QUEENSLAND MUSEUM

Sea Monsters

Prehistoric Ocean Predators

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LARGE PRINT

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We’re lucky they’re extinct!

Millions of years ago, Earth’s oceans were home to some of the largest, fiercest and most successful predators ever.

While dinosaurs ruled the land, huge prehistoric reptiles hunted the depths.

Ancestors of three types of ancient reptiles left the land and colonised the seas. They were **Ichthyosaurs**, **plesiosaurs** and **mosasaurs**.

These three groups developed into awesome sea monsters that make today’s great white sharks seem small.

Are you ready to meet them?

'A petrified crocodile [sic] head' 1798 copperplate engraving by G R Levillaire with original hand-colouring. Published in *Bilderbuch fur Kinder* Vol III by J L Bertuch.

Discovered before dinosaurs

People reported finding marine reptile fossils about 50 years before they dug up the first dinosaurs. This etching is the first publicised record of a fossil and shows one of the earliest discoveries.

In around 1770, quarry workers in an underground mine near Maestricht in Holland found a large skull. It was a sensational fossil and so popular that the French army had orders to seize the 'famous skull' when they invaded. They took it to Paris in 1794 and it is still there, though the Dutch have asked for it back.

The creature was named *Mosasaurus hoffmanni*. Mosa is the Latin name for the River Meuse, near where it was found, and Dr Hoffmann first recognised its importance.

Spot the difference

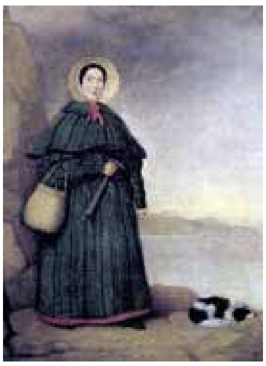
These pictures present the same scene, separated by 177 years of science. Both show what palaeontologists thought ancient creatures looked like. The differences between them reveal how our scientific knowledge has changed since the 1830s.

The painting from 1830 was the first time anyone had shown what extinct animals looked like, based on their fossils. It proved very popular. Its title *Duria antiquior* means 'a more ancient Dorset', as it was based on fossils found in Lyme Regis, Dorset, England, by the famous fossil finder Mary Anning. Mary found hundreds of important fossils, including the first two plesiosaurs ever discovered, but struggled make a living from her passion. Henry, a childhood friend of Mary's, sold prints of his painting to help raise money for her.

In 2007, Lyme Regis artist Richard Bizley worked with palaeontologist David Ward to update the scene based on modern knowledge of the creatures. Fresh fossil discoveries and the work of palaeontologists mean we're always learning new things about ancient animals and revising past ideas. Who knows what the next 177 years of research will reveal?

Duria antiquior by Henry de la Beche, 1830. Thanks to Amgueddfa Genedlaethol Cymru National Museum of Wales

Duria Antiquior Bizley by Richard Bizley, 2007. Thanks to bizleyart.com



Portrait of Mary Anning by Benjamin John Merifield Donne, 1850. Thanks to The Geological Society of London.

Mary is off fossil hunting with her rock hammer and dog called Tray.

Long, long ago

Ichthyosaurs, plesiosaurs and mosasaurs lived hundreds of millions of years ago.

Ichthyosaurs evolved first, then plesiosaurs, then mosasaurs. They became top predators and survived for millions of years, but none are alive today.

Modern humans have only been around for about 300,000 years.

Approx. Date *(mya= million years ago)*	
[time periods]	
252–201 mya	Triassic
201–145 mya	Jurassic
145–66 mya	Cretaceous
66–2.6 mya	Tertiary
2.6 mya – today	Quaternary
[creatures etc.]	
250 – 93 mya	Ichthyosaurs
203–66 mya	Plesiosaurs
100 mya – today	Sea turtles
98–66 mya	Mosasaurs
83–66 mya	Archelon
68–66 mya	Tyranosaurus Rex
28–3.6 mya	Megalodon
16 mya – today	Great White Shark
10–5 mya	Livyatan
300,000 ya – today	First modern humans
250,000 ya – today	Orca
0	Today

Turn back time

Turn the block to travel back in time.

How did Earth look when sea monsters lived?

Title	Text
Triassic	252–201 million years ago • The continents are joined together in a single C-shaped landmass called Pangaea. • By the end of the period, Pangaea has started to split into two: Laurasia in the north and Gondwana in the south. • There is one giant ocean called Panthalassa. • The oceans teem with ammonites and sea urchins and the first modern corals appear. • On land, the first dinosaurs and mammals evolve. • Top ocean predators: ichthyosaurs then plesiosaurs
Jurassic	201–145 million years ago • Laurasia and Gondwana split into smaller landmasses. • Australia is still joined to Antarctica, Madagascar and India. • Oceans flood the spaces between the landmasses, creating new shallow seas, full of life. • The climate changes from hot and dry to humid and subtropical. • On land, the dinosaurs are getting huge. • Top ocean predators: plesiosaurs

Cretaceous	145–66 million years ago • The continents continue splitting and move further apart. • Warm shallow seas fill the gaps and sharks fill the seas. • The Eromanga Sea floods up to half of Australia. It dries up when global sea levels drop and the continent lifts. • On land, flowering plants are spreading and dinosaurs rule. • At the end of the period, most of this rich life, including all dinosaurs (except birds), plesiosaurs and mosasaurs, die out in the extinction event. • Top ocean predators: plesiosaurs then mosasaurs
Today	0 million years ago • The continents continue to move. • The oceans are badly affected by pollution, over-fishing and climate change. • Humans have spread across the continents. • Many species are becoming endangered or going extinct. • Top ocean predators: orca

Sea change

Life began in the world's oceans. Some creatures crawled onto the land and developed into a huge range of different species. Then some of these went back to the sea. We don't know why they went back. It may have been to find food or to avoid land-based predators.

