus (once mistakenly known as Brontosaurus) was a herbivore, consuming vast quantities of foliage and grasses over the lands that now form modern-day North America. Interestingly, despite its size, its name is derived from the Greek 'apate' and 'saurus', which translate as 'deception lizard' – a name bestowed by its original discoverer, American palaeontologist Othniel Charles Marsh.

Prior to the 1970s, Apatosaurus, along with many other sauropods, were considered largely aquatic creatures that relied on being partially submerged in swamps and lakes to remain stable – a view seemingly confirmed by their

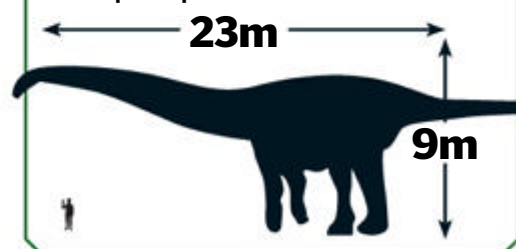
colossal bulk. However, recent evidence has demonstrated that through a combination of massive limb bones and a series of weight-reducing internal air sacs located throughout the neck and spine, Apatosaurus's home was, in fact, entirely land-based, only spending time at water sources to drink.

Speaking of drinking, the Apatosaurus required gallons of water per day to remain healthy, while it also needed to process vast amounts of food, spending a large proportion of each day grazing. It did this with few predators, as only the largest carnivorous dinosaurs had any chance of bringing down an Apatosaurus, largely thanks to its size. It also had a deadly weapon in its tail, which was capable of being swung at great velocity at any foes.

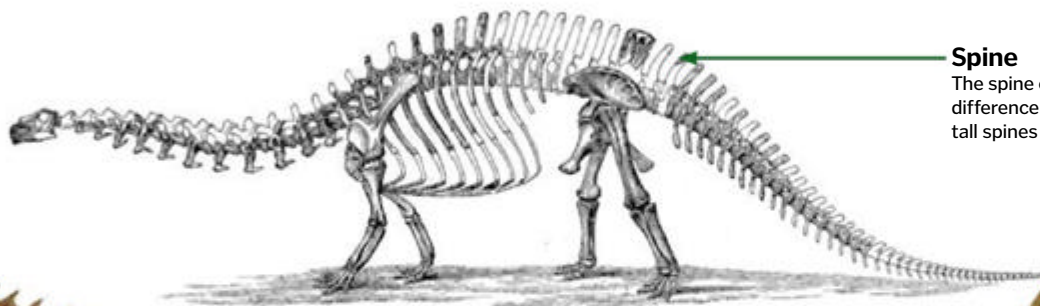
Despite its defensive prowess, however, the Apatosaurus could not battle off extinction, with it falling to a medium-sized extinction event around 150 million years ago.

Apatosaurus vs human

How would this enormous dinosaur have sized up to a person?

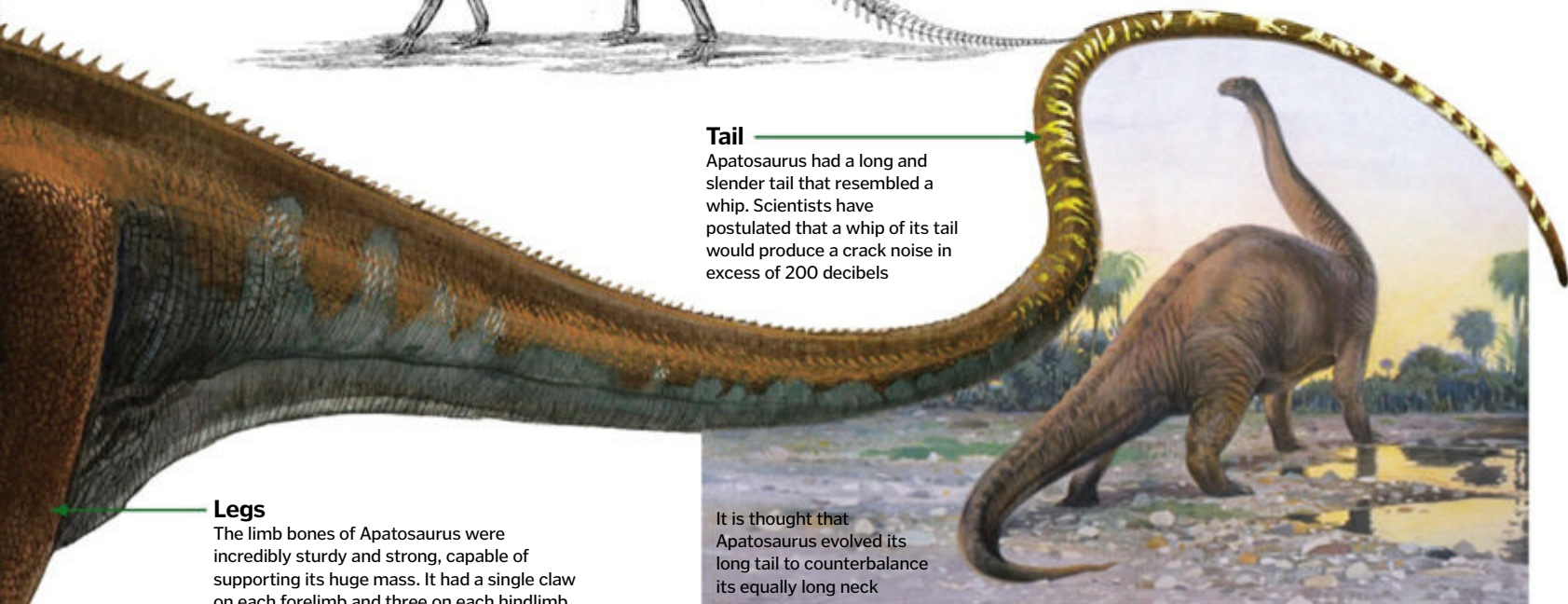


DID YOU KNOW? Apatosaurus skeleton fragments have been found in Wyoming, Colorado, Oklahoma and Utah



Spine

The spine of Apatosaurus was interesting in its difference to other sauropods, possessing incredibly tall spines that made up half its total height



Tail

Apatosaurus had a long and slender tail that resembled a whip. Scientists have postulated that a whip of its tail would produce a crack noise in excess of 200 decibels

Legs

The limb bones of Apatosaurus were incredibly sturdy and strong, capable of supporting its huge mass. It had a single claw on each forelimb and three on each hindlimb

It is thought that Apatosaurus evolved its long tail to counterbalance its equally long neck

The bone wars

During the beginning of the golden age of modern palaeontology, two prominent American palaeontologists, Edward Cope and Othniel Marsh, had a falling out over excavated dinosaur remains, with the men then proceeding to attempt to beat each other to unearth and describe new species of dinosaur. In this rush to become the foremost palaeontologist of the age, Marsh described first in 1877 and then later in 1879 two supposedly separate species of dinosaur. He named the first one Apatosaurus and called the second one Brontosaurus.

Following this, the name of Brontosaurus became world famous, with a complete skeleton mounted and displayed in the Peabody Museum, Yale, under the Marsh title in 1905. However, Marsh in his haste had made a terrible mistake. The Brontosaurus was actually just a fully-grown Apatosaurus and, since the Apatosaurus had been described first in 1877, its name took precedent, with 'Brontosaurus' made officially redundant in the early-20th century. Interestingly, however, as the Brontosaurus name had become firmly fixed in the public consciousness, it remained far more popular and is still in use to this day to the chagrin of many dinosaur experts.

A photograph of Othniel Marsh taken between 1865 and 1880



Stamp scandal

In 1989, the US Post Office decided to release a special edition set of four stamps depicting famous dinosaurs. These included a Tyrannosaurus, Stegosaurus, Pteranodon and, interestingly, a Brontosaurus.

The latter was included despite the fact that, as noted in 'The bone wars' boxout, the name 'Brontosaurus' had been made officially redundant in the early-20th century.

The fallout from this was massive, with many palaeontologists and dinosaur enthusiasts accusing the US Post Office of promoting 'scientific illiteracy' and re-opened a bone war-style feud between others. Indeed, even the celebrated palaeontologist Stephen Jay Gould got involved, writing a famous defence of the Brontosaurus name in his Natural History magazine piece 'Bully for Brontosaurus'.



© Corbis/Alamy



Marine reptiles

Discover the creatures that ruled and dominated the prehistoric waters

Pliosaurus

These marine reptiles were built to hunt deep



Pliosaurus were large carnivorous marine reptiles that mainly inhabited the waters around Europe in the Jurassic and Cretaceous periods. Their diet consisted of fish, sea-based dinosaurs and other marine reptiles.

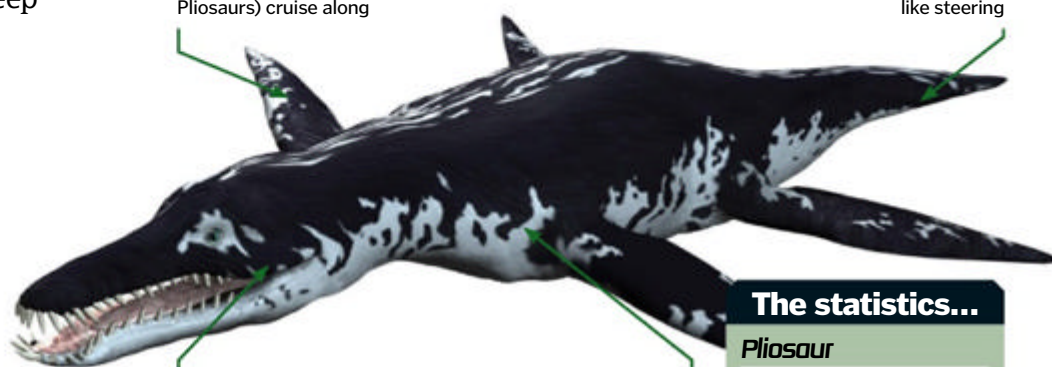
The two most well known varieties of pliosaur are the Kronosaurus and the Liopleurodon. The Kronosaurus was known to have stalked the seas around Australia and South America in the late Cretaceous period and measured up to nine meters (30ft) in length. Liopleurodons measured a colossal 12 meters (39ft) in length. Resembling a whale, it was a highly manoeuvrable creature that was capable of swimming at all depths.

Flippers

Four large flippers helped Liopleurodon (one of the most well known Pliosaurus) cruise along

Tail

Liopleurodon's tail was rather short and probably not very useful for rudder-like steering



Teeth

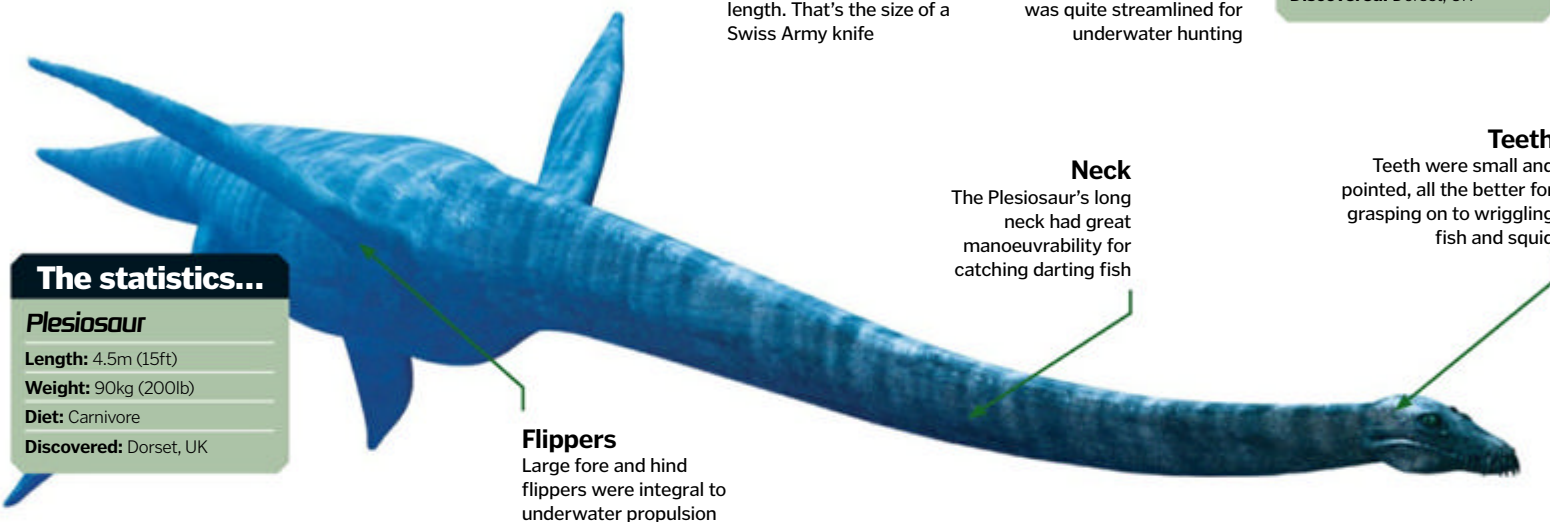
Liopleurodon teeth could reach up to 10cm (4in) in length. That's the size of a Swiss Army knife

Body

Despite its massive size and bulk, Liopleurodon was quite streamlined for underwater hunting

The statistics...

Pliosaur
Length: 10-12m (32-48ft)
Weight: 45,000kg (99,000lb)
Diet: Carnivore
Discovered: Dorset, UK



Neck

The Plesiosaur's long neck had great manoeuvrability for catching darting fish

Teeth

Teeth were small and pointed, all the better for grasping on to wriggling fish and squid

The statistics...

Plesiosaur

Length: 4.5m (15ft)
Weight: 90kg (200lb)
Diet: Carnivore
Discovered: Dorset, UK

Flippers

Large fore and hind flippers were integral to underwater propulsion

Plesiosaurs

These powerful reptiles were every inch the aquatic version of a dinosaur



Plesiosaurs were part of marine ecology from the late Triassic period to the end of the Cretaceous period and were powerful swimmers that could strike fast-moving prey with efficiency. Plesiosaurs typically had a stocky torso, four large flippers, a long neck and a small skull with small, pointed teeth and one such example was the

Plesiosaurus, which inhabited the shallow seas of Europe during the early Jurassic period.

Measuring anywhere between 3-5 meters in length, the Plesiosaurus was one of the very first prehistoric reptiles to be discovered and the fossil remains pointed very much towards a powerful creature that was build to cope with its precise fish-catching feeding habits. With a

forward burst of the flippers on one side of its body coupled with backwards thrust of the flippers on the other side could turn the Plesiosaurus on a sixpence, its relatively weak, stumpy tail acting as a rudder to steer it. It was such agility that the helped the plesiosaurs dominate the ecosystem as no unsuspecting fish would have been able to escape it.

DID YOU KNOW? The remains of a Dakosaurus, a marine reptile of the late Jurassic era were discovered high in the Andes mountains

Ichthyosaurs

Few marine creatures could outrun these 'fish lizards'



Ichthyosaurs inhabited much of the Earth's seas and oceans during the mid-Triassic to late Cretaceous periods.

To date there are more than 80 recorded species of Ichthyosaur, with more being added regularly. Although some bore a physical resemblance to modern day dolphins or sharks, skeletally they were more closely linked to reptiles – in fact Ichthyosaur translates as 'fish lizard'.

Ichthyosaurs ranged vastly in size, with the smallest (the Chaohusaurus) measuring in at around 70cm and the largest (as yet unnamed) was found in Canada and is believed to measure in the region of 23 meters in length. A typical ichthyosaur was the Ichthyosaurus, which frequented the waters around the British Isles during the early Jurassic period and measured two meters in length. Designed for speed with four flippers (in the hands and feet positions), a paddle-like tail and a dorsal fin, the Ichthyosaurus hunted mainly fish, its elongated skull and rows of sharp teeth ideal for catching slippery prey. It is thought that the smooth, Dolphin-like torso of the Ichthyosaurs could see them swim at speeds of up to 45kph, their powerful bodies being able to maintain that top speed for up to half an hour.

Dorsal fin

Not all species of Ichthyosaur had a dorsal fin, but it is believed that many types did

Teeth

The Ichthyosaur often had conical teeth to assist with catching smaller prey

Flippers

The Ichthyosaur had flippers which contained a large number of digits and phalanges

The statistics...

Ichthyosaur

Length: Up to 16m (52ft)

Weight: 930kg (2090lb)

Diet: Carnivore

Discovered: Dorset, UK

Mosasaurus

Introducing the T-Rex of the seas...



Mosasaurus lived in the late Cretaceous period and were the true giants of the sea. Some mosasaurs, such as the Hainosaurus, could reach lengths of up to 17 meters, their huge frames typically spent swimming slowly along the sea beds stalking slow-moving prey such as ammonites and turtles. However, as mosasaurs could breathe air, seabirds were also part of their ecosystem. Possessing two sets of conical teeth, mosasaurs used rocks and underwater plantation as cover to close in on their prey and then strike quickly. Some skeletal remains indicate that they were susceptible to attacks by shark-like predators.

The first mosasaur remains were uncovered around the 1770s in an underground mine near Maastricht, Holland, on the Meuse River. Fossil skin impressions indicate that they possessed scaly skin similar to that of a snake.

The statistics...

Mosasaur

Length: Up to 17m (56ft)

Weight: Up to 20 tonnes

Diet: Carnivore

Discovered: Maastricht, Netherlands

Jaw

Most mosasaurs had a double jaw which allowed them to eat their prey in one go

Snake-like

In 1869 it was suggested that mosasaurs shared common ancestry with snakes, who coined the term Pythonomorpha to unite them

Eating habits

The larger mosasaurs were the kings of the Late Cretaceous seas, feeding on fish and ammonites



Plesiosaurus

We turn the spotlight on a ferocious marine reptile that dominated Earth's oceans throughout the Early Jurassic

Streamlined

A muscular torso allows for great propulsion

The statistics...

Plesiosaurus

Length: 4.5m (15ft)

Neck vertebrae: 40

Weight: 90kg (200lb)

Diet: Carnivore; eg fish, squid

Discovered: Dorset, UK



Plesiosaurus was an unusual long-necked marine reptile that lived in the Early Jurassic period (circa 199-175 million years ago).

This member of the sauropterygian superorder measured in at approximately 4.5 metres (15 feet) in length, sported a muscular and stocky body, a long and narrow neck, plus a short, stubby tail. Four large flipper-like limbs that attached in pairs to the torso allowed the creature to propel itself through the water at great speed, while a small head packed with rows of sharp, curved teeth ensured that once it got hold of its dinner there was no getting away.

Despite the reptile's underwater dominance, the *Plesiosaurus* could not in fact breathe underwater like fish so had to surface to draw in air. Due to its size, however, it could spend a considerable length of time submerged, allowing it to repeatedly dart through shoals of fish and squid while hunting.

Plesiosaurus inhabited the shallow seas of what is now Europe, dominating the waters due to its size, agility and ferocity. Early in their history, this domination reached new heights when the order split-evolved into two main lineages: Pliosauroids and Plesiosaurids. The former developed a shorter neck and elongated head, while the latter developed a snake-like neck of epic proportions. This divergence allowed the species in each lineage to prey on an increasingly varied range of creatures, with some giants, such as *Pliosaurus funkei* (formerly 'Predator X'), even capable of attacking other *Plesiosaurus*.

Plesiosaurus became extinct at the opening of the Middle Jurassic period (175 MYA), being superseded by its larger, more dominant relatives, like the *Elasmosaurus*. The Plesiosauria order, however, survived much longer, thriving worldwide until the Cretaceous-Tertiary (K-T) extinction event.

DID YOU KNOW? The name Plesiosaurus comes from the Greek for 'near to lizard'

Plesiosaurus physiology

We break down the skeletal structure of this sauropterygian marine reptile

Skull

The skull is relatively short compared to other Plesiosaurs. Nostrils are located in a far-back position near the eyes

Limbs

Both the fore and hind limbs resemble large, sealion-like flippers, and grant fast propulsion in marine environments

Teeth

The Plesiosaurus sports two racks of sharp teeth, typically with 20-25 per upper jaw row and 24 per lower jaw row

Tail

Unlike many other marine reptiles, the Plesiosaurus's tail is very short and stubby. It's not used for propulsion as its bone construction makes it very weak

Body

The stocky, muscular body grants power to the large flippers and supports its neck

Neck

Plesiosaurus has approximately 40 cervical vertebrae in its long, narrow neck. The neck's flexibility allows it to capture super-agile fish

Agile

Long, flexible neck for striking at speedy fish

Savage

Razor-sharp teeth can pierce the flesh of prey

How the beast breathed

Learn how this marine reptile obtained oxygen in a world dominated by fish

1. Inhale

Air is drawn in through the mouth when the creature emerges at the surface. It can't absorb oxygen from the water

3. Exhale

Spent air then exits the reptile through its backward-set nostrils, which are positioned close to the eye sockets

2. Absorb

Oxygen from the air drawn in through the mouth is extracted and deposited into the reptile's lungs

© Thinkstock/SPL/Getty



Fly away

The discovery of embryo pterosaurs has led scientists to believe they could fly from birth due to well-developed wing membrane

Discovery

The first pterosaur was discovered by Italian naturalist Cosimo Alessandro Collini in 1784

Two groups

Pterosaurs are made up of two groups: the earlier rhamphorhynchoids and the later pterodactyloids

Pterosaurs

Whatever you do, don't call them 'flying dinosaurs'



These flying reptiles lived alongside dinosaurs in a variety of environments across the Earth from the Late Triassic to the end of the Cretaceous period (225 to 65 million years ago). They ranged in size from just a few centimetres to more than 12 metres (one inch-39 feet), mostly feeding on fish while some scavenged dead animals and ate insects inland.

The wing of the pterosaur was unique, a large membrane suspended from a hugely expanded fourth finger. Pterosaurs are largely regarded as the first vertebrates to achieve sustainable powered flight, although the largest relied mainly on the wind and gliding to stay in the air. There is much contention among palaeontologists as to whether these flying reptiles should be classed as dinosaurs, but the

physical similarities are plain to see nonetheless, which is why we have included them here.

The Quetzalcoatlus is the largest of the pterosaurs—in fact it is the largest known flying animal of all time. With a wingspan of up to 12m (39 feet) and a head the size of a car, the Quetzalcoatlus ruled the sky in the Late Cretaceous period (100 to 65 million years ago). It is widely believed that Quetzalcoatlus fed on living dinosaurs, unlike other pterosaurs who preferred fish and dead animals, to fuel its enormous metabolic needs. Despite its incredible size this giant reptile weighed no more than 250kg (550lb) due to the hollow bones associated with pterosaurs.

Pterosaurs faced extinction after more than 150 million years at the same time as the dinosaurs, conquering every single continent in the process.

DID YOU KNOW? The name 'Pterosaur' comes from the Greek words 'Pteron' (wing) and 'Sauros' (lizard)



Tupandactylus imperator had a large crest on its head



Flying with wings

The hollow bones of the pterosaurs led many scientists to believe that their wings could not produce the power needed to achieve flight from a standstill without wind assistance. Recent fossil evidence has indicated that smaller pterosaurs could achieve sustainable flight, although the larger creatures still struggled to get airborne without help.

Pterodactylus

The Pterodactylus is arguably the most famous pterosaur. Its iconic features were characteristic of many pterosaurs, although a longer neck and a shorter tail ensured it was more suited to flight than its earlier ancestors, the rhamphorhynchoids.

Walk, don't run

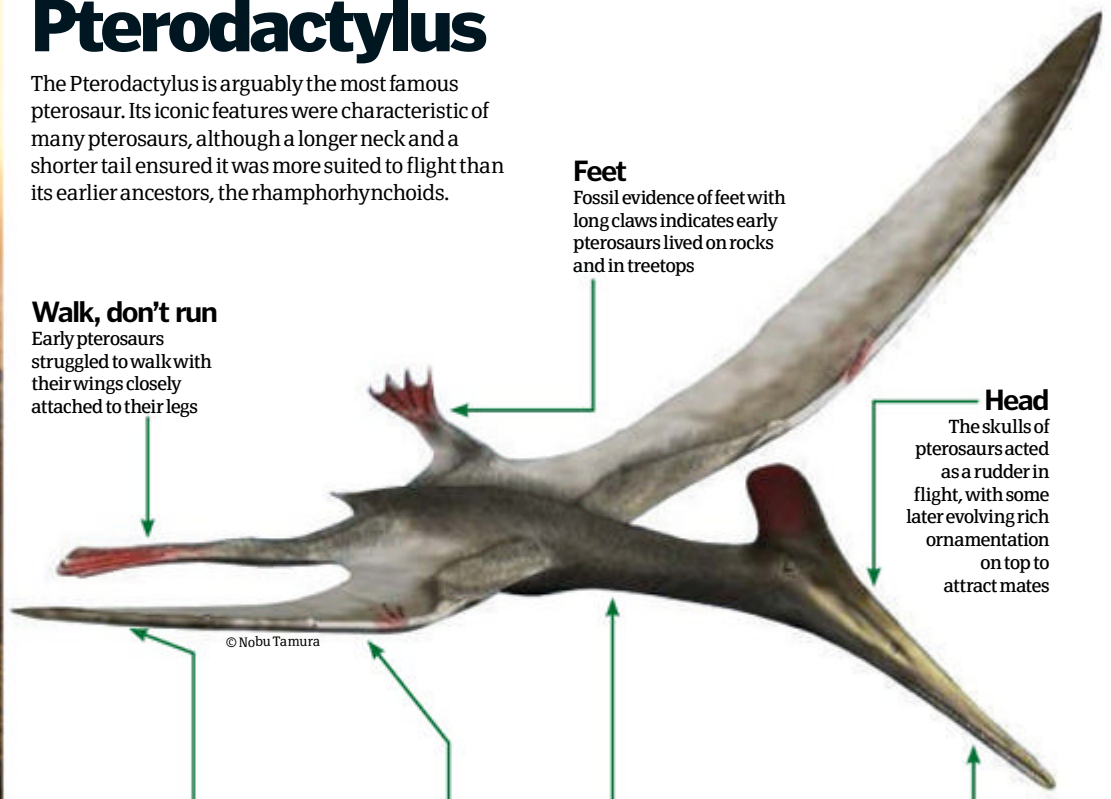
Early pterosaurs struggled to walk with their wings closely attached to their legs

Feet

Fossil evidence of feet with long claws indicates early pterosaurs lived on rocks and in treetops

Head

The skulls of pterosaurs acted as a rudder in flight, with some later evolving rich ornamentation on top to attract mates



This little pinky

Their wings were suspended from elongated fourth digits and joined to their legs and their body

Hollow bones

Pterosaurs were very light and able to fly thanks to their hollow bones filled with air sacs

Size

With its wingspan and body measuring over a metre, pterodactylus was not the largest pterosaur

Mouth

The long jaws allowed it to hunt fish, using its small teeth to grab them out of the water

These giant creatures fed on fish and scavenged animals

© Thinkstock



Quetzalcoatlus

Discover more about the mysterious serpent of the sky and the largest flying vertebrate of all time



Not a great deal is actually known about this pterosaur that dates back to the late Cretaceous period, as only fragments have ever been discovered. However, evidence suggests that the Quetzalcoatlus possibly boasted a wingspan of up to 12m – making it the largest flying vertebrate of all time. But, despite its colossal size, its weight has been suggested could have been as low as 190lbs, but certainly no more than 550lbs. This was perhaps down to a complex system of air sacs situated inside many of the creature’s bones that kept its weight down so as to be able to stay airborne for longer.

The Quetzalcoatlus’s long, narrow wings made it an excellent glider, and while initial reports suggested that it could have used this skill to hover over water and scour the oceans for prey, it is now believed that it lived

inland. The Quetzalcoatlus would have used rising thermals to glide high above the land, its keen eyes spotting prey from long distances like a modern day vulture – prey that consisted of vertebrates of all sizes. Thanks to its long neck and sharp, toothless jaws, the Quetzalcoatlus would have been able to probe deep inside large carcasses to devour the contents in order to fuel its gigantic metabolic requirements.

So far, fragments of the Quetzalcoatlus have only been found in Texas, North America, but it would be safe to assume that they were well equipped to traverse far further afield. Putting things into perspective, the next flying reptile down on the size scale, the Pteranodon, boasted a wingspan of 7m, a whole five meters shy of the Quetzalcoatlus (whose span would dwarf many small planes). More

extensive remains of Pteranodons have been found as far afield as Europe and North America (England and Kansas, to be precise).

So while not as famous as some of the other species of winged reptiles, Quetzalcoatlus has emerged to be something of a winged wonder amongst the pterosaurs. A creature that steered a course inland away from its sea-scouting Pteranodon peers (the fragment remains were discovered about 400 kilometers inland from the nearest coastline and away from any large rivers or lakes present in the area during the Cretaceous period) to survive on a diet of small vertebrates and the discarded remains of other larger dinosaurs. And with new theories emerging regularly as to how the creature lived, it appears that the Quetzalcoatlus isn’t quite ready to give up all of its secrets yet.

Quetzalcoatlus in flight

Quetzalcoatlus may have formed breeding colonies, like modern Albatrosses



The statistics...

Quetzalcoatlus

Height: 5m (18ft)

Wingspan: 10-12m (32-39ft)

Weight: 135kg (300lb)

Diet: Carnivore

Discovered: Texas, USA



DID YOU KNOW? Quetzalcoatlus was named after the ancient Aztec god, Quetzalcoatl, a feathered serpent

Eyes

The keen eyes of the Quetzalcoatlus would have been able to spot land-based prey from long distances like a modern day bird of prey

Beak

Although initially believed to be blunt, the beak of the Quetzalcoatlus was later discovered to be long and pointed

Skull

The Quetzalcoatlus had a skull measuring 2.5 meters, the majority of which was reserved for its long beak

Jaws

The long, toothless, jaws of the Quetzalcoatlus were well suited to probing the carcasses of dead dinosaurs

Bones

Many of the Quetzalcoatlus's bones contained a complex series of air sacs that kept the creature's weight down considerably

Neck

The structure of the Quetzalcoatlus's neck vertebrae show that it was highly flexible - ideal for scouring the land below for prey

Wings

With a span of 12m, the Quetzalcoatlus's wings were long and narrow - perfect for gliding over long distances and making quick descents

Height: **5m (18ft)**
Wingspan: **10-12m (32-39ft)**





10 deadliest dinosaurs

Counting down the fiercest, most terrifying beasts that ever lived

Tyrannosaurus rex



Tyrannosaurus rex ("tie-RAN-a-SORE-uss rex") needs no introduction; its reputation as the ultimate carnivore and most badass dinosaur ever to roam the Earth precedes it. Tyrannosaurus rex (T-rex for short) literally means "tyrant lizard king", and there can be no doubt that it lived up to its name.

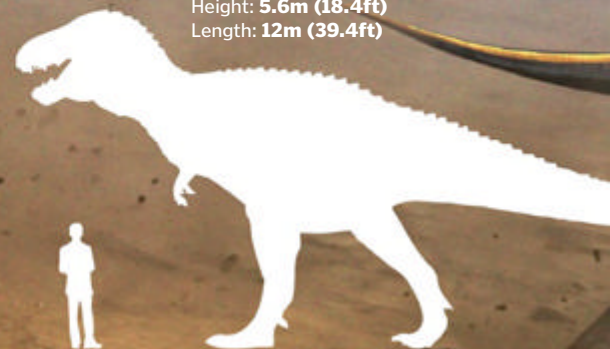
Standing at over five metres (16.4 feet) tall and 12 metres (39.4 feet) long, and weighing a staggering seven tonnes (15,400 pounds), the T-rex was once thought to have been the largest terrestrial carnivore in history, but subsequent discoveries of fellow titans *Carcharodontosaurus*, *Giganotosaurus* and *Spinosaurus* challenged this.

The T-rex walked on a pair of powerful hind legs and could run as fast as a professional footballer, but balance issues meant that

Giganotosaurus could outrun it. Its brain was twice the size of most other predatory giants, but its intellectual prowess wasn't a patch on that of raptors like *Utahraptor*. So how does T-rex manage to cling to its crown?

It may not have been the biggest, fastest, heaviest, or smartest, but the king was the ultimate all-rounder. Its extraordinary sense of smell allowed T-rex to track prey over long distances and sniff out abandoned carcasses to scavenge. And then there is its not-so-secret weapon: its phenomenal bite, which was stronger than that of any land animal that ever lived. Its bone-splintering jaws chomped down with a force almost as huge as its own body weight, bringing to bear its 60 saw-edged conical teeth. Other dinosaurs had to close their mouth around prey multiple times to bring it down; T-rex only had to bite once.

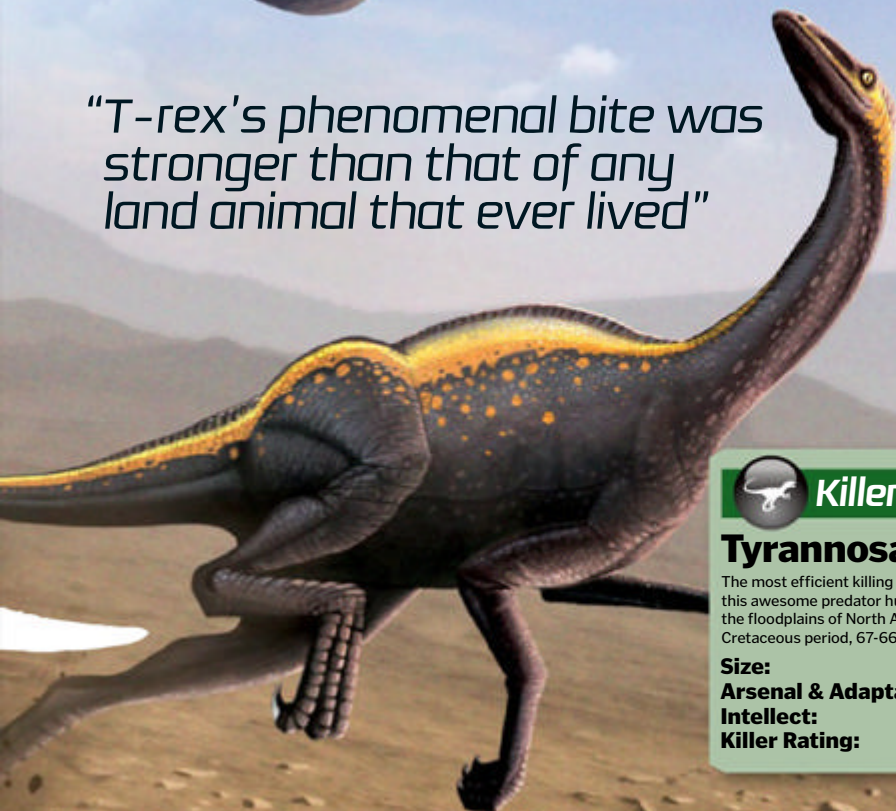
Height: **5.6m (18.4ft)**
Length: **12m (39.4ft)**



DID YOU KNOW? Watch out for your crown, T-rex: on average, a new species of dinosaur is discovered every six weeks



"T-rex's phenomenal bite was stronger than that of any land animal that ever lived"



Killer stats

Tyrannosaurus Rex

The most efficient killing machine that ever lived, this awesome predator hunted indiscriminately on the floodplains of North America at the end of the Cretaceous period, 67-66 million years ago.