Marine reptiles evolved from land-based reptiles. They had to change to survive in a very different environment. They had to be able to move through the water, breathe, find food, avoid predators and reproduce without returning to land.

They changed gradually, generation by generation. While they all faced the same challenges to live in the ocean, they solved them in different ways.

Back to the sea cartoons

If you want to change from living on land to living in the sea, there are a few things you need to do

.

Caption	Idea for cartoon
1. You need to learn to swim	A lizard with floaties on and swim ring
2. You need to stay the right way up	A lizard swimming (awkwardly) upside down. Onlooker (sea monster) says "I don't think you've quite got it yet."
3. You need to reproduce	A clutch of eggs is bobbing around on the surface of the ocean. A young sea monster nearby thinks "I hate babysitting."
4. You need to find your prey and avoid predators	A lizard is struggling in a diving mask thinking "It keeps fogging up" oblivious to large sea monster looming behind

5. You need to eat	Sad-looking sea monster reading café menu that lists only “Fish, squid, ammonites” Thinking “But I’m a vegetarian.”
6. You need to slip through the water	Lizard trying on ichthyosaur outfit, looking in the mirror, striking a pose, thinking “It flattens out my curves.”
7. You need to deal with all the salt	Sea monster MasterChef: Three judges behind a table. One plate of food (fish). Sea monster in apron in front of them looking sad. One judge says “A little heavy on the salt.”
8. You need to stay warm	Cold-looking lizard on beach dipping toe into sea. Thinking “Brrrr, maybe I won’t evolve ‘til summer.”
9. You still need to breathe	Plesiosaur hides underwater from *T. rex* on shore, breathing through a reed.
10. You mustn’t sink or float	Plesiosaur with distended stomach plummeting to the depths thinking “Swallowing that last rock was a mistake”. His stationary mate calls after him – “You should have had the ice cream!”

Human hunters

When we go hunting in the oceans, we have to solve the same problems as prehistoric reptiles. And so did the ancestors of today's dolphins. While we use special equipment to help us, other species gradually adapted their bodies to survive.

Text on key	*Location on dolphin image*	**Text** on arrow	*Location on spearfishing mannequin*	**Text** on arrow
1. Swimming through the water	*Tail*	A powerful tail	*Fins*	Long fins
2. Staying the right way up	*Fins*	Fins on their back and sides help them steer and stay the right way up	*Fins*	They use their fins and arms to adjust their position
3. Finding prey	*Head*	They use echolocation to find prey	*Mask*	A mask lets them see underwater
4. Catching prey	*Teeth*	Lots of sharp teeth to grip slippery prey	*Spear gun*	A sharp spear to stab prey
5. Streamlining the body	*Body*	A smooth body shape	*Wetsuit*	A tight wetsuit
6. Keeping warm	*Body*	Insulating blubber	*Wetsuit*	Water trapped by the wetsuit and warmed by the body
7. Breathing	*Blowhole*	A blowhole on the top of their head	*Snorkel*	A snorkel above their head

8. Staying underwater	*Body*	They change how much breath they hold to adjust how much they float or sink	*Weight belt*	Weights stop them floating up

Scary seas

This fossil is called the 'fish within a fish' - can you see why?

The large fish is a *Xiphactinus* (pronounced ziff-act-in-us), which means 'sword ray'. It died after swallowing a whole *Gillicus* fish. It definitely bit off more than it could chew!

*Xiphactinu*s was one of the largest bony fish of the Cretaceous period, growing up to six metres long and weighing 500 kg. They lived in the shallow waters of North America.

The ancient seas were scary places where almost everyone was a predator. Small fish were eaten by big fish, and big fish were eaten by bigger fish.

Forming fossils

We learn about prehistoric life by studying fossils. Fossils are the remains of dead creatures preserved in rock over millions of years. Only a few animals become fossils after they die. Most are eaten by other animals or quickly rot away.

You need the right conditions and a lot of time to form a fossil:

- The dead creature must be quickly covered by mud, silt or sand.
- Its soft parts often rot away, leaving only the hard bones and teeth.

- Over millennia, the silt or sand slowly turn into rock, preserving the bones and teeth inside.
- Sometimes, minerals completely replace the bones and teeth, forming a rock replica.

Impossible fossil

Reconstruction of the ‘Fish-within-a-fish’ or ‘Impossible fossil’ discovered by George F Sternberg in Kansas, USA, in 1952. Made by John and Tracie Bennitt, Colorado USA.

ICHTHYOSAURS

Ichthyosaur, (pronounced: ick-thee-o-sore) means ‘fish-lizard’. They were the first major group of reptiles to go back to the sea, where they ruled for nearly 150 million years.

Ichthyosaurs were shaped like dolphins with streamlined bodies and powerful tails. This made them the fastest marine reptiles. Some could swim as fast as 40 kilometres per hour.

Ichthyosaurs were great hunters. They had large eyes to see in the dark depths and lots of teeth to snap up slippery prey.

Like dolphins, they breathed air, gave birth to live young and were probably warm-blooded.