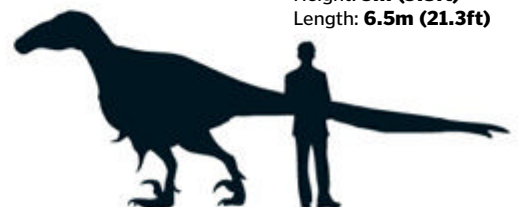
Size:	8/10
Arsenal & Adaptations:	8/10
Intellect:	7/10
Killer Rating:	10/10



Utahraptor

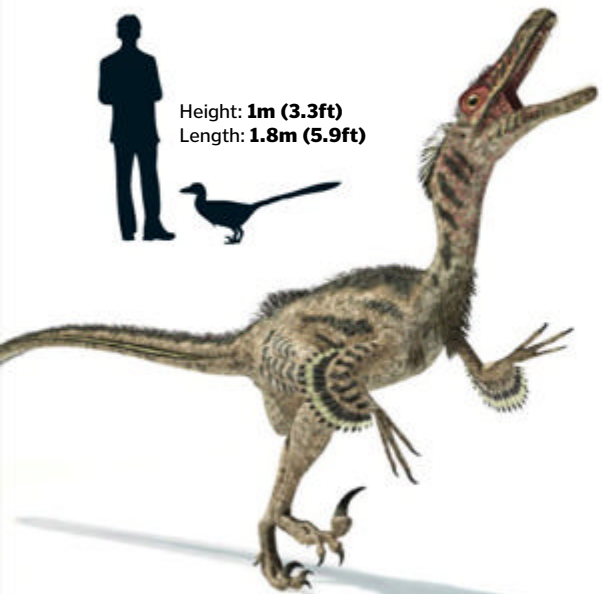
The mighty Utahraptor ("YOU-tah-RAP-tor") was three times larger and meaner than its cousin, the Velociraptor. Armed with a 30-centimetre (12-inch)-long sickle-shaped claw on each hind foot, it would kick, rip and tear its prey to death. Its leg bones were unusually thick, in order to support the powerful muscles dedicated to repeatedly driving the killing claw into its prey. In keeping with its smaller raptor cousins, it's possible that Utahraptor hunted in packs, like terrible three-metre (9.8-foot)-tall 500-kilogram (1,100-pound) wolves, and targeted prey many times larger than itself.

Height: **3m (9.8ft)**
Length: **6.5m (21.3ft)**



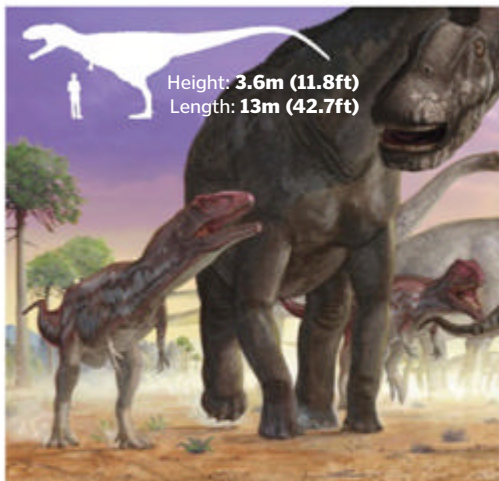


Height: **1m (3.3ft)**
Length: **1.8m (5.9ft)**



Velociraptor

Star of the infamous kitchen scene in Jurassic Park, the curious creature with the deadly curved toe claw has been terrorising nightmares for two decades. The film may have overstated their size and stripped them of their feathers, but it did get some things right: Velociraptors ("vel-OSS-e-RAP-tors") were fast and polished predators that oozed agility and intelligence, and may have hunted in packs.



Height: **3.6m (11.8ft)**
Length: **13m (42.7ft)**

Mapusaurus

A close cousin and look-alike of Giganotosaurus, Mapusaurus ("MAH-puh-SORE-uss") hunted some of the largest dinosaurs that ever lived – the 35-metre (115-foot)-long herbivore Argentinosaurus. Its narrow blade-like teeth were ideal slicing tools, and the discovery of bones from several individuals found in one place has experts speculating that they formed groups or hunted in packs for extra lethality.



Lightweight body structure
Slender and with a rod-like tail, Troodon was swift and nimble on its feet

Feathers?
Experts speculate that cool-climate-dwelling Troodon may have sported feathers for insulation

Brain
Record brain-to-body-weight ratio suggests it was the quickest-thinking and most intelligent of all known dinosaurs

Eyes
Large and forward facing, giving it excellent stereoscopic vision and perhaps even the ability to see at night

Fingers
A semi-opposable finger on each hand meant it had the dexterity to grab and snare small mammals and reptiles

Claw
A retractable sickle-shaped claw on each foot was used for slashing and kicking at captured prey

Killer stats

Troodon

This diminutive dinosaur used cunning and cooperation to slay supposedly superior beasts in the wilds of North America during the Late Cretaceous Era, 74-65 million years ago.

Size:	3/10
Arsenal & Adaptations:	8/10
Intellect:	10/10
Killer Rating:	8/10

Troodon

Deadliness doesn't always come down to bulk and bite force. Troodon ("TROH-oh-don") – standing just 1.3 metres (4.3 feet) tall and weighing in at 40 kilograms (88 pounds) – was a wily whippet that made up for its lack of brawn with a whole lot of brain. In fact, it had the highest brain-to-body-weight ratio of any known dinosaur. Not only that; reconstructions of its brain have revealed nascent signs of folding – where more neural cells are packed into the same area for more efficient brain functioning – making it the most neurologically advanced specimen too.

The shape of fossilised skull remains suggest it possessed huge orb-like eyes that gave it superior vision – as well as the ability to see in low-lighting

conditions and hunt nocturnally – and its slight frame made it extremely fleet of foot. While they may have been dwarfed by many of the behemoths on this list, a pack of alert and agile Troodons hunting as a pack could easily have brought down much bigger animals.



Height: **1.3m (4.3ft)**
Length: **2m (6.6ft)**





Killer stats

Spinosaurus

The largest carnivorous dinosaur in history and once thought to have been an aggressive land-killer, recent evidence reveals it was more of a threat to water-dwellers in late-Cretaceous North Africa 95-70 million years ago.

Size: 10/10
Arsenal & Adaptations: 6/10
Intellect: 6/10
Killer Rating: 7/10

Head

Crocodile-like skull with small, high nostrils – ideal for breathing with a partially submerged snout

Snout

Pressure-sensitive receptors could detect the motions of aquatic prey

Arms

Strong, muscular and equipped with a fearsome set of 12.7cm (5in) claws for grabbing and slashing

Jaw

Long, slender and spoon-shaped, and filled with sharp conical teeth – perfect adaptations for gripping slippery prey like fish

Feet

Wide and flat feet and claws, well suited to paddling

Sail

Anchored by a series of spines extending from the dorsal vertebrae; possibly used for display or temperature regulation

BELOW Although Spinosaurus mainly hunted for fish, it was fully capable of defending itself



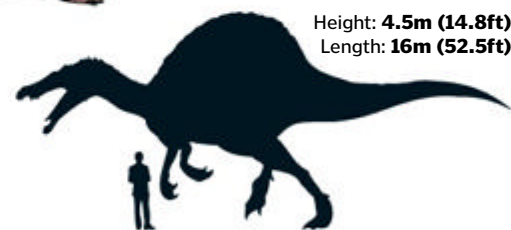
Spinosaurus

The largest carnivorous dinosaur ever to stalk the Earth, Spinosaurus is thought to have been as long as one and a half double-decker London buses – 16 metres (52.5 feet) – and as heavy as a herd of Asian elephants (20 tonnes). Its vertebrae were 20 per cent larger than those of T-rex and to top it off, it sported a gigantic sail of skin supported by two-metre (6.6-foot)-long spines protruding from its back.

Despite its imposing physique, recent evidence suggests Spinosaurus spent more of its

time terrorising the water than it did the land, and would only supplement its fishy diet with scavenged carrion. Its crocodile-like jaw had smooth, conical, pointed teeth, well adapted to spearing slippery prey like Onchopristis – eight-metre (26-foot)-long prehistoric sawfish – rather than ripping flesh from bone. Special structures in its snout helped it detect pressure waves caused by prey moving in the water.

Nevertheless, Spinosaurus was fast, strong and possessed a cruel set of claws, meaning it



could likely hold its own against other massive predators, like Carcharodontosaurus, who shared its territory. Despite what you might think, they never came up against the T-rex.



HOW IT WORKS

DINOSAURS

Deadliest dinosaurs



Killer stats

Carcharodontosaurus

Among the largest and heaviest carnivorous dinosaurs known, this hulking mouthful of razors terrorised North Africa during its reign in the mid-Cretaceous Era, 100-93 million years ago.

Size:	8/10
Arsenal & Adaptations:	7/10
Intellect:	3/10
Killer Rating:	8/10

Carcharodontosaurus

Its name is a mouthful in more ways than one; Carcharodontosaurus ("Kar-KAR-o-don-toe-SORE-uss") means "shark-toothed lizard" and refers to the beast's jaw-full of 20-centimetre (eight-inch)-long serrated teeth. These could slice through flesh like switchblades through butter and leave enormous gaping wounds that would quickly incapacitate prey.

Although it was larger than T-rex and had an enormous skull the size of a person,

Carcharodontosaurus – along with its close cousins Giganotosaurus and Mapusaurus – was a more primitive dinosaur with a smaller brain. Instead, it had powerful legs and fossilised tracks suggest it was capable of outrunning T-rex – at about 32 kilometres (20 miles) per hour. Whether or not it actually did – given that its disproportionately small arms would be incapable of bracing its seven-tonne weight in a fall – is another matter.

Height: **4m (13.1ft)**
Length: **13m (42.7ft)**



Majungasaurus

Majungasaurus ("Mah-JUNG-a-SORE-uss") has a bit of a bad-lizard reputation; telltale tooth marks on Majungasaurus bones, found on its native island of Madagascar, line up perfectly with Majungasaurus's own dental patterns. That's right – the evidence suggests this one-tonne theropod feasted on its own kin, at least occasionally – surely the hallmark of a ruthless killer? What isn't known, though, is whether these were the spoils of active hunts or just efficient tidying up of already-dead relatives.



Height: **2m (6.6ft)**
Length: **6m (19.7ft)**

DID YOU KNOW? T-rex could eat the equivalent of 1,500 sausages a day. That's one heck of a barbeque



Height: **1.5m (4.9ft)**
Length: **3m (9.8ft)**

Deinonychus

The discovery of Deinonychus ("Dee-NON-i-KUSS") in 1964 overhauled our perception of dinosaurs as languid and lumbering; here was a creature clearly built for speedy pursuit. Almost twice the size of Velociraptor (insider tip – the 'Velociraptors' in Jurassic Park were actually modelled after the bigger, badder Deinonychus!), but a similar weight, it was a sprightly and most likely a quick-witted pack hunter. Among other advantages, it possessed interlocking vertebrae that allowed its tail to stiffen for balance when running, and a retractable 13-centimetre (five-inch) claw on each foot to disembowel prey restrained in its hands and jaw.

Giganotosaurus

Carcharodontosaurus's South American cousin, Giganotosaurus ("GIG-a-NOTE-o-SORE-uss") was another beast to rival T-rex for size. Depending on the specimen, it is thought to have been slightly smaller than Carcharodontosaurus, but longer, taller and more slender than T-rex. It was the fastest of the three, besting the others by at least 16 kilometres (ten miles) per hour, perhaps thanks to its superior balance.

It had a very large skull but, like Carcharodontosaurus, it was more neurologically primitive than T-rex; its brain was a puny half the size of T-rex's. Still, evidence suggests it had a keen sense of smell, which coupled with its athletic prowess and eight-tonne bulk made it a formidable foe.

Like Carcharodontosaurus, Giganotosaurus's teeth were serrated and laterally compressed – wide in profile but narrow when viewed from the front – making them ideal tools to deliver a series of injurious slices to the body of its prey, which would eventually keel over from exhaustion and blood loss.

Olfactory system

Large nostrils and advanced olfactory bulbs in its small brain gave it a keen sense of smell for hunting down prey

Bite

Although Giganotosaurus's jaw was only a third as powerful as T-rex's, it was packed with sharp, serrated 20cm (8in) daggers

Tail

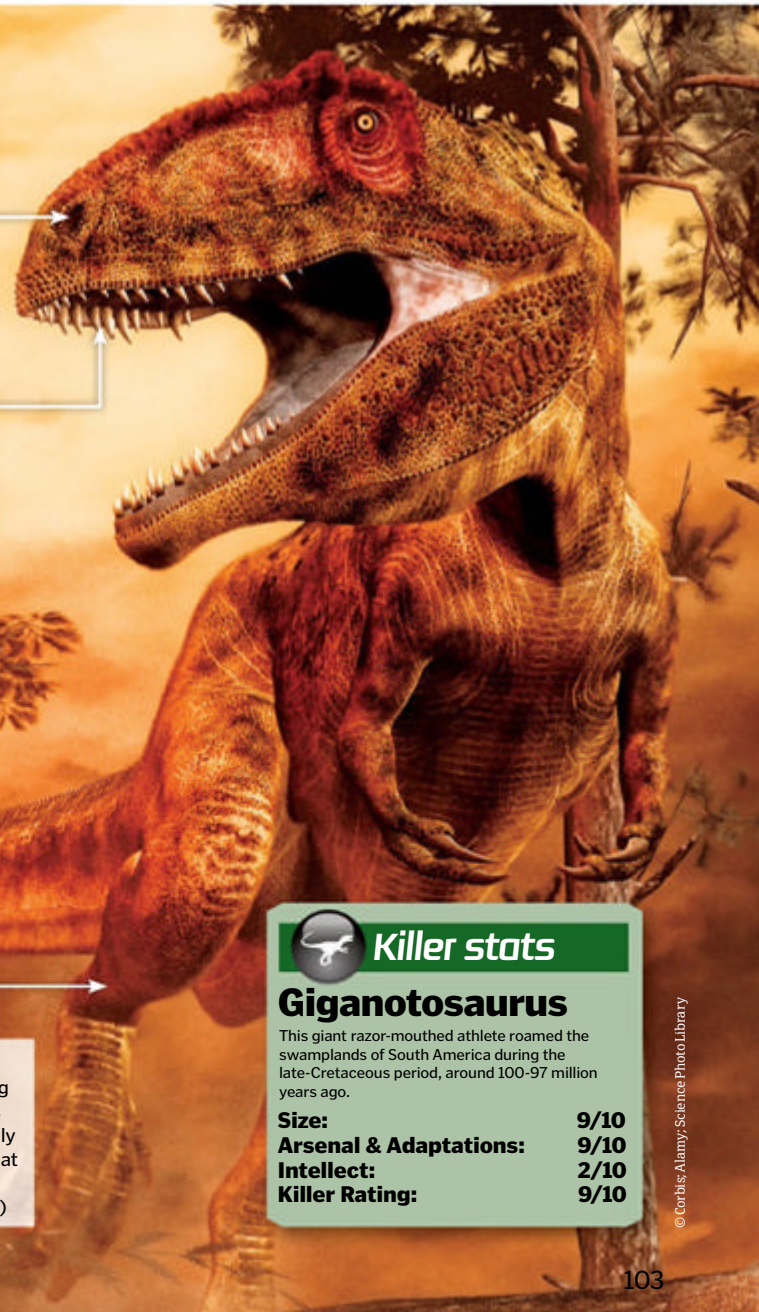
Thin and pointed, it gave Giganotosaurus the ability make quick turns at top speeds without toppling over

Legs

Long and strong legs meant this killer could easily outspurt T-rex at an estimated 50kmh (31mph)



Height: **4m (13.1ft)**
Length: **12.5m (41ft)**



Killer stats

Giganotosaurus

This giant razor-mouthed athlete roamed the swamplands of South America during the late-Cretaceous period, around 100-97 million years ago.

Size:	9/10
Arsenal & Adaptations:	9/10
Intellect:	2/10
Killer Rating:	9/10



HOW IT WORKS BOOK OF DINOSAURS

DINOSAURS' LEGACY

Dinosaurs' legacy

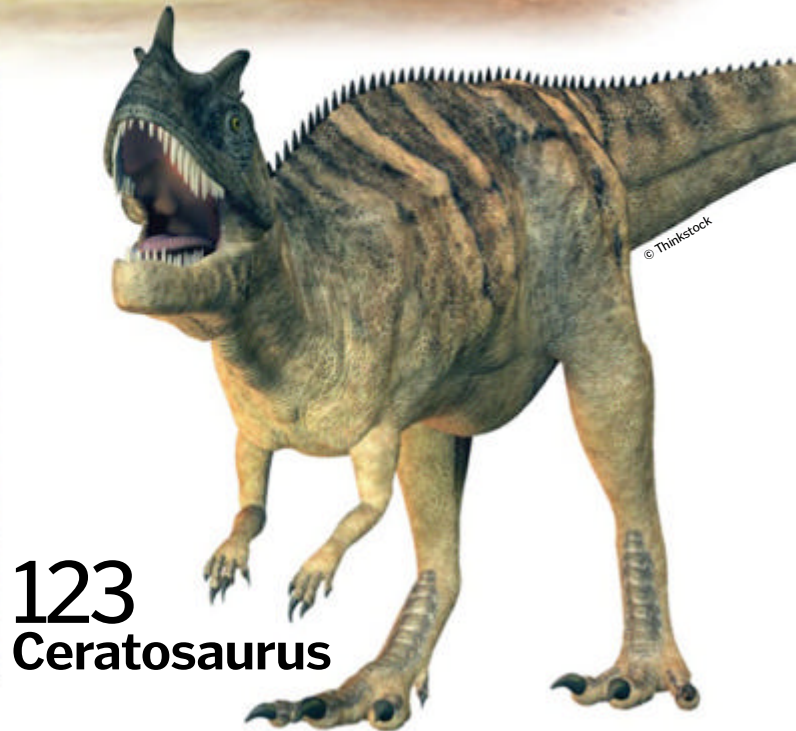
- 106** Death of the dinosaurs
What extinction event killed the dinosaurs?
- 108** What are fossils?
How do dead dinosaurs become fossils?
- 112** Finding fossils
How palaeontologists dig for fossils
- 116** 101 dinosaur questions answered
What everyone should know about dinosaurs



120 Ultimate T-rex facts



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How are fossils made?