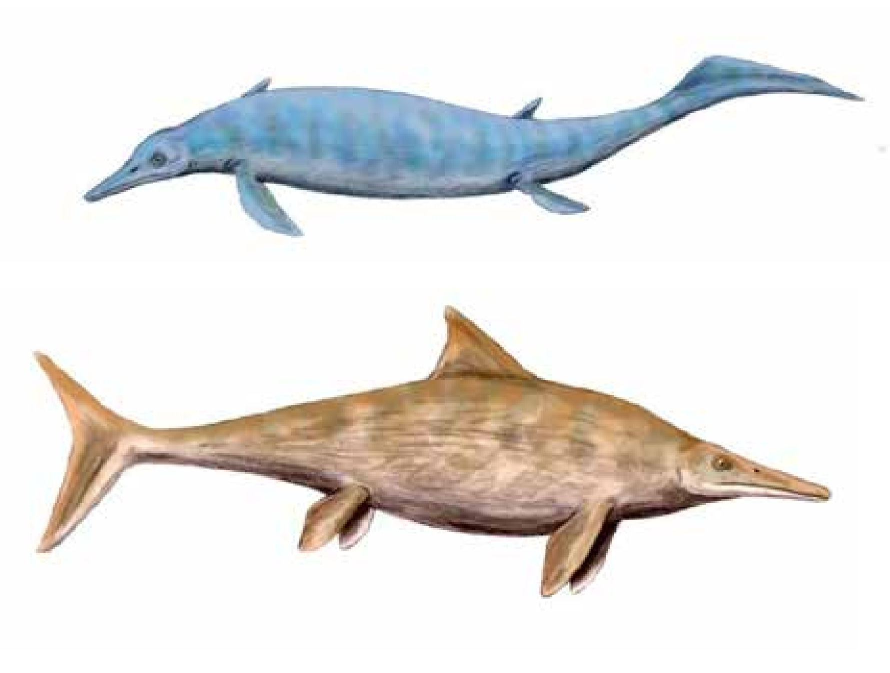
They were discovered by children – Mary Anning was 12 when she and her 15-year-old brother Joseph found the first complete fossil in 1811.

Shape shifters

There have been lots of different shapes and sizes of ichthyosaur. Early versions had long, bendy bodies. Over time they became more streamlined, with compact, rigid bodies and crescent-shaped tails, like tuna and sharks.

They developed more bones in their flippers to stiffen them and used them for steering.

[illustration of early and late ichthyosaur body-shapes]



iBones

Can you see the circle of bones in this ichthyosaur's eye? It's called a sclerotic ring, each bone in the circle is called an ossicle. These bones helped the ichthyosaur's eye keep its shape against the push of water as it swam.

Ichthyosaurs had very large eyes – the biggest were over 26 cm across, as big as dinner plates.

Rather than being ball-shaped like ours, they were almost hemispherical, with curved fronts like half grapefruits.

Heavy head

This is a cast of a *Platypterygius* (pronounced plat-ip-tair-ridge-ee-us) *australis* skull. It was made by Debra Lewis at Queensland Museum from their original specimen, which was found near Hughenden, central Queensland. The real fossil also includes some of the animal's backbone and ribs.

Platypterygius australis lived in the Eromanga Sea that covered much of inland Australia for 30 million years.

Seeing in the dark

Can you see your eyes change?

Use the mirror to look yourself in the eye. How big are your pupils (the black dots in the middle of your eyes)? Do they change size as the light changes?

Like cats' eyes, our eyes adapt to low light by opening the pupils wide to let in more light.

Photo thanks to www.xafiandauri.com

Ichthyosaurs had huge eyes with huge pupils to let in as much light as possible in the dark depths of the ocean. At 500 m down, the ocean looks pitch black to us, but an ichthyosaur would have been able to see moving objects.

Eye opener

Our irises open and close our pupils like the aperture controls on a camera.

Use the levers to open and close the irises.

Terrible teeth

Can you tell what these ichthyosaurs ate by looking at their teeth?

Match the prey with the jaws that evolved to eat it.

(May need an additional line of instructions here when know how it works)

Scientists use the size, shape and wear patterns of teeth to work out what different ichthyosaurs ate and how they caught their prey. They divide them into four groups called guilds:

- The **crush** guild had tough blunt teeth for crushing hard prey like ammonites.
- The **smash** guild had small rounded teeth for smashing soft prey like squid.
- The **pierce** guild had long pointed teeth for trapping and piercing prey like small fish.
- The **cut** guild had large pointed teeth with sharp edges for biting off chunks of large prey like big fish and reptiles.

Preserved poo

These are pieces of fossilised ichthyosaur poo, called coprolites. Scientists study them to learn what ichthyosaurs ate.

Can you see the black specs in the poo? They're the armoured scales from fish like these: **[arrow to fish replica on table top]** So we know these ichthyosaurs ate these fish.

You can get more clues about what ichthyosaurs ate from their size, the shape of their teeth and if any of their last meals have been fossilised in their stomachs.

Early turds

Ichthyosaur coprolites found in Charmouth, Dorset, UK. Luckily their smell wasn't preserved!

Flat fish

Replica of a *Dapedium* (pronounced da-pee-dee-um) fish, made by Craig Chivers. Craig made a silicone mould from the original fossil, cast it in resin and painted it by hand.

Dapedium had small strong teeth to bite through the shells of their prey. The original fossil was found in Lyme Regis, Dorset, UK.

Bags of bones

Count the bones on the X-ray and the fossil.

How many are in a human hand?

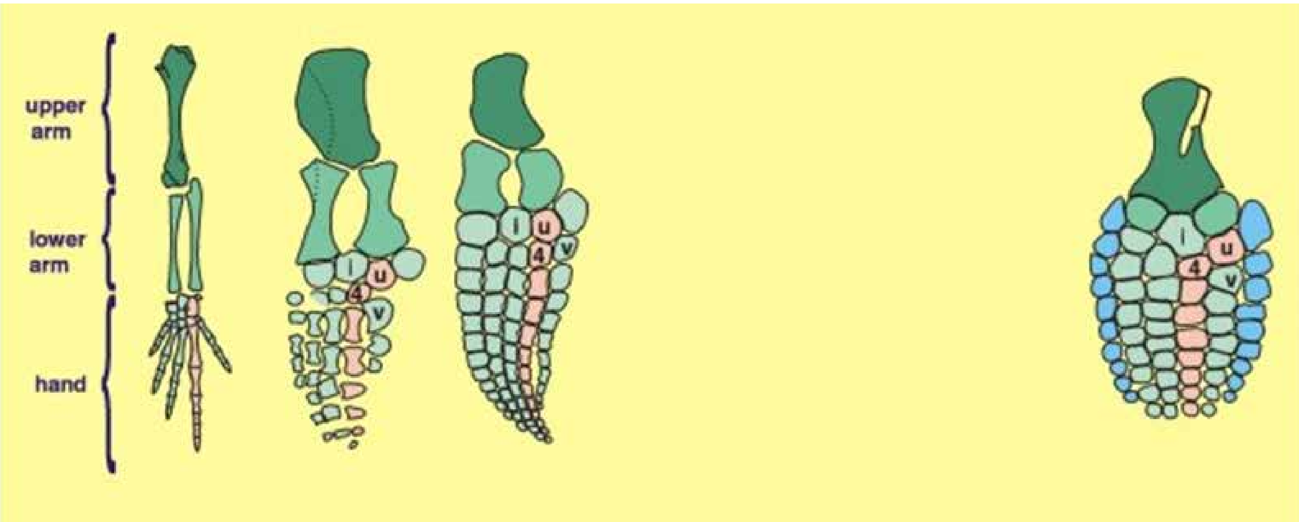
How many are in the ichthyosaur paddle?

Over time ichthyosaurs developed more and more bones in their paddles. This is called hyperphalangy (having lots of finger bones) and hyperdactyly (having more than five fingers or toes). Some had 10 fingers and over 200 finger bones. We only have five fingers and 14 finger bones.

The more bones, the stiffer the paddle, which is better for pushing through water. Think about how you would splash water at someone. Would you lock your fingers together or leave them spread apart?

Fossil fingers

Resin replica of a fossil Jurassic ichthyosaur paddle. The original fossil was found in Somerset, UK. Only the paddle was found, so we can't be sure what species it was.



Over time, ichthyosaur arm bones and finger bones got shorter. They developed more finger bones and, eventually, more fingers.

Bendy backs

Which string bends the most? What is different about it?

The string with the taller beads is less flexible. This is what happened to ichthyosaur backbones as they slowly evolved to become better swimmers.

Early ichthyosaurs had bendy spines and wriggled through the water. They probably relied on ambushing their prey.

Later ichthyosaurs had stiffer spines with bones shaped like plates. Their stiff spines could support crescent-shaped tails and strong muscles. This meant they could swim very quickly and chase down their prey.

Super spine

This beautiful real fossil is part of the backbone from an Australian ichthyosaur *Platypterguis australis*. Found and loaned to us by Tom Hurley at Boulia, Queensland.

Skin and bones

Some incredible ichthyosaur fossils show more than just bones and teeth. They have also preserved soft tissue, skin and blubber.

In this fossil the remains of the soft tissue show us the shape of the animal. You can see the dorsal (or back) fin and dorsal tail fluke. Neither of these have bones in them, so they're usually lost in fossils.

Fossil of a juvenile *Stenopterygius* (pronounced sten-op-terry-gee-us) *quadriscissus* from the Early Jurassic of Ohmden, Southern Germany. Its name means 'narrow wing' because it had thin fins. Photographed by Mike Eklund. You can see the real fossil at the Stuttgart State Museum of Natural History, Germany.

From these fossils we discovered ichthyosaurs had smooth skin like dolphins, not scaly skin like lizards. This helped them swim more efficiently.

Most were coloured like sharks – dark on top and pale underneath, which helped them blend in from above and below.

They had blubber, which helped them keep warm. It may mean they were warm blooded.

Kinky tail

When ichthyosaur fossils were first found, scientists thought their tails had been broken until they realised they all had these downward kinks. Specimens like this one, showing soft tissue, confirmed the bones just supported the bottom part of the tail; the top was cartilage. Some shark spines kink the other way into the tops of their tails.

Big bash bodies

Ichthyosaurs were the biggest and some of the smallest marine reptiles. grew up to 21 metres long – a bit longer than a cricket pitch. *Mixosaurus* was only as big as a cricket bat – about one metre long.

Here you can see the relative sizes of some of the ichthyosaurs you'll meet today.

[labels under images]

- *Shonisaurus sikanniensis* 21 m
- *Platypterygius australis* 7 m
- *Stenopterygius quadriscissus* 3 m
- *Mixosaurus* 1 m

Minnee Model

This is a model of Minnee, a baby ichthyosaur found in Queensland in 2011.

It was made by Paul Stumkat, a palaeontologist and artist, who also excavated Minnee's fossil.

Sadly Minnee's snout was sticking up bit and was accidentally destroyed by the excavation machine, so two thirds of it is missing.

Minnee is an ichthyosaur called *Platypterygius* (pronounced plat-ip-tair-ridge-ee-us) *australis* and is one of the most complete ichthyosaur fossils ever found in Australia.

Platypterygius means 'flat fin'. The first fossils were found in 1865 on a station in outback Queensland. Since then, they've also been found in the Northern Territory, South Australia and New South Wales.

Minnee had 200 teeth, so Paul had a fiddly few days attaching them all.

Paul installing teeth
Photos: Paul Stumkat

Paul making Minnee.

Minnee's jaws have grooves in them that may have held electro-sensory organs, like sharks use to detect prey. This would have been useful as research on their ear bones suggests these ichthyosaurs were deaf.

Eating underwater

Why did these ichthyosaurs need so many teeth?

It's hard to eat underwater. As you swim forward, water pushes your prey away. And when you try to bite down on something, your closing jaws push water out of your mouth, which carries your meal away with it.

Having a lot of sharp teeth helps. You can grip your prey so it isn't carried off by the moving water.

Ancient antique

This fossil of an ichthyosaur snout was collected in 1880. It's one of the earliest in the Queensland Museum's collection. It's from a *Platypterygius australis*, like Minnee.

Queensland Museum has over 52,000 fossils, including the largest collection of marine reptile fossils in Australia.

Shark supper

This is a resin cast of the jaw of a *Temnodontosaur* (pronounced tem-no-dont-o-saur), which means 'cutting tooth lizard'. You can probably guess how it got its name.

Look closely. Can you spot the fin spine from a shark trapped between the teeth? This could have been the ichthyosaur's last meal.