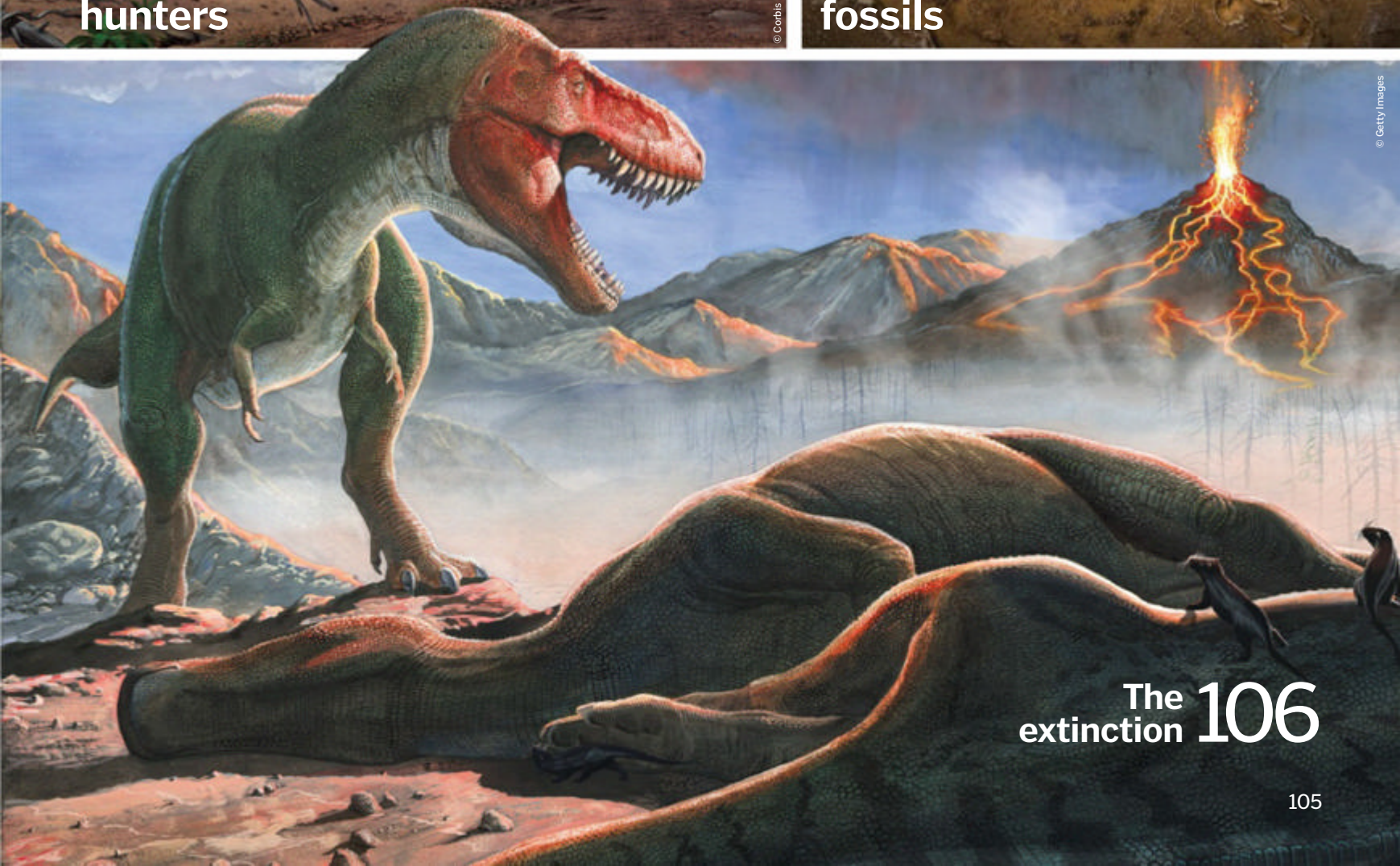
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Cretaceous hunters



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Finding fossils



The extinction 106



HOW IT
WORKS

DINOSAURS' LEGACY


The death of the dinosaurs



Atmosphere
The volcanic eruptions added more carbon dioxide to the air, sucking the oxygen out of the water

The death of the dinosaurs

Loads of theories surround the death of the dinosaurs, we get to the bottom of it

 It is believed that there have been at least five mass extinctions in the last 540 million years, the most famous being the one that signalled the end of the Cretaceous period around 65.5 million years ago and effectively wiped out the dinosaurs.

Palaeontologists initially believed that this mass extinction event was caused by climate and geological changes. This theory changed in the 1980s when scientists Luis and Walter Alvarez discovered a layer of iridium in the geological record that corresponds with the time that the dinosaurs became extinct. This substance existed only space and so its presence on Earth must have come as a result of

a comet, asteroid or meteor colliding with Earth. The discovery of the colossal Chicxulub Crater in Mexico's Yucatán Peninsula that dates back to the time of the mass extinction adds significant weight to this theory.

As a result, the Earth suffered a series of volcanic eruptions. Research has shown that the common factors in mass extinctions include large-scale lava flow and volcanic gases, which desecrate the land and suck all of the oxygen out of our oceans. The gases coughed out of volcanic eruptions, most notably carbon dioxide, are linked to short-term regional warming, acid rain and ozone depletion – the perfect cocktail to snuff out any creature.

Based on the fossil record, mass extinctions are followed by recovery. Following the events of the Cretaceous period that rendered the dinosaurs extinct, the gradual recovery of vegetation was evident by the discovery of fern spores. Plants managed to adapt to cope with conditions on Earth. The fossil record tells us that the last dinosaur to walk the Earth was the *Corythosaurus*. This herbivore stood upright, with two arms used to strip and devour vegetation and was easily identifiable by a decorative semicircular crest on its head. Much effort has been spent searching for the causes of mass extinctions because ultimately there is no reason why another couldn't occur again.

Events of mass extinction

The mass extinction at the end of the Cretaceous period followed four others. The first signalled the end of the Ordovician period, which existed between 490-440 million years ago. The area to the north of the tropics was almost all ocean and the nature of the thriving marine faunas changed and the land saw the arrival of arthropods, such as Eodolmanitina, Cyclopyge and the Triarthrus. This mass extinction hit the flora and fauna, eroding much of the ecosystem of the most primitive creatures.

Next came the mass extinction at the end of the Devonian period (420-360 million years ago). This effectively wiped out around three-quarters of the Earth's species, though this could have taken the form of several extinctions over many millions of years rather than occurring as a result of a single event. The mass extinction at the end of the Permian period (300-250 million years ago) wiped out 96 per cent of the Earth's species, meaning all that exists today is descended from the four per cent that remained. The penultimate mass extinction occurred at the Triassic-Jurassic period (250-140 million years ago), with climate change, flood basalts (that come as a result of a volcanic eruption coating the Earth with basalt lava) and asteroid impact all being possible causes.

Volcanic eruptions

Common factors in extinction events is the presence of lava and volcanic ash

The end of the dinosaurs is commonly disputed among scientists

Plant survival

After a mass extinction event, it is common for there to be recovery. After the dinosaurs became extinct, the plants, mostly ferns, became the dominant survivor

Fauna

The Corythosaurus is theorised as being the last dinosaur standing after the mass-extinction event

"The common factors in mass extinctions include large-scale lava flow and volcanic gases"



HOW IT
WORKS

DINOSAURS' LEGACY

What are fossils?

What are fossils?

Obliterating the traditional perception of the origins and evolution of life on Earth, fossils grant us unique snapshots of what once lived on our ever-changing planet

Adpression

A form of fossilisation caused by compression within sedimentary rock. This type of fossilisation occurs mainly where fine sediment is deposited frequently, such as along rivers. Many fossilised plants are formed this way

Resin

Referred to as amber, fossil resin is a natural polymer excreted by trees and plants. As it is sticky and soft when produced, small invertebrates such as insects and spiders are often trapped and sealed within resin, preserving their form

Bioimmuration

Bioimmuration is a type of fossil that in its formation subsumes another organism, leaving an impression of it within the fossil. This type of fossilisation usually occurs between sessile skeletal organisms, such as oysters

Types of fossilisation

Dependent on climate and ground conditions, deceased animals can be fossilised in many ways



Permineralisation

A process in which mineral deposits form internal casts of organisms, permineralisation works when a deceased animal dies and then is rapidly submerged with groundwater. The water fills the creature's lungs and empty spaces, before draining away leaving a mineral cast

Recrystallisation

When a shelled creature's shell, bone or tissue maintains its original form but is replaced with a crystal – such as aragonite and calcite – then it is said to be recrystallised

Mold

A type of fossilisation process similar to permineralisation, molds occur when an animal is completely dissolved or destroyed, leaving only an organism-shaped hole in the rock. Molds can turn into casts if they are then filled with minerals



The origin of life on Earth is irrevocably trapped in deep time. The epic, fluid and countless beginnings, evolutions and extinctions are immeasurable to humankind; our chronology is fractured, the picture is incomplete. For while the diversity of life on Earth today is awe-inspiring, with animals living within the most extreme environments imaginable – environments we as humans brave every day in an effort to chart and understand where life begins and ends – it is but only a fraction of the total life Earth has seen inhabit it over geological time. Driven by the harsh realities of an ever-changing environment, Armageddon-level extinction events and the perpetual, ever-present force of natural selection, wondrous creatures with five eyes, fierce predators with 12-inch fangs and massive creatures twice the size of

a double-decker bus have long since ceased to exist. They are forgotten, buried by not just millions, but billions of years. Still, all is not lost to us. By exploiting Earth's natural processes and modern technology over the last two hundred years, scientists and palaeontologists have begun to

but, in general, it occurs when a recently deceased creature is rapidly buried by sediment or subsumed in an oxygen-deficient liquid. This has the effect of preserving parts of the creature – usually the harder, solid parts like its skeleton – often in the original, living form within the Earth's crust. The softer parts

“The softer parts of fossilised creatures tend not to survive due to the rapidity of decay”

unravel Earth's tree of life and, through the discovery and excavation of fossils – preserved remains and traces of past life in Earth's crust – piece the jigsaw back together.

The fossilisation of an animal can occur in a variety of ways (see 'Types of fossilisation' boxout)

of fossilised creatures tend not to survive due to the speed of decay and their replacement by minerals contained in their sediment or liquid casing, a process that can leave casings and impressions of the animal that once lived, but not its remains. Importantly, however, creature fossilisation tends to

Carbon dating

A crucial tool for palaeontologists, carbon dating allows ancient fossils to be accurately dated

Carbon dating is a method of radioactive dating used by palaeontologists that utilises the radioactive isotope carbon-14 to determine the time since it died and was fossilised. When an organism dies it stops replacing carbon-14, which is present in every carbonaceous organism on Earth, leaving the existing carbon-14 to decay. Carbon-14 has a half-life (the time it takes a decaying object to decrease in radioactivity by 50 per cent) of 5,730 years, so by measuring the decayed levels of carbon-14 in a fossil, its time of death can be extrapolated and its geological age determined.



This scientist is dating archaeological specimens in a Tandatron particle accelerator



HOW IT WORKS

DINOSAURS' LEGACY

What are fossils?

be specific to the environmental conditions in which it lived – and these in themselves are indicative of certain time periods in Earth's geological history. For example, certain species of trilobite (an extinct marine arthropod) are only found in certain rock strata (layers of sedimentary and igneous rocks formed through mineral deposition over millions of years), which itself is identifiable by its materials and mineralogic composition. This allows palaeontologists to extrapolate the environmental conditions (hot, cold, dry, wet, etc) that the animal lived and died in and, in partnership with radiometric dating, assign a date to the fossil and/or the period.

Interestingly, however, by studying the strata and the contained fossils over multiple layers, through a mixture of this form of palaeontology and phylogenetics (the study of evolutionary relatedness between organism groups), scientists can chart the evolution of animals over geological time scales. A good example of this process is the now known transition of certain species of dinosaur into birds. Here, by dating and analysing specimens such as archaeopteryx – a famous dinosaur/bird transition fossil – both by strata and by radiometric methods, as well as recording their molecular and morphological data, scientists can then chart its progress through strata layers to the present day. In addition, by following the fossil record in this way, palaeontologists can also attribute the geophysical/chemical changes to the rise, fall or transition of any one animal/plant group, reading the sediment's composition and structural data. For example, the Cretaceous-Tertiary extinction event is identified in sedimentary strata by a sharp decline in species' diversity – notably non-avian dinosaurs – and increased calcium deposits from dead plants and plankton.

Excavating any discovered fossil in order to date and analyse it is a challenging, time-consuming process, which requires special tools and equipment. These include picks and shovels, trowels, whisks, hammers, dental drills and even explosives. There is also an accepted academic method all professional palaeontologists follow when preparing, removing and transporting any discovered fossil. First, the fossil is partially freed from the sedimentary matrix it is encased in and labelled, photographed and reported. Next, the overlying rock (commonly referred to as the 'overburden') is removed using large tools up to a distance of two to three inches from the fossil, before it is once again photographed. Then, depending on the stability of the fossil, it is coated with a thin glue via brush or aerosol in order to strengthen its structure, before being wrapped in a series of paper, bubble wrap and Hessian cloth. Finally, it is transported to the laboratory.



A Europasaurus fossil is examined

© Lorenz

© Nils Knödschke

The fossil record

By examining discovered fossils, it is possible to piece together a rough history of the development of life on Earth over a geological timescale

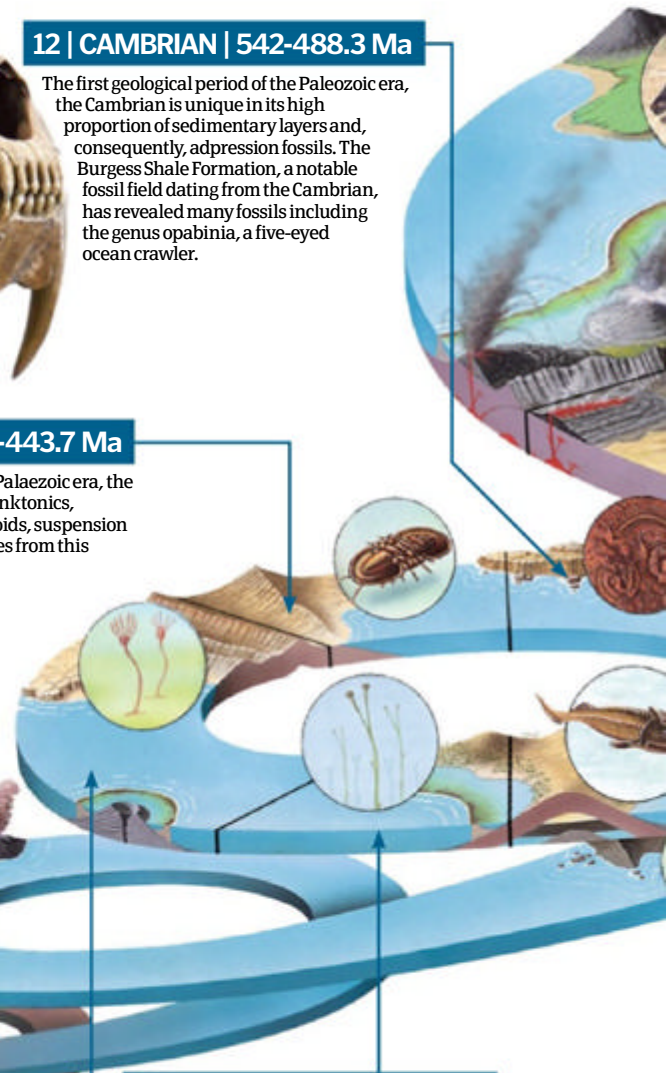


12 | CAMBRIAN | 542-488.3 Ma

The first geological period of the Paleozoic era, the Cambrian is unique in its high proportion of sedimentary layers and, consequently, adpression fossils. The Burgess Shale Formation, a notable fossil field dating from the Cambrian, has revealed many fossils including the genus opabinia, a five-eyed ocean crawler.

11 | ORDOVICIAN | 488.3-443.7 Ma

Boasting the highest sea levels on the Palaeozoic era, the Ordovician saw the proliferation of planktonics, brachiopods and cephalopods. Nautiloids, suspension feeders, are among the largest creatures from this period to be discovered.



9 | DEVONIAN | 416-359.2 Ma

An incredibly important time for the development of life, the Devonian period has relinquished fossils demonstrating the evolution of the pectoral and pelvic fins of fish into legs. The first land-based creatures, tetrapods and arthropods, become entrenched and seed-bearing plants spread across dry lands. A notable Devonian find is the genus tiktaalik.



10 | SILURIAN | 443.7-416 Ma

With its base set at major extinction event at the end of the Ordovician, the silurian fossils found differ markedly from those that pre-date the period. Notable life developments include the first bony fish, and organisms with moveable jaws.

DID YOU KNOW? The minimum age for an excavated specimen to be classed as a fossil is 10,000 years

3 | PALEOGENE | 65.5-23.03 Ma

The first period of the Cenozoic era, the Paleogene is notable for the rise of mammals as the dominant animal group on Earth, driven by the Cretaceous-Tertiary extinction event that wiped out the dinosaurs. The most important fossil to be discovered from this period is *Darwinius*, a lemur-like creature uncovered from a shale quarry in Messel, Germany.

4 | CRETACEOUS | 145.5-65.5 Ma

Fossils discovered from the Cretaceous indicate an explosion of insect diversification, with the first ants and grasshoppers evolving, as well as the dominance of large dinosaurs such as the colossal *Tyrannosaurus rex*. Mammals increased in diversity, however remained small and largely marsupial.

5 | JURASSIC | 199.6-145.5 Ma

The period in Earth's history when the supercontinent Pangaea broke up into the northern Laurasia and southern Gondwana, the Jurassic saw an explosion in marine and terrestrial life. The fossil record points to dinosaurs thriving, such as *Megalosaurus*, an increase in large predatory fish like *Ichthyosaurus*, as well as the evolution of the first birds – shown famously by the *Archaeopteryx* fossil find.

7 | PERMIAN | 299-251 Ma

A period characterised by the diversification of early amniotes (egg-bearing invertebrates) into mammals, turtles, lepidosaurs and archosaurs, the Permian has yielded many diverse fossils. Notable examples include reptile therapsids, dragonflies and, driven by late warmer climates, lycopod trees.