[*may need to add arrow to point to the spine*]

The original fossil was found in Lyme Regis, UK. Craig Chivers made the cast after using acid to extract the fossil from its rock nodule.

Huge head

This skull is reconstructed from a fossil at the Royal Tyrrell Museum, Alberta, Canada.

It's a *Shonisaurus* (pronounced show-nee-sore-us), the world's largest marine reptile. The 21-metre-long fossil was painstakingly extracted from a remote river bank in British Columbia, Canada, by palaeontologist Dr Elizabeth Nicholls. It took over four years to recover the 'Triassic giant' and was one of the most ambitious fossil excavations ever.

The replica was created by Dinosaur Valley Studios using laser scanners and sculpting software. They scanned the original flattened bones, then 'reinflated' them back into a three-dimensional shape with guidance from Dr Makato Manabe.

[Dr Don Brinkman with the flattened Shonisaurus. ©Royal Tyrrell Museum]

[Dr Elizabeth Nicholls removing the fossil from the riverbank. ©Royal Tyrrell Museum]

Toothless titan

This ichthyosaur sucked!

See how it doesn't have any teeth? Bones in their throats suggest they had powerful tongues, which they may have used to create suction to draw prey into their huge mouths.

Today's largest sharks (called whale sharks) have tiny teeth and only eat plankton. The largest ichthyosaurs also ate some of the smallest creatures, like tiny fish and squid.

Juvenile *Shonisauruses* had some teeth but, once the animals grew big enough, they didn't need them.

Life and death

Can you see the baby ichthyosaur coming out of its mother? There are also the tiny bones of its three siblings still inside.

Fossils like this prove ichthyosaurs gave birth to live young, rather than laying eggs like most reptiles today. It's a key adaptation to living in the sea, as ichthyosaurs couldn't crawl back onto land to lay eggs.

Like dolphins, baby ichthyosaurs were born tail-first. This means as soon as their heads come out they're free to swim up to the surface and take their first breath.

Printed parent

This is a replica fossil of a mother *Stenopterygius* (pronounced sten-op-terry-gee-us) *quadriscissus*, who died during or just before giving birth. (The baby may have been pushed out by gases after the mother died). It was reproduced using photogrammetry and 3D printing. You can see the real fossil at the Stuttgart State Museum of Natural History, Germany.

Heinrich photographing the fossil in Germany.

Photo-copy

This is a copy of a fossil that's thousands of kilometres away in a museum in Germany.

In the past, to make a copy, we'd have taken the original off display, made a mould, cast it in resin, painted it and then shipped the panel to Australia – a lot of work, and risks damaging the original fossil.

New technology means we didn't have to do this. Instead, Heinrich Mallison, an expert on photogrammetry, took hundreds of very high quality photographs of the fossil. He then used a computer program to stitch them all together into a 3D file. He sent the file to us in Australia, where we had it 3D printed in colour to create this copy.

Water birth

Like ichthyosaurs, dolphins give birth to their babies tail first. Most humans are born head first.

This film shows Katrl, a 28-year-old Pacific white-sided dolphin giving birth to her calf at the John G Shedd Aquarium, Chicago USA. It was filmed by videographer Sam Cejtin.

The film runs for 1 minute.

PLESIOSAURS

Plesiosaur, (pronounced: plea-zee-o-sore) means ‘near-lizard’, as scientists felt they were more lizard-like than the ichthyosaurs or ‘fish-lizards’.

All plesiosaurs had short tails, long flippers and flattened bodies. But they came in two different versions at the head-end – either small heads on long necks, or big heads on short necks.

They evolved after the ichthyosaurs, lived with them for about 100 million years, then out-lasted them to share the oceans with the mosasaurs.

Plesiosaurs spread across the whole world. Their fossils have been found on every continent, including Antarctica.

Spin and swim

Spin the drum and look through the slots.

Notice how each group of marine reptiles developed a different way of swimming. Do they remind you of any modern animals?

Swimming styles

The three main groups of marine reptiles developed very different ways of swimming.

Ichthyosaurs swam like tuna – quickly flipping their tails from side to side.

Plesiosaurs were ocean fliers – flapping their flippers like birds’ wings.

Mosasaurs swam like crocodiles – swinging their long tails back and forth.

Backwards and bendy

An American palaeontologist called Edward Cope wrote the first description of these creatures in 1868, based on fossils found in Kansas. He said **they had short necks and long tails** – he had built it backwards, putting its head on its tail!

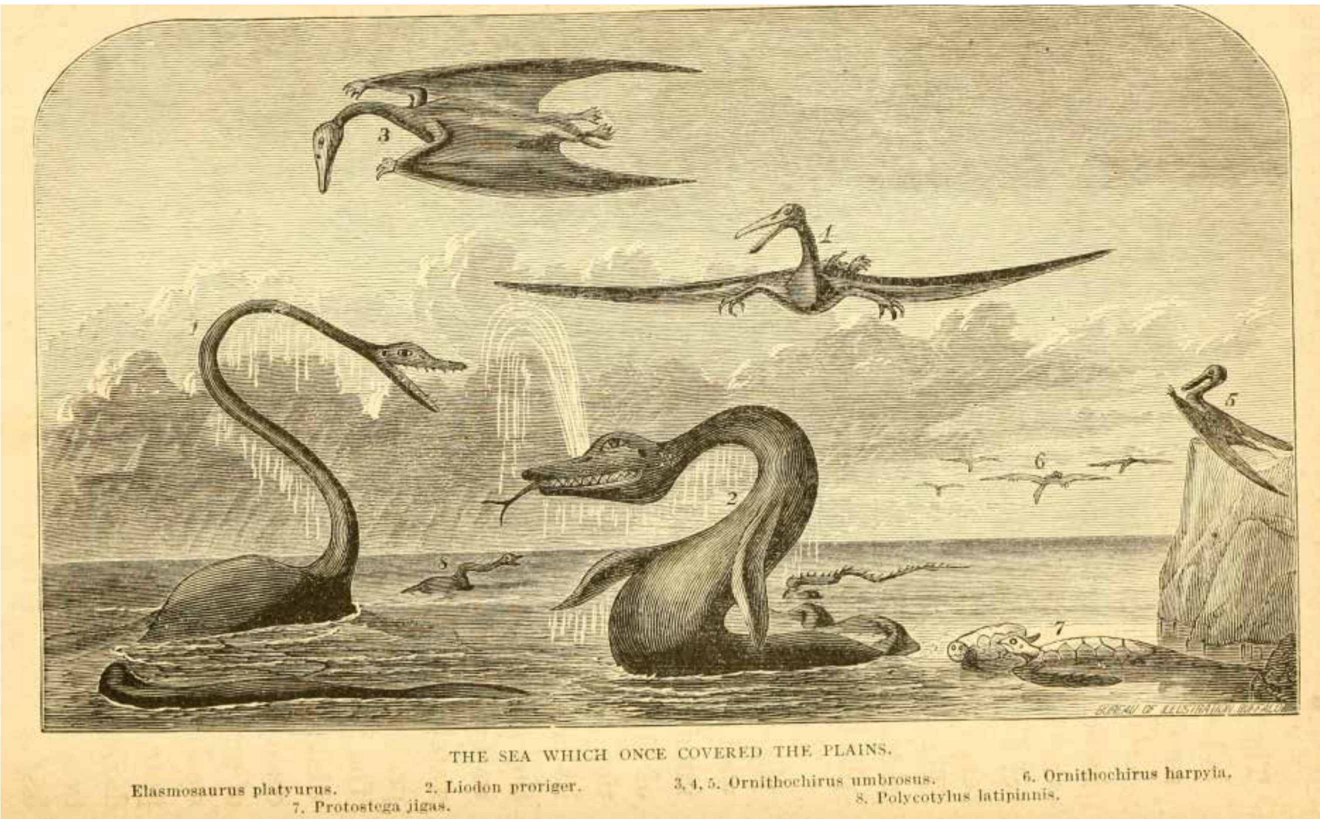
When he realised his mistake, he was very embarrassed and tried to

recall as many copies of his paper as possible, but was never allowed to forget his error.

[cartoon of plesiosaur with head on wrong end thinking 'I don't feel right']]

People used to think their long necks were bendy, like a swan's, and could be lifted high out of the water. But studying their spines shows their neck bones were locked together to keep them straight. They couldn't bend them very far at all.

The long necks might have made them stealth hunters. They could keep their large bodies out of sight so they could sneak up on schools of fish or squid, without alarming them.



Early pictures of long-necked plesiosaurs showed them as much bendier. Etching from the book '*Buffalo land*' by William Webb, 1872.

How many bones can you count in this Thalassomedon's neck?

[*it's 63!*]

The plesiosaur Albertonectes had 72 neck bones – more than any other animal. We have only seven.

Long-necked lord

This huge creature is a *Thalassomedon* (pronounced thal-ass-oh-mee-don), which means 'lord of the seas'. As you can probably tell, it's a long-

necked plesiosaur. It’s 13 metres long.

This is a cast of a fossil found in 1939 in Colorado, USA. It was assembled and painted by Gondwana Studios in Launceston, Tasmania. The original is in the Denver Museum of Nature and Science.

Crushed and killed

This Eromangasaurus (pronounced: eh-ro-manga-sore-us) skull reveals a violent death. It’s been crushed and has tooth marks, showing it was probably attacked and killed by a Kronosaurus.

Eromangasaurus was a long-necked plesiosaur named after its home, the Eromanga sea, which covered ancient Australia. Based on similar animals, we think they probably grew to about 9–10 metres long, but so far we have only found this skull.

Palaeontologists often have very few or even just single fossils of particular species to study. New finds of rare specimens are very exciting and can add a lot to our knowledge. Hopefully we’ll find some more Eromangasaurus fossils soon.

Cast copy

This is a replica of a skull from Queensland Museum. It was made by their Senior Technical Officer Debra Lewis. The original fossil was found in the 1970s in Maxwelton, Queensland.

Challenging behaviour

It can be hard to learn about the behaviours of extinct animals. Scientists use all sorts of clues to work out how these animals may have reproduced and cared for their young.

Big baby

With their huge flippers, massive bodies and giant heads or necks, plesiosaurs wouldn’t have been able to get out of the sea to lay eggs on land. They must have given birth to live young in the water. This was confirmed by the discovery of pregnant plesiosaur fossils.

LEFT: Fossil of pregnant plesiosaur from Natural History Museum of Los Angeles

RIGHT: Artist Stephanie Abramowicz's reconstruction of a plesiosaur birth. ©Natural History Museum of Los Angeles

Unlike ichthyosaurs, which had up to eleven babies at once, plesiosaurs only had one at a time. The babies were an incredible 40 per cent of the size of their mothers when they were born. That's like a human giving birth to a six-year-old child!

Many modern animals such as whales, seals and humans that give birth to single large babies, care for them for a long time after birth. So plesiosaurs were probably caring mothers that invested a lot of time and energy into their young. By studying their bones, scientists found that plesiosaur babies grew very quickly inside their mothers. This takes a lot of energy and may mean they were warm blooded.

Family gathering

Many modern animals that have single babies that they take care of for years, like seals and dolphins, live in social groups of extended family. Plesiosaurs may have done the same. Lots of juvenile plesiosaur fossils have been found in South Australia, so it may have been a breeding ground where plesiosaur mothers gathered to give birth.

Which begs the question – what do you call a group of plesiosaurs?