8 | CARBONIFEROUS | 359.2-299 Ma

A period of significant glaciation, the Carboniferous saw the development of ferns and conifers, bivalve molluscs and a wide-variety of basal tetrapods such as labyrinthodontia. Notable fossilised finds include the seed ferns *pecopteris* and *neuropteris*.

2 | NEOGENE | 23.03-2.588 Ma

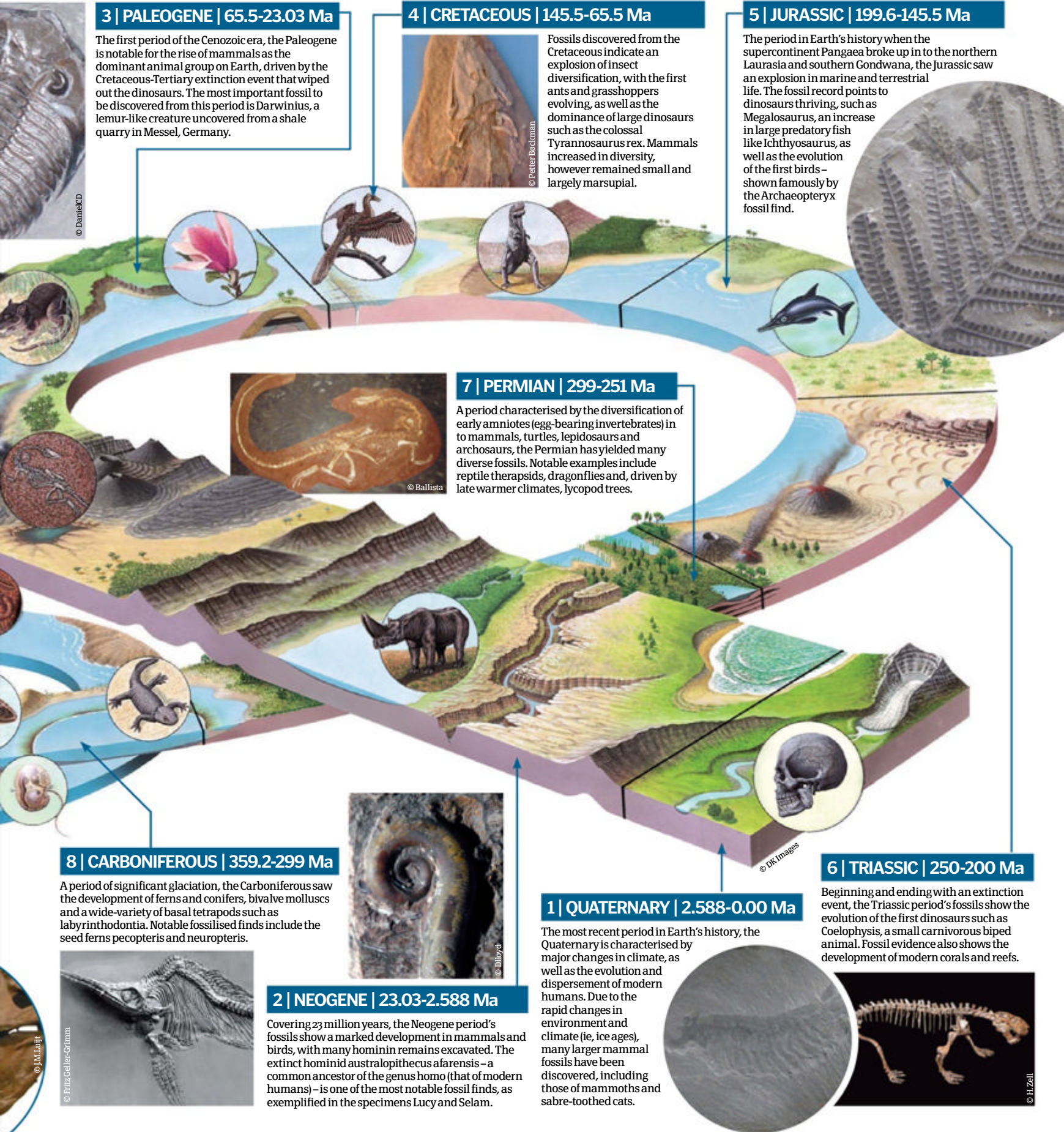
Covering 23 million years, the Neogene period's fossils show a marked development in mammals and birds, with many hominin remains excavated. The extinct hominid *australopithecus afarensis* – a common ancestor of the genus *homo* (that of modern humans) – is one of the most notable fossil finds, as exemplified in the specimens *Lucy* and *Selam*.

1 | QUATERNARY | 2.588-0.00 Ma

The most recent period in Earth's history, the Quaternary is characterised by major changes in climate, as well as the evolution and dispersement of modern humans. Due to the rapid changes in environment and climate (ie, ice ages), many larger mammal fossils have been discovered, including those of mammoths and sabre-toothed cats.

6 | TRIASSIC | 250-200 Ma

Beginning and ending with an extinction event, the Triassic period's fossils show the evolution of the first dinosaurs such as *Coelophysis*, a small carnivorous biped animal. Fossil evidence also shows the development of modern corals and reefs.





HOW IT
WORKS

DINOSAURS' LEGACY

Finding fossils



Finding fossils

How are prehistoric remains uncovered and what can scientists learn from them? Let us dig up the facts...



Ever since Mary Anning first began piecing together the fossils of Jurassic beasts in the early nineteenth century, scientists have been learning more and more about the dinosaurs that ruled the world millions of years ago. Buried deep beneath the ground for aeons, the remains of countless extinct creatures

are waiting to be unearthed by palaeontologists, who can gradually unlock their secrets.

Dinosaurs and other prehistoric fossils have been discovered around the world for thousands of years, with reports of 'dragon bones' found in China more likely indicating some of the earliest dino finds. However, it wasn't until the brilliant

scientists of the Enlightenment in the late-18th and early-19th centuries that it became clear just how old these ancient skeletons really were.

Before long, fossil hunting became an obsession for naturalists and amateurs alike, with the strange extinct 'lizards' being discovered at sites all over the globe.

DID YOU KNOW? A study in 2006 indicated that only around 28 per cent of dinosaur genera have been found so far

Though ground-penetrating radar now helps archaeologists identify hidden underground remains, modern palaeontologists still often rely on the same methods their 19th-century predecessors did: plain luck. Of course, through a greater understanding of geology, as well as by searching in so-called fossil hotspots, it's possible to predict where fossils will likely be found. Once a fossil site has been identified, the long and delicate process of unearthing the dino remains begins.

Digging for fossils can be as simple as sieving through sand and silt in the search for tiny teeth, or cracking open large rocks with a hammer and chisel to see what may be lying within. Hills, quarries, mountainsides and ravines are often prime locations for fossil finds, as the deep layers of rock have become exposed by millions of years of erosion. In these cases heavy diggers and drills are crucial to reach the finds. Dozens of scientists, students and even enthusiastic volunteers are employed with brushes and trowels during the course of an excavation. However, because of the delicate nature of specimens that are millions of years old, it can often take what must seem like another million to safely uproot an entire dinosaur skeleton.

Of course, palaeontologists do much more than just dig up old bones. Mixing together the disciplines of geology and biology, palaeontology is the study of fossils to reveal the history of life on Earth. So, once the fossilised remains have been fully excavated, the real work can begin back in the lab. Here scientists painstakingly remove any residual earth and stone from the specimens in preparation for full analysis. Electron microscopes, CAT scanners and X-ray machines are all employed to gather as much information about the creature as possible.

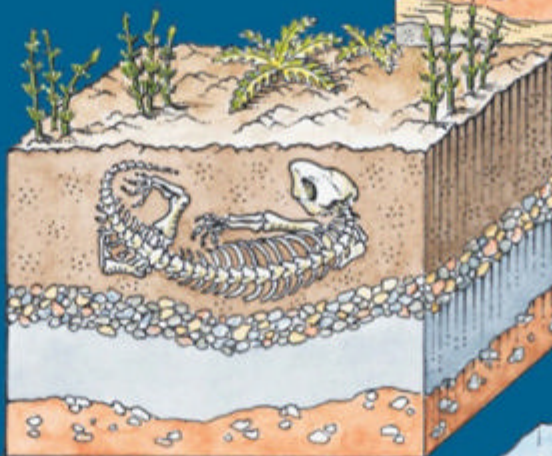
By studying the shape, length and arrangement of each fossilised bone, palaeontologists have been able to determine not only what certain dinosaurs looked like and how they moved, but also what they ate. The discovery of indentations on fossilised arm bones similar to those found on modern birds has also indicated that many species of dinosaur were actually feathered.

Bigger, stranger and ever-more unbelievable dino discoveries are being made all the time, each one challenging past theories and shedding new light on the distant land of the Mesozoic beasts. Thanks to the pioneering work of the scientists and enthusiasts of the past, each new fossil found could slot yet another piece of the prehistoric jigsaw into place.

How fossils form

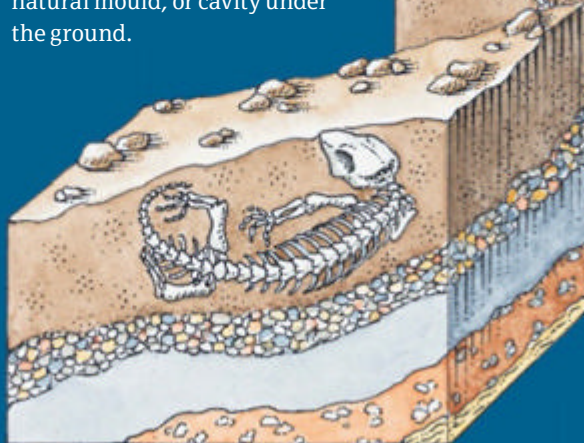
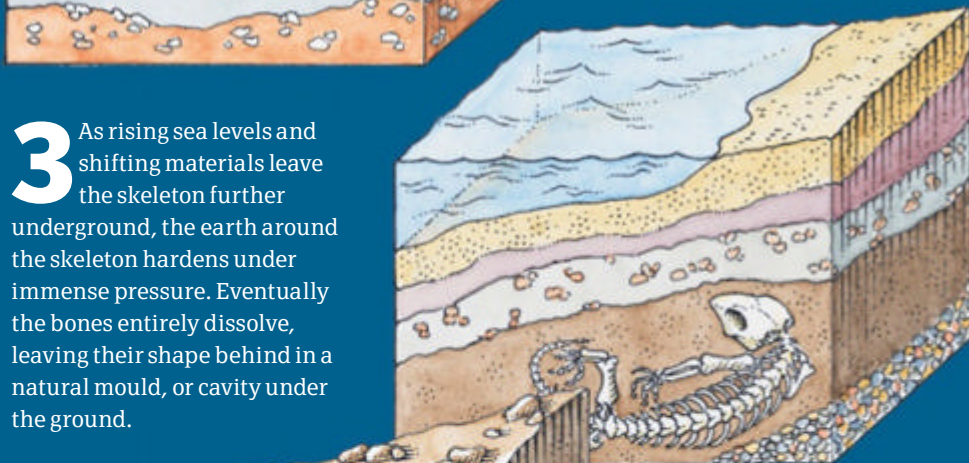
How do the remains of prehistoric animals become fossils, and why do they survive through the ages?

1 After death, a dinosaur's remains would often just rot and erode away completely, leaving not even a skeleton behind. However, in the right conditions, where the remains are kept safe from weather and hungry scavengers, the process of fossilisation can begin.



2 Over a long period of time, shifting sands, soil and sediment entirely cover the skeleton, encasing it in the ground. Any remaining soft tissue such as skin and organs, decays away entirely, leaving only the creature's bones. At this stage the remains are only partly fossilised.

3 As rising sea levels and shifting materials leave the skeleton further underground, the earth around the skeleton hardens under immense pressure. Eventually the bones entirely dissolve, leaving their shape behind in a natural mould, or cavity under the ground.



4 Over time, mineral deposits slowly gather in the creature's mould, chemically replacing the original bone. As sea levels recede away and materials shift around, the fossil draws closer to the surface. Eventually it can be found either entirely exposed or close to the topsoil.



HOW IT WORKS

DINOSAURS' LEGACY

Finding fossils

Digging for dinosaurs

How palaeontologists discover and unearth prehistoric giants

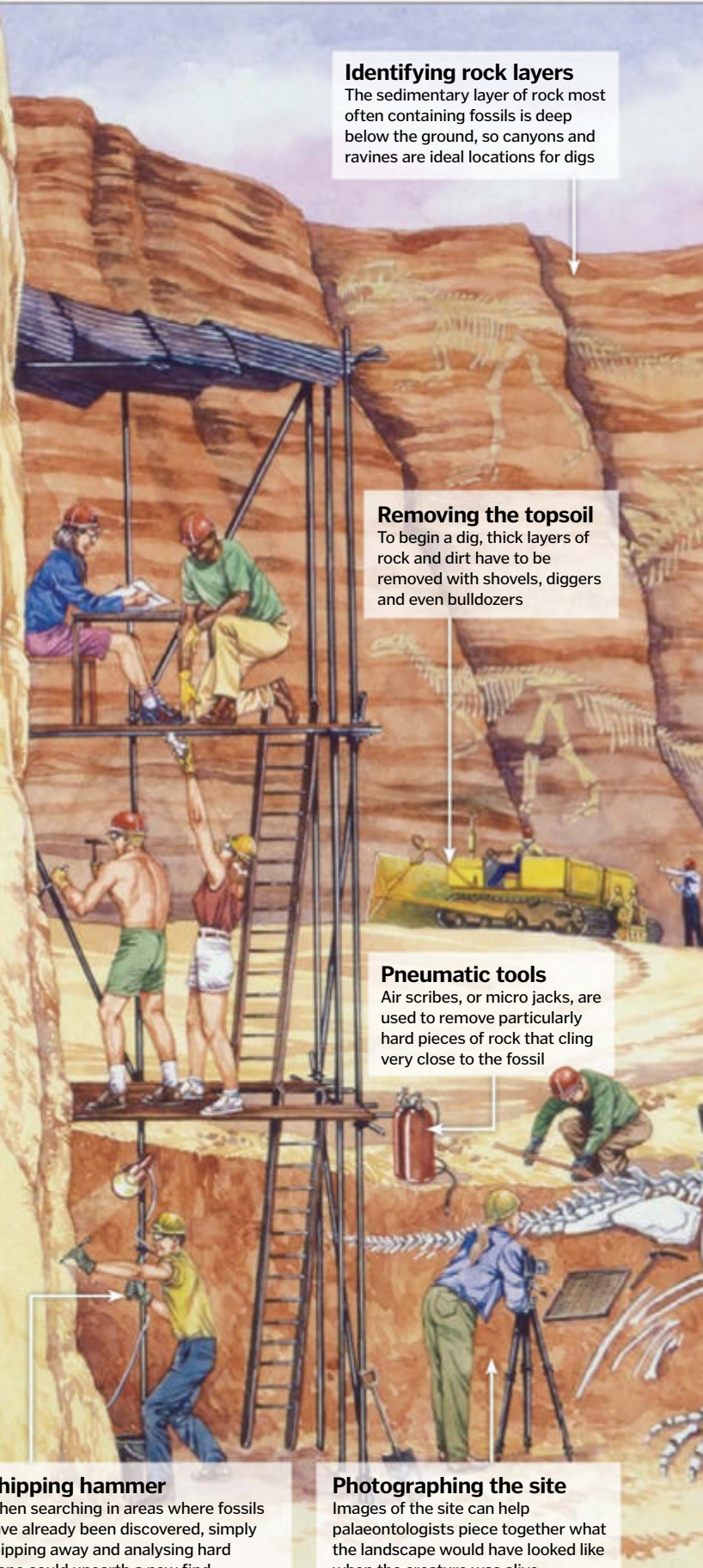
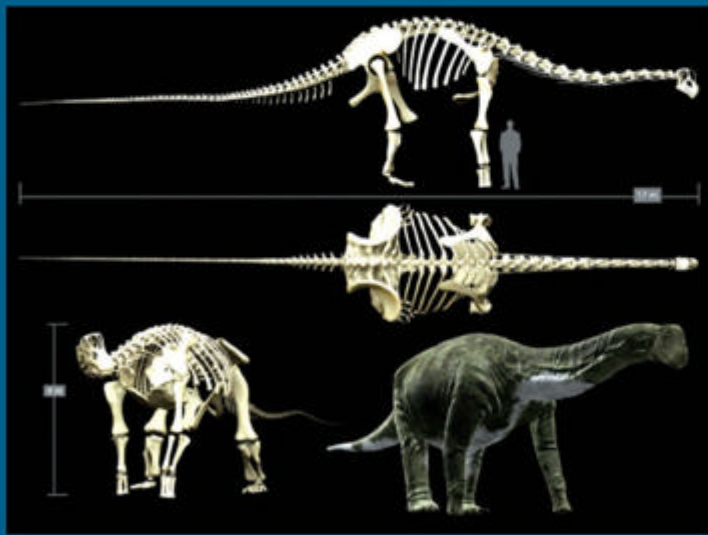


Bulldozers, hammers, chisels, drills and even dynamite – you'd be forgiven for thinking these were part of a construction-site inventory. In fact, they are the basic tools a palaeontologist will use to uncover the mysteries of the past. From removing tons of topsoil with diggers and other heavy machinery, to carefully clearing away clinging dust and debris with delicate brushes, the process of excavating a dinosaur skeleton can take many years.

The largest dino fossil

Even in this ancient time when giants ruled the Earth, sky and sea, *Dreadnoughtus schrani* truly was a behemoth of a creature. Standing over two-storeys tall and weighing as much 60 tonnes, the remains of this beast were found by a team in Patagonia, Argentina, and have been dated back over 77 million years. A member of the titanosaur sauropod group of dinosaurs, *Dreadnoughtus* was a plant-eater and is to date the largest known land animal ever to have lived.