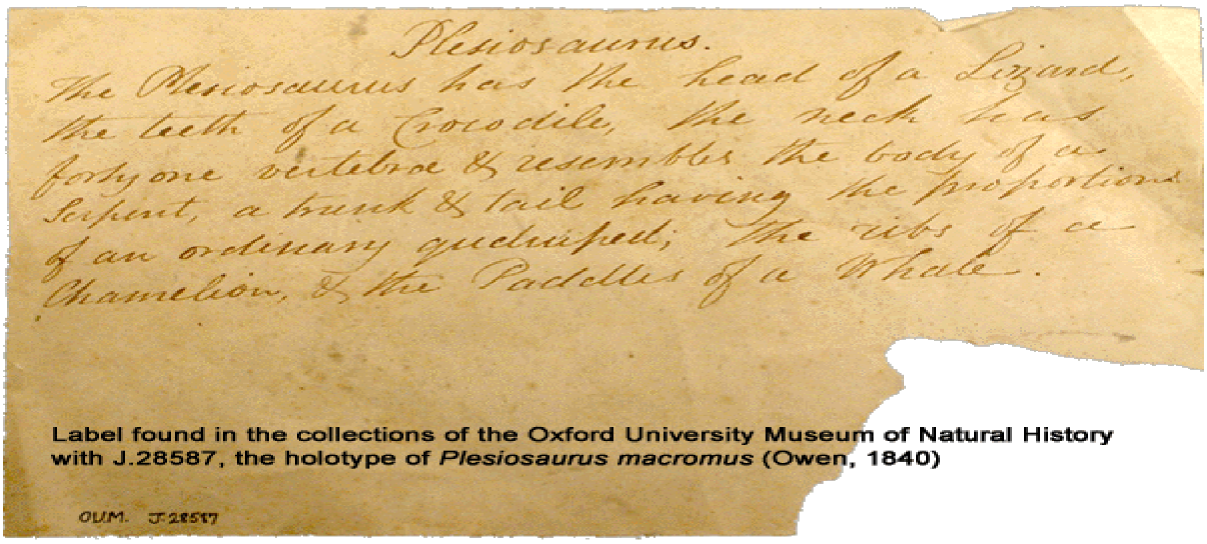
[cartoon – group of young plesiosaurs being supervised in a 'cretaceous crèche']

Funny-looking fossils

It was the discovery of plesiosaur fossils in the 1820s that started people thinking about evolution. Previous discoveries of ichthyosaurs, as they're similar to dolphins and tuna, didn't challenge too many beliefs. But plesiosaurs are so unlike any modern animals, they took some explaining.

This label from 1840 found in the Oxford University Museum of Natural History shows one scientist described them as having:

'... the head of a lizard, the teeth of a crocodile, the neck ... resembles ... a serpent ... the ribs of a chameleon and the paddles of a whale.'



Copy of an original hand-written label about a plesiosaur by Richard Owen (who also coined the term 'dinosaur'). Thanks to the Oxford University Museum of Natural History.

Killer kiwi

This is a cast of a plesiosaur skull from New Zealand – the only adult skull found there. It's from a *Tuarangisaurus*, named for the Maori word 'tuarani' meaning ancient. It grew to about 8 metres long. The original fossil was collected by Joan Wiffen in Hawke's Bay, NZ. This replica was made by Bootleg Design in Auckland.

Cyber-sculp ting

Ross Gibbs made these models in virtual reality (VR).

He loaded pictures of the creatures into the sculpting program to refer to. Then put on a VR headset and used touch controllers in both hands to sculpt and carve models in cyberspace

As the models developed, he showed them to Dr Espen Knutsen, a palaeontologist, to check they were correct. Once they were ready, Ross 3D printed them in sections, assembled them like a model kit and painted them. He chose colours and patterns based on modern marine reptiles like sea snakes.

Ross with his VR tools

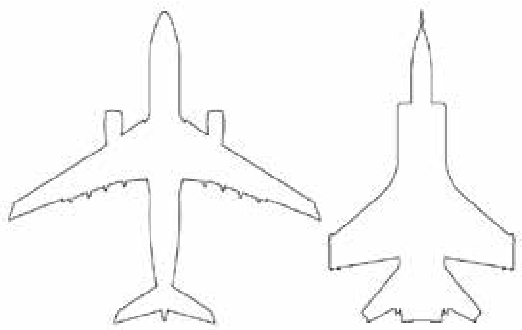
Sculpture on screen

3D printed *Kronosaurus* being assembled

Flipper flights

Long-necked and short-necked plesiosaurs had different shaped flippers. Long-necked plesiosaurs generally had long, thin flippers. Short-necked ones had shorter flippers.

You can think of them as a bit like aeroplanes. Slide the panel to see why.



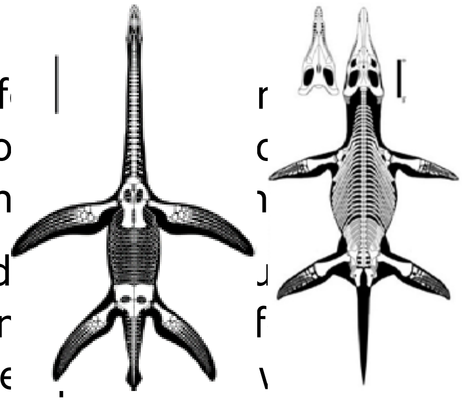
outlines of planes on clear acrliyc can be slid over the top of plesiosaur illustrations

Passenger planes have long thin wings. They're built to travel long

distances. But long wings mean they can't turn quickly. Fighter jets have short wings and can turn very quickly.

Perhaps long-necked plesiosaurs swam long distances, looking for prey to sneak up on, while short-necked plesiosaurs manoeuvred quickly to chase down their prey.

Ocean fliers



Plesiosaurs swam by flapping all f[illegible] r[illegible] ke flippers. No other creature has ever develo[illegible] g. Turtles and penguins swim by flapping, but th[illegible] nbs.

Scientists worked this out by stud[illegible] , especially the structure of their shoulders ar[illegible] f[illegible] plesiosaurs had powerful muscles to move the[illegible] ut they wouldn't have been able to move them very far backwards or forwards. So they must have flapped through the water, rather than rowed.