Two *Dreadnoughtus* titanosaurs were found at the site, and it's believed the pair died in a massive flash flood, which would explain why their remains were so complete. The preservation of the skeletons enabled scientists to take full advantage of 3D-printing technology, scanning in each individual bone into a digital format for even greater scrutiny. This 3D rendering of *Dreadnoughtus* provided even greater insight into how it likely looked and moved.



Identifying rock layers

The sedimentary layer of rock most often containing fossils is deep below the ground, so canyons and ravines are ideal locations for digs

Removing the topsoil

To begin a dig, thick layers of rock and dirt have to be removed with shovels, diggers and even bulldozers

Pneumatic tools

Air scribes, or micro jacks, are used to remove particularly hard pieces of rock that cling very close to the fossil

Chipping hammer

When searching in areas where fossils have already been discovered, simply chipping away and analysing hard stone could unearth a new find

Photographing the site

Images of the site can help palaeontologists piece together what the landscape would have looked like when the creature was alive

Studying the surroundings

Dig-team members have to carefully record the arrangement and surroundings of the fossil, to learn as much as they can about how the creature lived and died

Moving to the lab

Once they are carefully recorded and stored, the fossils are transported off the site for closer analysis

Protecting the bones

Before being removed, each bone is wrapped in paper towels, and then encased in plaster strips that dry to protect the fossils

Isolating the fossil

After the main layers of dirt are cleared, the fossil is carefully dusted to isolate it from the surrounding earth

Tools of the trade

What do you need for a fossil dig?

Chisels

Chisel blades come in a range of sizes for either cracking apart larger stone or trimming away a rock face

Hammers

Crack and chipping hammers are essential for carefully removing and trimming hard rock. They are also needed for working with chisels

Sieve

Not all fossils come in huge sizes, so wire sieves are perfect for sifting through sand and silt for teeth and other small remains



Maps

If travelling to more remote locations, as well as for making reliable notes for future reference, a good map and compass are a must

Brushes

Small, soft bristles are ideal for working with delicate remains, while larger, harder brushes are best for removing thicker dust

Journals and reference

Accurately recording everything you find, where it's found, as well as referencing what it could be, is vital for making new discoveries



ON THE MAP

The world's fossil hotspots

- 1 Jurassic Coast, Devon and Dorset, UK
- 2 Auca Mahuevo, Patagonia, Argentina
- 3 Dinosaur Cove, Victoria, Australia
- 4 Joggins Fossil Cliffs, Nova Scotia, Canada
- 5 Chengjiang Fossil Site, Chengjiang County, China
- 6 Como Bluff, Wyoming, USA





HOW IT WORKS

DINOSAURS' LEGACY

101 dinosaur facts

01 The word 'dinosaur' means terrible lizard

The word 'dinosaur' was first used in 1841 by biologist Sir Richard Owen. It is from the Greek word 'deinos', meaning terrible or great, and 'sauros', meaning lizard.

Camarasaurus
Late Jurassic
North America

02 Dinosaurs were not lizards

Despite being named 'terrible lizards', dinosaurs were anatomically very different from other reptiles and are not that closely related.

Monolophosaurus
Mid Jurassic
China

FACT 3

200 TONS

No dinosaur even came close to the weight of a blue whale

101 GIGANTIC FACTS ABOUT

DINOSAURS

WE'VE DUG UP THE MOST ESSENTIAL DINOSAUR FACTS THAT EVERYONE SHOULD KNOW

Deinonychus
Early Cretaceous
North America

Sauropelta
Early Cretaceous
North America

04 Cavemen never met the dinosaurs

The reign of the dinosaurs came to an end 66 million years ago, but humans have only been around for 200,000 years. Our ancestors did not share a world with the dinosaurs, but they did encounter sabre-toothed cats and woolly mammoths.

DID YOU KNOW? Dinosaur skin sometimes left impressions in the rocks, providing a fossil record of what they looked like

Corythosaurus
Late Cretaceous
North America

05 No one knows what colour dinosaurs really were

The coloured pictures of dinosaurs seen in textbooks are guesswork based on what we know about animals today, but scientists have analysed melanosomes (pigment cells) found in fossils and are piecing together their real colours.

"230 million years ago, the Earth was dominated by mammal-like reptiles, such as Dimetrodon and Lystrosaurus"

FACT 6

5cm

Stegosaurus had a brain the size of a plum

Stegosaurus
Late Jurassic
North America

Triceratops
Late Cretaceous
North America

07 Triceratops had up to 800 teeth

Triceratops might be known for their horns, but these icons of the Cretaceous period had another special feature. They had hundreds of teeth, stacked on top of one another in groups of three to five in piles called 'dental batteries'.

Dimetrodon
Early Permian
North America

FACT 9

3.5kg

Compsognathus, one of the smallest dinos, was only just larger than a chicken

Compsognathus
Late Jurassic
Europe

08 Not all prehistoric reptiles were dinosaurs

Over 230 million years ago, the Earth was dominated by large mammal-like reptiles like Dimetrodon and Lystrosaurus. They might look like dinosaurs, but they are actually more closely related to modern mammals than they are to dinosaurs.



Sauropods

These long-necked giants are among the largest animals to have ever lived

10 Sauropods were huge herbivores

The four-legged dinosaurs with long tails and necks are known as sauropods. The most common were Diplodocus and Camarasaurus.

11 Diplodocus had 15 vertebrae in its neck

At least, we think it did - there are very few complete specimens. For comparison, a human has seven neck vertebrae.

12 Sauropods did not live in water

Early ideas about how sauropods like Diplodocus lived portrayed them walking underwater like hippos. They had nostrils on the top of their heads, and scientists thought they would use their necks like snorkels. However, with large bodies, the crushing weight of water would have prevented them from breathing, and we now know they lived on land.

13 Titanosaurs laid the largest eggs

The larger an egg is, the thicker its shell has to be. Even the monstrous titanosaurs had to lay relatively small eggs so that oxygen and carbon dioxide could cross over the walls of the shell.

FACT 14

33m

Diplodocus was the length of three buses

Aegyptosaurus
Mid Cretaceous
Africa

15 You can tell if a dinosaur was female by looking at her bones

Medullary bone lines the inside of bones and stores calcium to make eggshells. It forms in female birds, its presence in fossils can also reveal the sex.

Pachycephalosaur
Late Cretaceous
North America



Charonosaurus
Late Cretaceous
China



Struthiomimus
Late Cretaceous
North America



24 Dinosaurs didn't have two brains

Stegosaurus had a tiny brain, but at the base of its spine there was an enlarged space. Scientists once thought it might have housed a second, larger brain to control its legs, but this idea has been discredited as birds have a similar opening to store the energy-rich substance glycogen.



25 Pachcephalosaurs had thick skulls

Pachycephalosaur means 'thick-headed lizard'. The bone at the top of their skull could be up to 25cm (10in) thick, and their faces were covered in bumps and spikes. These dramatic features could have been for fighting, or they might just have been for show, like the antlers on modern deer.

22 Hadrosaurs had duck-like bills

Hadrosaurs were the first dinosaurs found in North America, and since the nineteenth century, hundreds have been unearthed. These herbivores had a very distinctive appearance, with duck-like beaks adapted for clipping vegetation, and crested heads that might have helped to transmit sounds over long distances.

23 Ornithomimids looked and lived like ostriches

Ornithomimid means 'bird mimic', and these two-legged dinosaurs really do look familiar. They had long, muscular legs, large, rounded bodies and long necks with small heads. Like modern ostriches, these dinosaurs were extremely fast on their feet.

DID YOU KNOW? The Cuban bee hummingbird is the smallest living descendant of the dinosaurs, measuring just 5cm (2in)

16 Ankylosaurus was one of the last surviving dinosaurs

These heavily armoured dinosaurs had clubbed tails, weighed over 4,000kg (8,818lb) and were covered in bony plates. They were extremely tough, and no predator could tackle a full-grown adult.

17 Herds of dinosaurs were fossilised together

At a bonebed in Alberta, Canada, at least 27 ceratopsids with frilled heads and horns were found buried together.

FACT 18

18.5m

Sauroposeidon was about three times taller than a giraffe



Nests & eggs

28 All dinosaurs laid eggs

Dinosaurs all reproduced by laying eggs like modern-day birds, and some of the hatchlings were thousands of times smaller than the full-grown adults.

29 Some dinosaurs cared for their young

Adult Psittacosaurus have been found alongside the fossilised remains of their young, and the bones of older babies have been found in the nests of Maiasaura, indicating that they probably helped to raise their young.

30 The largest dinosaur egg was over 60cm long

The largest dinosaur eggs were found in Mongolia in the 1990s, and measured around 45cm (17.7ft) across. Compared to the size of the adults, they are still surprisingly small.

31 Some of the best dinosaur fossils are babies

A 113-million-year-old fossilised baby dinosaur found in Italy still contains traces of preserved soft tissue, including intestines and tail muscles.

32 Baby dinosaurs grew rapidly

Sauropods like Diplodocus weighed a tiny 5kg (11lb) at birth, and grew to 10,000 times their size within just 30 years. Fossilised embryos show sauropod bones filled with blood vessels, bringing nutrients to allow rapid growth.

33 There are two main types of dinosaur egg

Dinosaur eggs can be divided into two main categories – spheroidal and elongated. Rounder eggs were laid by herbivores such as sauropods, while elongated, bird-like eggs were laid by theropods.

34 Oviraptors didn't steal eggs

The name 'Oviraptor' means egg thief, but these dinosaurs weren't criminals. They were actually devoted parents, and fossilised nests found in Mongolia show they arranged their eggs in spiral layers.

19 Pterosaurs weren't dinosaurs

Pterodactyls are the iconic flying dinosaurs, but they weren't actually dinosaurs at all. Dinosaurs were all land animals. Quetzalcoatlus, the largest pterosaur of all, had a 12m (39ft) wingspan, making it the largest animal that ever flew.

20 Big bodies kept dinosaurs warm

This process is known as 'thermal inertia'. The larger the body of an animal, the lower the surface-to-volume ratio – preventing heat escaping from the skin.

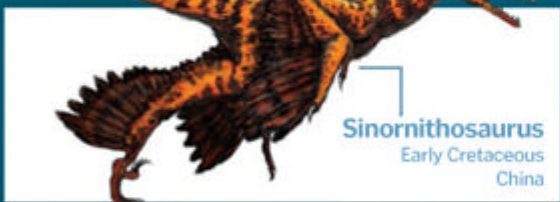
21 The Sea level dropped as the dinosaurs went extinct

At around the time the dinosaurs went extinct, the sea level fell by 150m (492ft).

Styracosaurus
Late Cretaceous
Canada



Sinornithosaurus
Early Cretaceous
China



26 Dinosaurs had feathers

Despite what you might see in textbooks, museums and even in this bookazine, we now know that most dinosaurs were not all scaly and bald. We have known for a while that the two-legged theropods had feathers, but in 2014 a very distantly related beaked dinosaur found in Siberia was also found to have feathers, suggesting scales were replaced early in dinosaur evolution.

27 Ceratopsians had horned faces

The most famous ceratopsian is Triceratops, but there were other dinosaurs with horns and frills. These huge herbivores started to appear around 160 million years ago, and it is thought the frill was used as protection against predators, to impress potential mates and as a radiator to get rid of excess heat.



HOW IT WORKS

DINOSAURS' LEGACY

101 dinosaur facts

Tyrannosaurus rex

35 You probably couldn't outrun a Tyrannosaurus

Computer simulations of T-rex running suggest that it had a top speed of around 29kmh (18mph). Not quite fast enough to catch up with a car, like in Jurassic Park, but quick enough to catch any human that's not an athlete.

Head

It measured 1.5m (4.9ft) long, and had eye and nose cavities. The skull was of thick and heavy bone, although in some points it was pretty flexible.

36 The largest T-rex fossil is called Sue

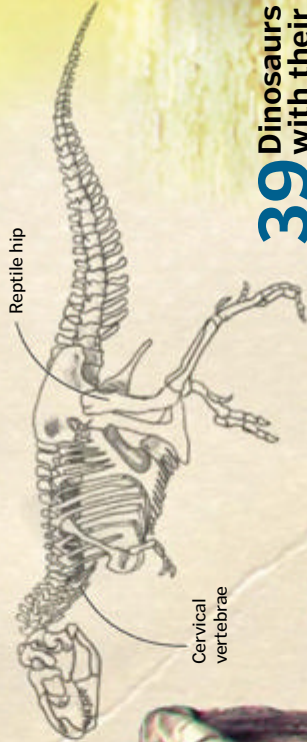
Complete dinosaur fossils are incredibly rare, but there is one T-rex specimen that stands out from the rest. Sue is over 12.8m (40ft) long and stands over 3.9m (13ft) high. She is on display at the Chicago Field Museum and is the most complete specimen ever recovered.

37 Stegosaurus never met Tyrannosaurus

Despite being depicted together, these two would never have been in the same place at the same time. Stegosaurus lived during the Jurassic period and went extinct around 80 million years before T-rex first appeared at the end of the Cretaceous period.

38 Some dinosaurs had a wishbone

The 'V'-shaped wishbone you find in your Sunday roast is also present in meat-eating theropods such as T-rex.



39 Dinosaurs walked with their tails up

Dinosaurs like T-rex had enormous heads, and used their tails as a counterweight, holding them up for balance.

40 The meat-eating dinosaurs were all theropods

T-rex, Allosaurus and Deinonychus belonged to a group of dinosaurs known as theropods. Some members of this group are the largest carnivores ever to have walked the Earth.



Among the T-rex's favourite prey were the Ceratopsians, such as Triceratops



Data sheet



LENGTH 12.5m
 WEIGHT 5,000kg
 DIET Carnivorous
 GENUS Tyrannosaurus
 CLASSIFICATION Theropoda;
 Coelurosauria;
 Tyrannosauridae

41 T-rex had teeth the size of bananas

The largest Tyrannosaurus rex teeth measured 30cm (12in) in length. There has been much debate as to what they were used for, but scientists generally agree that T-rex was both a hunter and a scavenger. Broken T-rex teeth found in the fossilised tailbones of Hadrosaurs indicate that hunts weren't always successful.



42 T-rex had stronger arms than human beings

T-rex is often ridiculed for its little arms, but they were much stronger than you imagine. They were used for grasping prey, could move rapidly and were capable of lifting around 200kg (440lb), more than three times as much as an adult man.



43 The most expensive fossil is worth more than \$8 million

The famous Tyrannosaurus rex fossil known as Sue fetched \$8.36 million at auction back in 1997 and is likely to be worth significantly more than that today.

Found in...

The T-rex was found in what is now North America, just like its cousins the Daspletosaurus, the Gorgosaurus and the Albertosaurus. The Tarbosaurus and the Guanlong, a primitive tyrannosaur of the Jurassic period, were discovered in Asia.



Phylogenetic tree



44 There was a dinosaur called 'Irritator'

Irritator was a fish-eating spinosaur first described in 1996. It got its name because the fossilised head had been modified by fossil hunters with car body filler to make it look more impressive. The scientists understandably found this very irritating.



45 Dinosaurs in the sea didn't live

Dinosaurs were land animals and were not closely related to the famous sea-dwelling Plesiosaur, but Spinosaurus was semi-aquatic and could run along the riverbed in pursuit of food.

46 No dinosaur could fly

Dinosaurs were all land-dwelling reptiles, and despite the fact that they are the ancestors of modern birds, none of them could fly. They could probably glide, though.



47 Archaeopteryx is the first fossil evidence of evolution

Archaeopteryx was the first feathered dinosaur to be discovered, linking birds and dinosaurs. The breakthrough came in 1861, just two years after Charles Darwin published his theory of evolution.



48 Dinosaurs were neither warm nor cold blooded

It was long thought that dinosaurs were cold blooded, like reptiles, but new evidence suggests that they were mesothermic – able to burn energy to make some body heat, but not warm blooded like mammals.



© Sojo, Nobu Tamura; H. Zell; Thinkstock



Classification

Dinosaurs can be split into two major groups, with many more subdivisions

49 The meat-eating dinosaurs walked on two feet

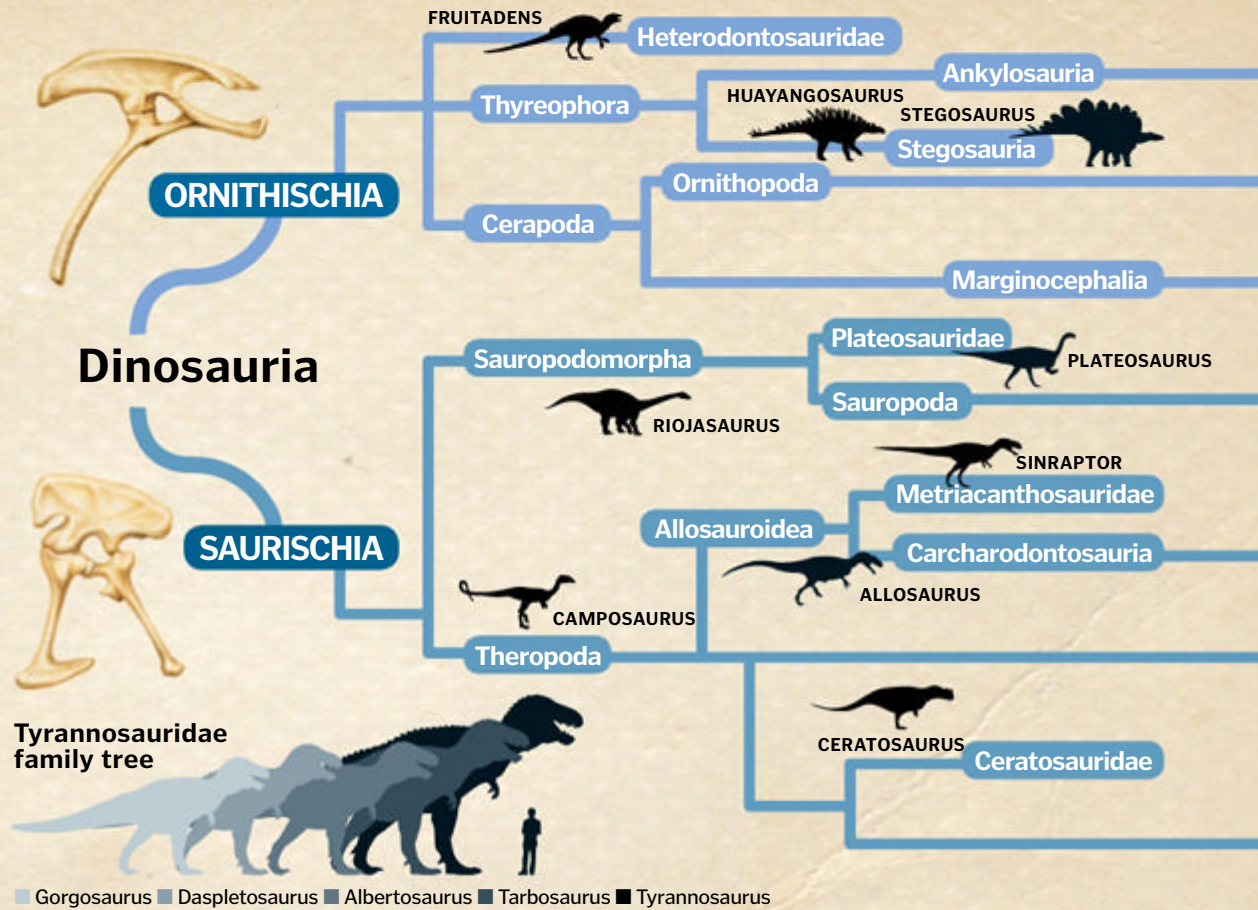
All the carnivorous dinosaurs were theropods (although not all theropods were carnivores) and walked upright on their two hind legs. They typically had hollow bones, three main fingers on each hand and foot, and sharp, curved teeth and claws used for hunting and eating.

50 Dinosaurs either had lizard hips or bird hips

Dinosaurs can be divided into two major groups based on their hipbones. The Ornithischia, or 'bird-hipped' dinosaurs had a pubic bone that pointed toward the tail, and the Saurischia, 'lizard-hipped' dinosaurs pointed toward the head. Interestingly, birds evolved from lizard-hipped dinosaurs.

51 Most dinosaurs ate plants

Dinosaurs are often portrayed as fearsome hunters, but the majority of species were herbivores. Even some of the ferocious-looking theropods actually ate plants and used their sharp claws for digging.



56 Dinosaurs lived during the Mesozoic Era

Dinosaurs ruled the Earth for 165 million years, in a time period known as the Mesozoic Era. This era can be split into three periods, Triassic, Jurassic and Cretaceous

57 Dinosaurs first appeared 230 million years ago

Dinosaurs evolved during the Triassic period, between 250 and 200 million years ago. The warm, dry conditions were perfect for breeding reptiles.

58 Volcanic eruptions contributed to the extinction of the dinosaurs

Huge lava flows are present in the fossil record for about 500,000 years before the extinction of the dinosaurs, and many scientists think eruptions contributed to their extinction by filling the air with a thick cloud of ash.

59 Early dinosaurs lived on the continent of Pangaea

When dinosaurs first appeared, the landmasses of the Earth were joined into a supercontinent called Pangaea. This later fractured into two continents - Laurasia and Gondwana.

Camposaurus
Late Triassic
North America

Riojasaurus
Late Triassic
South America

Torvosaurus
Late Jurassic,
North America,
Europe

Apatosaurus
Late Jurassic
North America

Stegosaurus
Late Jurassic
North America,
Europe

TRIASSIC 252-201 MILLION YEARS AGO

JURASSIC 201-145 MILLION YEARS AGO

DID YOU KNOW? A theropod known as *Concavenator* had a hump on its back like a camel

52 There were more than 700 species of dinosaur

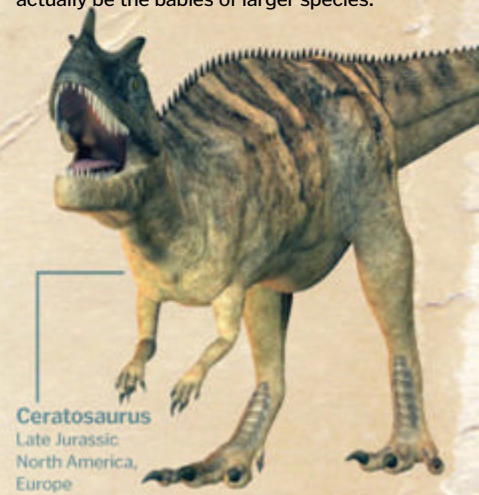
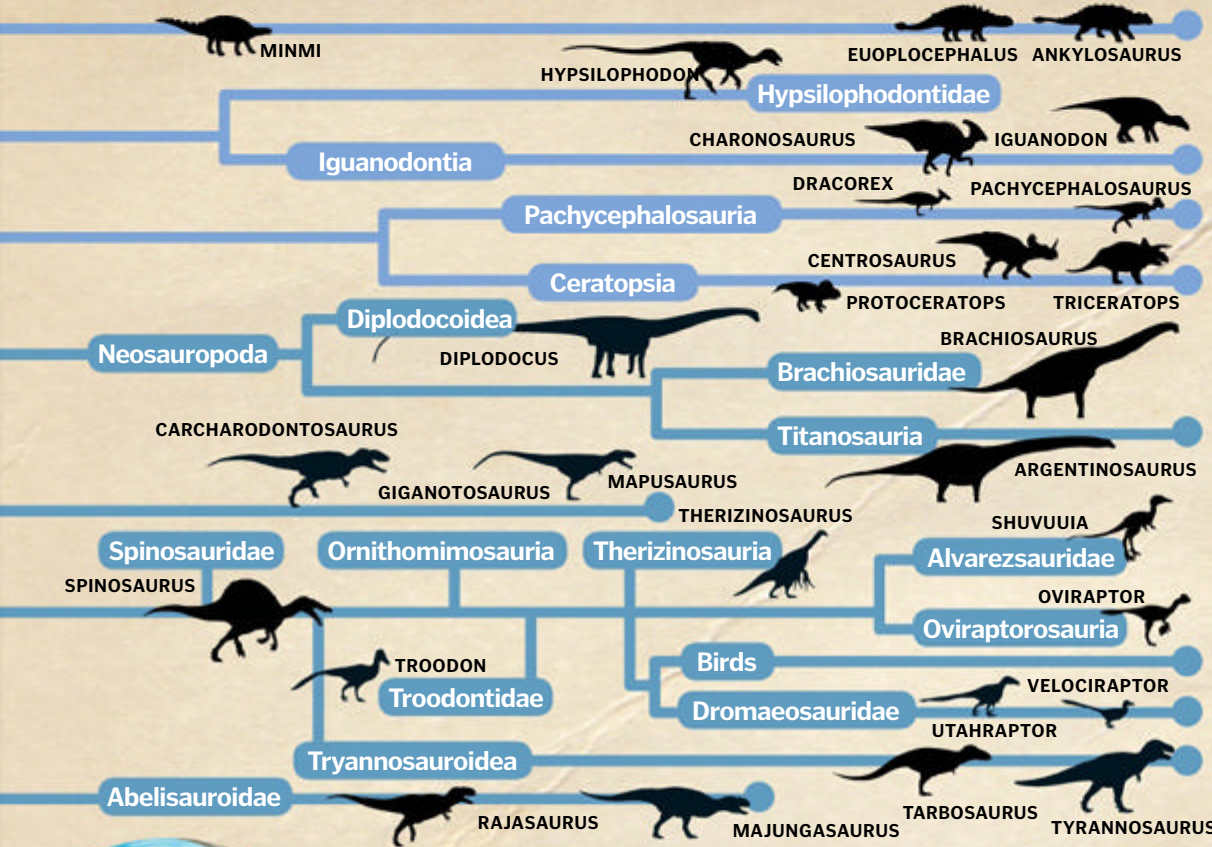
To date, over 700 species of dinosaur have been identified, but only around 300 have been confirmed as entirely unique. There are more yet to be found, so this number will continue to change.

53 There are hundreds of dinosaurs yet to be found

It is estimated that we have only found around a tenth of the dinosaur species that ever existed. Some are buried in rocks we cannot reach, while others lived in areas where conditions did not favour fossil formation.

54 There were fewer dinosaur species than we thought

Hundreds of species of dinosaur have been named, but few baby dinosaurs have been found. Scientists have reviewed the evidence and have found that some smaller species might actually be the babies of larger species.



Ceratosaurus
Late Jurassic
North America,
Europe

55 Dinosaurs are still alive today

In the 19th century the fossilised remains of a feathered dinosaur called *Archaeopteryx* were discovered, and since then evidence linking dinosaurs to birds has stacked up. It is thought that early birds started to evolve from the carnivorous theropods in the late Jurassic, and a few managed to survive the mass extinction, giving rise to the bird species we see today.

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60 Sea levels were at an all-time high in the Cretaceous

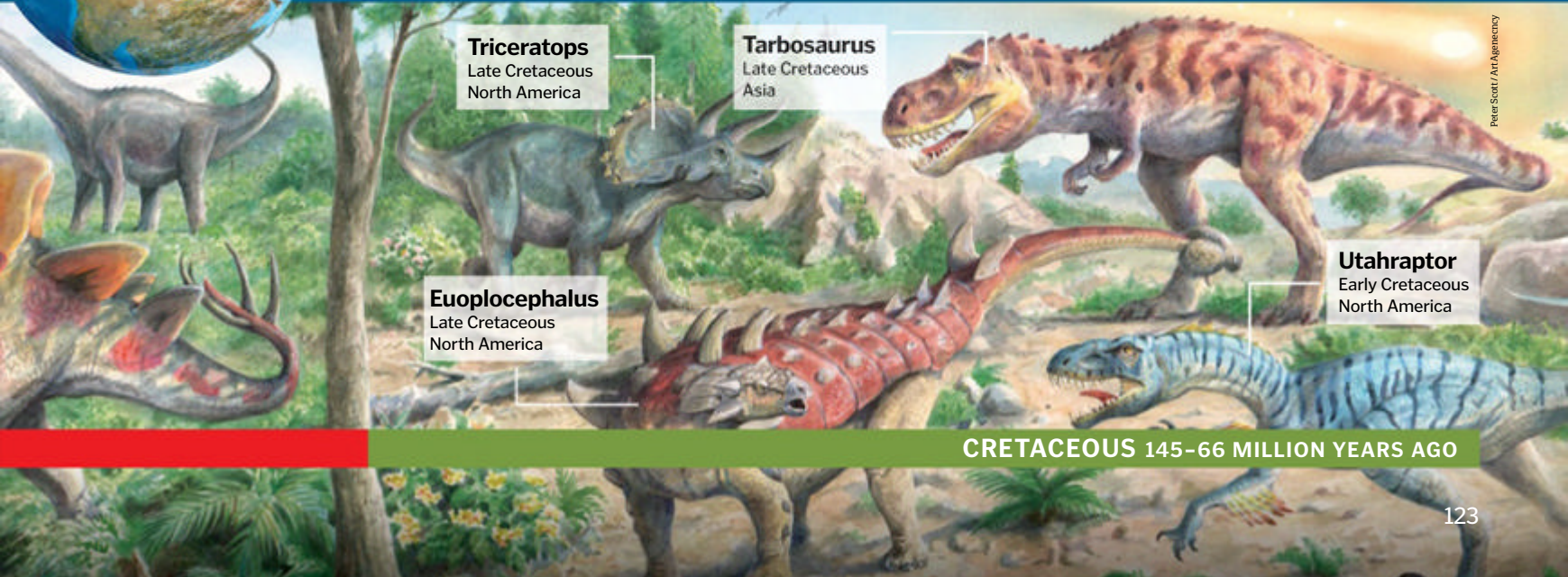
During the Cretaceous period, sea levels rose and fell dramatically, and large areas of land disappeared under water. At times the sea was 100-250m (330-820ft) higher than it is today.

61 High oxygen levels fuelled fires during the extinction event

During the Cretaceous period, oxygen levels in the atmosphere were much higher than they are now, which may have helped to fuel fires after the famous meteor impact 66 million years ago, contributing to the mass extinction.

62 They experienced more than one mass extinction

There was a mass extinction at the end of the Triassic period, when many land animals died out, leaving room for the evolution of some of the giants of the dinosaur world.



Peter Scott/Art Agency

CRETACEOUS 145-66 MILLION YEARS AGO



Minmi
Early Cretaceous
Australia

63 Armoured dinosaurs are known as 'Thyreophora'

Stegosaurus and Ankylosaurus are famous for their armour plating and were members of a group of dinosaurs called Thyreophora. Ankylosauria were the most heavily armoured and had bony plates, spikes and clubbed tails.

64 Dinosaur's legs are positioned beneath their bodies

Crocodiles and lizards walk with their legs out to the sides, but dinosaurs have their legs underneath their bodies, allowing them to run faster.

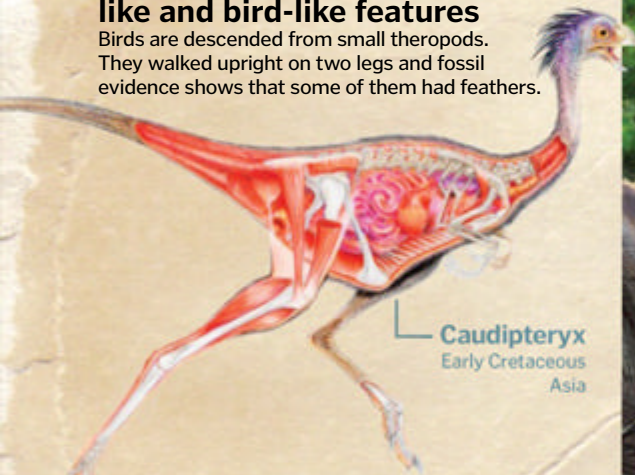


65 Some dinosaurs swallowed rocks

Many plant-eating dinosaurs have been found with groups of rounded stones inside their ribcages, indicating they swallowed stones to aid digestion, like modern birds.

66 Some dinosaurs had a mixture of dinosaur-like and bird-like features

Birds are descended from small theropods. They walked upright on two legs and fossil evidence shows that some of them had feathers.



Caudipteryx
Early Cretaceous
Asia

67 Dinosaurs lived in a changing world

Around 250 million years ago, all of Earth's landmasses were joined in a supercontinent known as Pangaea. During the reign of the dinosaurs, this landmass split apart, first into two and then into the seven continents we see today.

68 Paleontologists study fossils

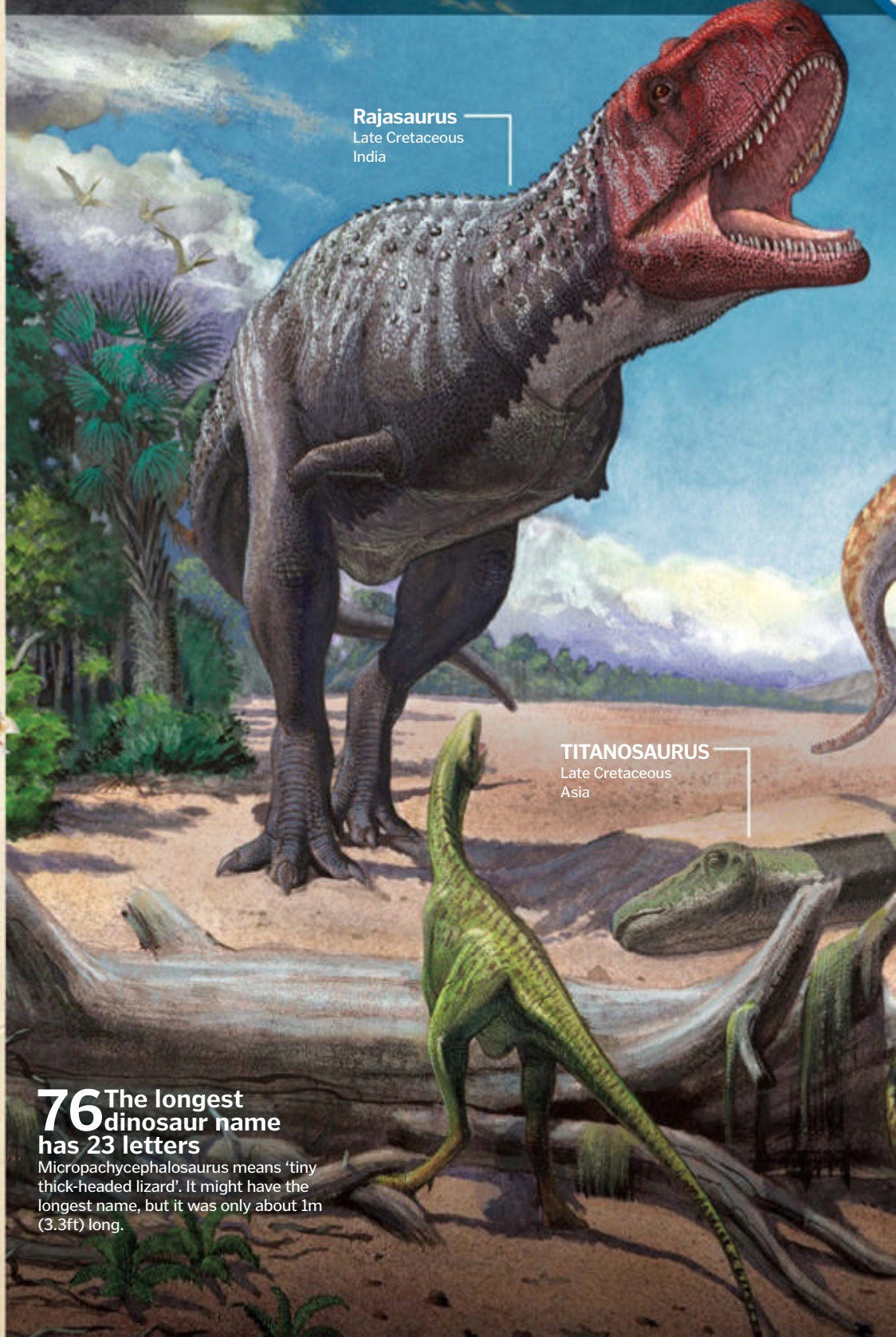
Scientists that study dinosaur remains are known as palaeontologists. Anthropologists study human remains, and archaeologists study artefacts.

69 Some herbivores had self-sharpening teeth

As their jaws closed, the teeth of some plant-eating dinosaurs would grind against each other, wearing the surface into a sharp point.

70 Hadrosaurs had the most teeth

The duck-billed dinosaurs had up to 50 rows of teeth stacked on top of one another, making a total of over 1,000.



Rajasaurus
Late Cretaceous
India

TITANOSAURUS
Late Cretaceous
Asia

76 The longest dinosaur name has 23 letters

Micropachycephalosaurus means 'tiny thick-headed lizard'. It might have the longest name, but it was only about 1m (3.3ft) long.

DID YOU KNOW? In 2005, collagen tissue was found in a T-rex fossil. Scientists think iron molecules helped prevent its decay



71 Dinosaurs had giant fleas

Fossilised remains reveal that dinosaurs in the Cretaceous and Jurassic were hosts to giant flea-like insects measuring ten times the size of modern fleas.

72 Ornithopods walked on two legs

Dinosaurs like Iguanodon and the duck-billed Hadrosaurs walked upright on two legs, and lived in herds like modern-day antelope.

73 one dinosaur is named after the Harry Potter books

Dracorex hogwartsia (“dragon king of Hogwarts”) was a pachycephalosaur with a large bulge on its forehead and a dragon-like spiked frill.

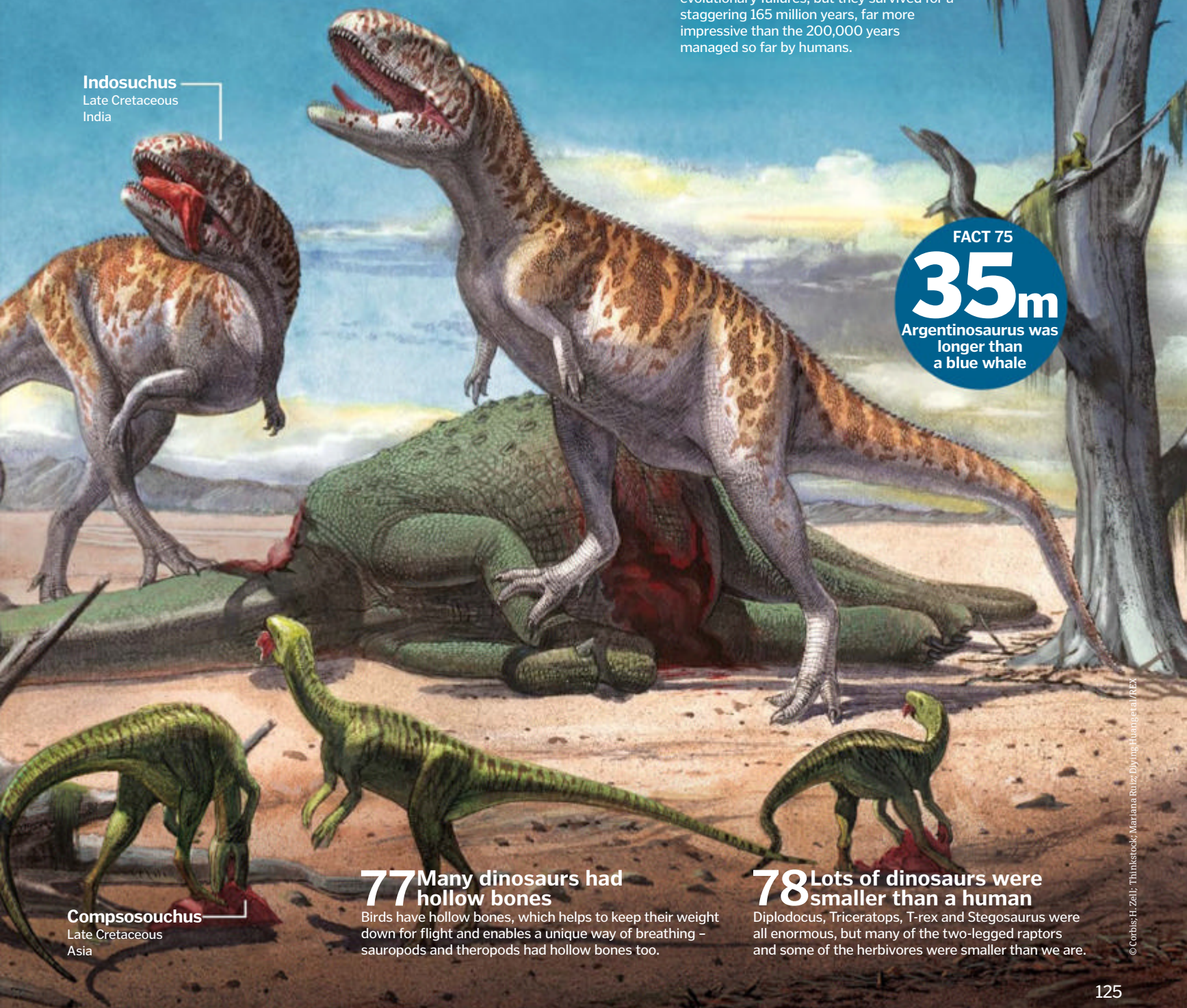


Dracorex
Late Cretaceous
North America

74 Dinosaurs survived for 165 million years

People often think of the dinosaurs as being evolutionary failures, but they survived for a staggering 165 million years, far more impressive than the 200,000 years managed so far by humans.

Indosuchus
Late Cretaceous
India



FACT 75
35m
Argentinosaurus was longer than a blue whale

Compsosuchus
Late Cretaceous
Asia

77 Many dinosaurs had hollow bones

Birds have hollow bones, which helps to keep their weight down for flight and enables a unique way of breathing - sauropods and theropods had hollow bones too.

78 Lots of dinosaurs were smaller than a human

Diplodocus, Triceratops, T-rex and Stegosaurus were all enormous, but many of the two-legged raptors and some of the herbivores were smaller than we are.

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HOW IT WORKS

DINOSAURS' LEGACY

101 dinosaur facts

Hunting dinosaurs

Fossils have been found on every continent on Earth...

79 North America has excavated the most dinosaur fossils

North America, Argentina and China have more than their fair share of dinosaur fossils. Areas with desert-type environments prevented the build-up of thick layers of plants, leaving the remains easier to find under sand and rock.

Ankylosaurus
Late Cretaceous
North America



80 The first dinosaur fossil was found in England

The first dinosaur to be scientifically documented was *Megalosaurus*, formally named by William Buckland in 1824. The fossils were found in a quarry in Oxford.

81 Fossilised dinosaur highways allow us to retrace ancient steps

Enormous mudflats captured the imprints of dinosaur footprints, and some were preserved as fossils. Utah in the United States is particularly famous for its dinosaur trackways, which can be found on what used to be an ancient muddy floodplain.

CLEVELAND-LLOYD DINOSAUR QUARRY
Utah, USA

JURASSIC COAST
South coast, UK

82 New dinosaurs are discovered every year

There are hundreds of dinosaur fossils still to be discovered, and a new dinosaur is found and named approximately every seven weeks.

83 Chicxulub crater marks the asteroid impact that killed the dinosaurs

Chicxulub crater in Mexico is a 66 million-year-old, 180km (112mi)-wide impact created by a 10km (6mi)-wide asteroid. It is thought to represent the aftermath of the impact that killed the dinosaurs. In 2016, scientists plan to drill into the crater to learn more about its history.

CANDELEROS FORMATION
Argentina



84 Dinosaur bones can be recognised by distinctive skull holes

All dinosaurs have the same basic skull, with two holes for jaw muscles behind the eye and an air socket between the eyes and nose.

Giganotosaurus
Late Cretaceous
South America



85 Dinosaur bones can be aged by radiometric dating

Carbon dating doesn't work on dinosaur bones, so scientists estimate the age of fossils by measuring radioactive isotopes in the surrounding rocks.

95 Dinosaurs weren't the first reptiles to rule the Earth

Around 300 million years ago amphibians dominated Earth, but as it got warmer, reptiles took over. There were pelycosaurs, mammal-like reptiles called therapsids, and archosaurs, from which dinosaurs, crocodiles and pterosaurs evolved.

96 Dinosaurs lived for up to 300 years

Paleontologists estimate the large dinosaurs had life spans ranging from 75 to 300 years. These estimates were made based on information we have on cold-blooded animals - warm-blooded creatures have shorter lives.

97 Troodonts were probably the cleverest dinosaurs

Troodonts lived around 77 million years ago and were about two metres (6.6 feet) long. They were carnivores, walked on two legs and had relatively large brains. They are also thought to be related to modern birds.

98 Amber insects don't contain dinosaur DNA

Jurassic Park is based on the idea that you could extract dinosaur DNA from blood preserved inside the bodies of mosquitoes encased in amber. Despite several attempts to recover DNA, it seems it doesn't actually survive inside the amber.

DID YOU KNOW? Smilodon, the sabre-toothed cat, first appeared over 62 million years after the extinction of the dinosaurs

86 More than 100 different dinosaurs lived in Britain

Britain used to form a land bridge that connected Europe to North America, and has been described as a dinosaur paradise. It was home to over 100 different species, including armoured ankylosaurs, giant sauropods and three different types of fearsome tyrannosaur.



Megalosaurus
Mid Jurassic
Europe

87 There's no actual bone in a dinosaur fossil

When dinosaurs died, their bones were covered in sediment that was compressed and turned to rock. Over time, the bone itself dissolved away, leaving a bone-shaped hole in the rock, which then filled with minerals, forming a cast.



Diplodocus
Late Jurassic
North America

88 Most dinosaur fossils were found by amateurs

There are many more amateur fossil hunters than professionals, and they can cover much more ground. The largest T-rex fossil ever was found by an amateur.

89 There are two main types of fossil

Body fossils show the actual shape of dinosaur remains, while trace fossils show evidence of their lives, like footprints and nests.

FACT 90
77 tons
Argentinosaurus, weighed the same as a Boeing 737

91 Fossilised footprints tell us how they moved

Preserved dinosaur tracks revealed some theropods could run at 43.5kmh (27mph).



BAHARIYA FORMATION
Western Desert, Egypt

FLAMING CLIFFS
Gobi Desert, Mongolia

ZHUCHENG
Shandong, China

Iguanodon
Early Cretaceous
Europe, North America

LARK QUARRY
Queensland, Australia

93 The most ancient dinosaur fossils were found in Tanzania

One of the earliest-ever dinosaur fossils found is a 243-million-year-old dog-sized dinosaur called *Nyasasaurus parringtoni*. Bones from two different individuals were excavated in the 1930s, but weren't properly studied until 2012.



92 Dinosaurs ran along riverbeds

Fossilised dinosaur tracks found in Australia reveal a superhighway where two-legged dinosaurs travelled on tiptoe through a fast-moving river.

94 Dinosaur fossils are found on all seven continents

Dinosaur fossils have been found in the very northern parts of Canada, right down to the frozen wastes of Antarctica.

99 Raptors had feathers

Of all the dinosaurs, the most feathery were the theropods. Velociraptors were covered in a layer of feathers, and so too was T-rex. Many other dinosaurs had spiny quills or feathery stubs.

100 Mammals used to eat dinosaurs

Repenomamus robustus was a 1m (3.3ft)-long mammal that lived approximately 125 million years ago. One specimen was found with dinosaur remains inside it.

101 Brontosaurus might have been a real dinosaur after all

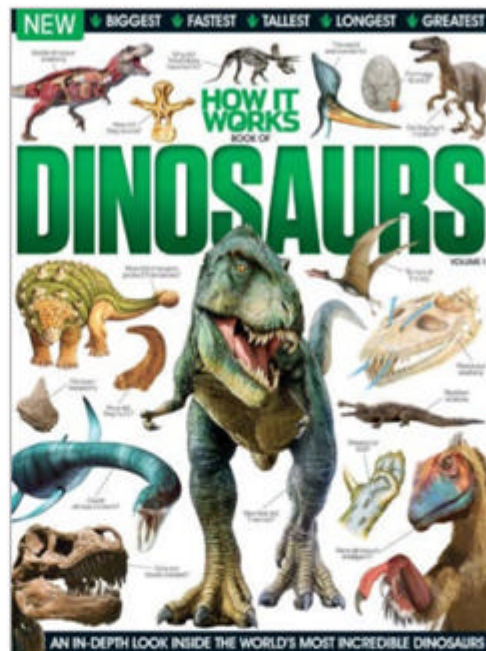
Fossils were mixed up and the head of a *Camarasaurus* was placed on the body of an *Apatosaurus*. However, in 2015, a new study of the bones revealed that *Brontosaurus* has a longer and thinner neck than *Apatosaurus* and thus might be a distinct species after all.

Utahraptor
Early Cretaceous
North America



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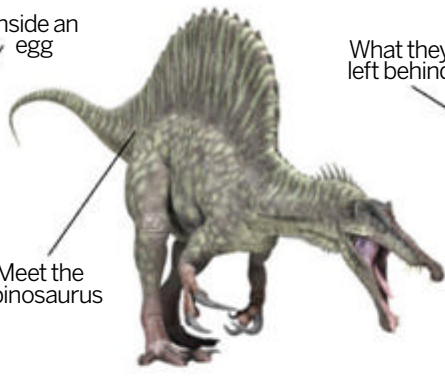
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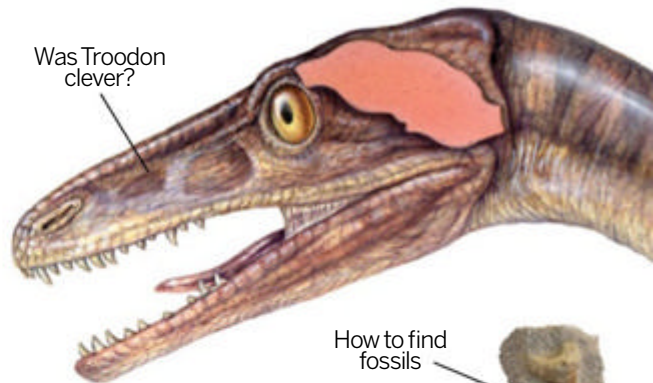


Inside an egg



Meet the Spinosaurus

What they left behind



Was Troodon clever?

How to find fossils



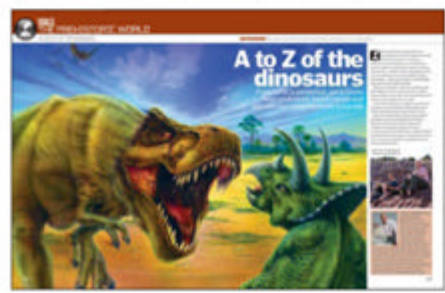
How tall did they stand?



HOW IT WORKS
BOOK OF

DINOSAURS

Could they fly?



THE PREHISTORIC WORLD
Take a tour of prehistoric Earth and explore the dinosaurs' vast and varied habitat



DINOSAURS UP CLOSE
Come face to face with the most incredible dinosaurs, from Allosaurus to Zuniceratops



DINOSAURS' LEGACY
Discover how the dinosaurs went extinct and uncover what they left behind

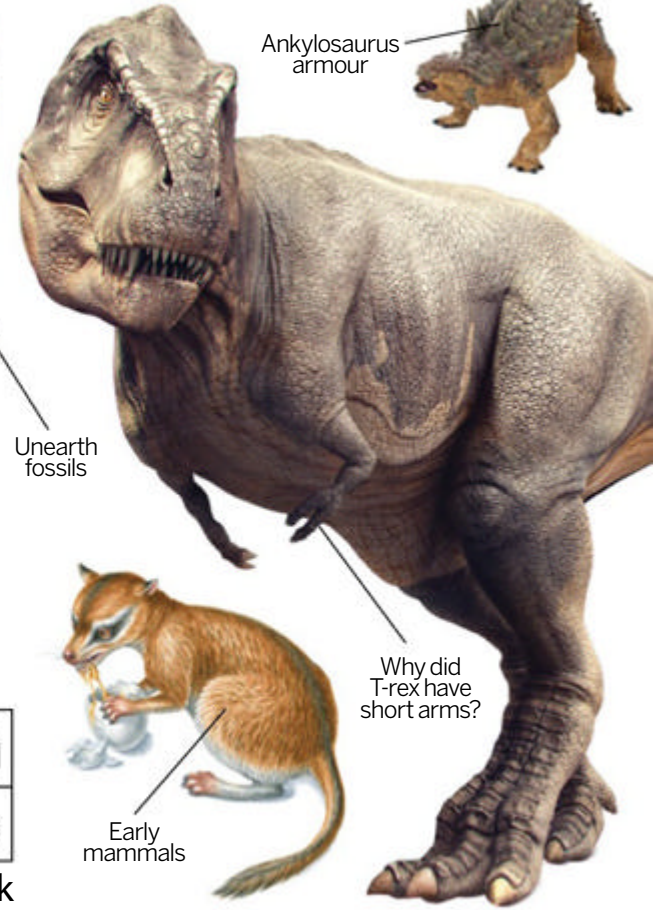


Stegosaurus plates

What did Spinosaurus hunt?



Why grow large spines?

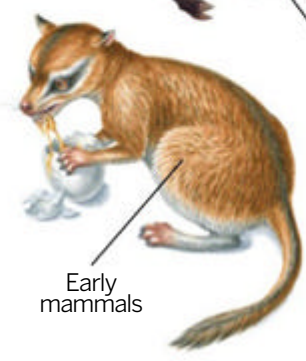


Ankylosaurus armour



Unearth fossils

Why did T-rex have short arms?



Early mammals

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EVERYTHING THAT YOU WANT TO KNOW ABOUT THE AGE OF DINOSAURS