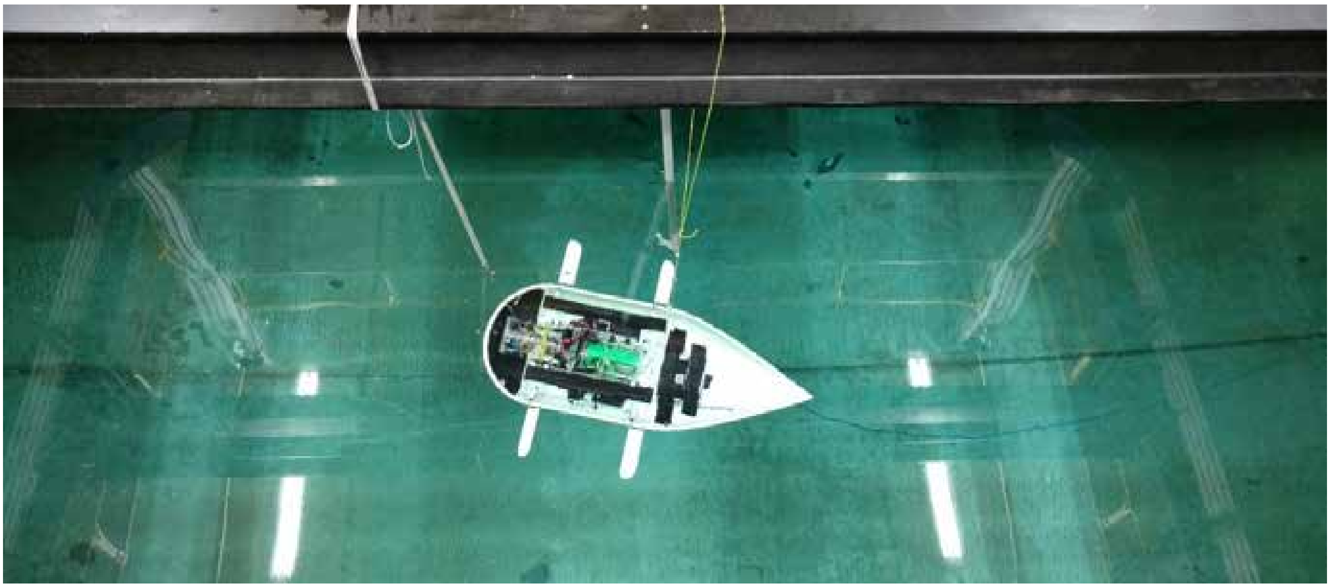
Research using flow tanks and computer modelling has given us more clues about their swimming style.

Printed paddles

3D printed paddles made by Dr Luke Muscutt at Southampton University, UK.

Luke designed them by studying plesiosaur fossils, which he noticed were tear-drop-shaped in cross-section, like aeroplane wings. He mounted the 3D paddles in a tank of flowing water, then ran coloured dye from the tiny holes along the front edges to show the movement of water across them and the turbulence they create.

He tested different flapping patterns to see which worked best. He discovered that the back flippers supply more power than the front ones.



Testing *Atlantis*. Photo from Prof Gabe Weymouth, University of Southampton

Robo plesio

Scientists at Southampton University used 3D printed paddles in flow tanks to find out more about how plesiosaurs swam.

They learnt the best way to swim with four paddles is to push the front pair down first, then start flapping the back ones a fraction later. This proved to be very efficient. They built an underwater robot with four paddles they called *Atlantis*. The swimming method proved so effective it didn't need very big paddles. It's also very manoeuvrable.

New underwater vehicles based on this biologically inspired engineering could be very useful. Current ones are either torpedo-shaped or box-shaped. Torpedo-shapes are good for going in straight lines, covering large distances to collect samples. Box-shaped ones are more

manoeuvrable, but are tethered to the surface for power, and hard to control in strong currents. Robots like *Atlantis* could soon be exploring our oceans, like the plesiosaurs that inspired them.

Gravel guts

Many plesiosaur fossils have stones in their stomachs. These are called gastroliths. They are stones plesiosaurs may have swallowed to make themselves heavier and help them stay underwater, like weight belts used by scuba divers. Crocodiles also swallow stones to help them sink. Alternatively, the stones may have helped them digest hard-shelled prey.

These stones also give clues about where the plesiosaur has been, based on what type of rock they are.

Paleo diet

This fossil is part of a marine reptile, probably a plesiosaur, that swallowed lots of small stones. It was found near Hughenden, central Queensland, and is on loan from Queensland Museum.

Hard to swallow

Feel this rock. Can you imagine swallowing it? Would it make you feel heavy?

Some plesiosaurs swallowed rocks this big, but most went for smaller mouthfuls.

Printed Percy

This is a 3D print of a long-necked plesiosaur nicknamed ‘Percy’. Percy is being studied by Queensland Museum palaeontologist Dr Espen Knutsen. 3D printing technology allows palaeontologists to study fossils anywhere in the world without moving or damaging them.

Percy is one of the more complete long-necked plesiosaurs found in Australia. Prior to its discovery, only fragments of creatures had been found. It’s missing its head, but it would have been about eight metres long.

Percy was found by accident near Boulia, Queensland, when palaeontologist ‘Dinosaur’ Dick Suter rolled his ankle on a hidden rock

as he stepped out of his car. The rock was one of Percy's neck bones.

Percy with finders Dick Suter (sitting) and Tom and Sharon Hurley. Photo from Boulia Shire Council

Percy plus

Percy has a namesake: a plesiosaur found by geology students on a beach in Yorkshire, England, has also been called Percy. It's now on display at the Manchester Museum.

Boulia's bones

Last year Queensland Museum Palaeontologist Dr Espen Knutsen travelled to Plesiosaur Percy's home in Boulia, western Queensland. He hunted for fossils and talked to local school children about 'their' sea monster and other discoveries.

Film runs for 1½ minutes.

Kid cruncher

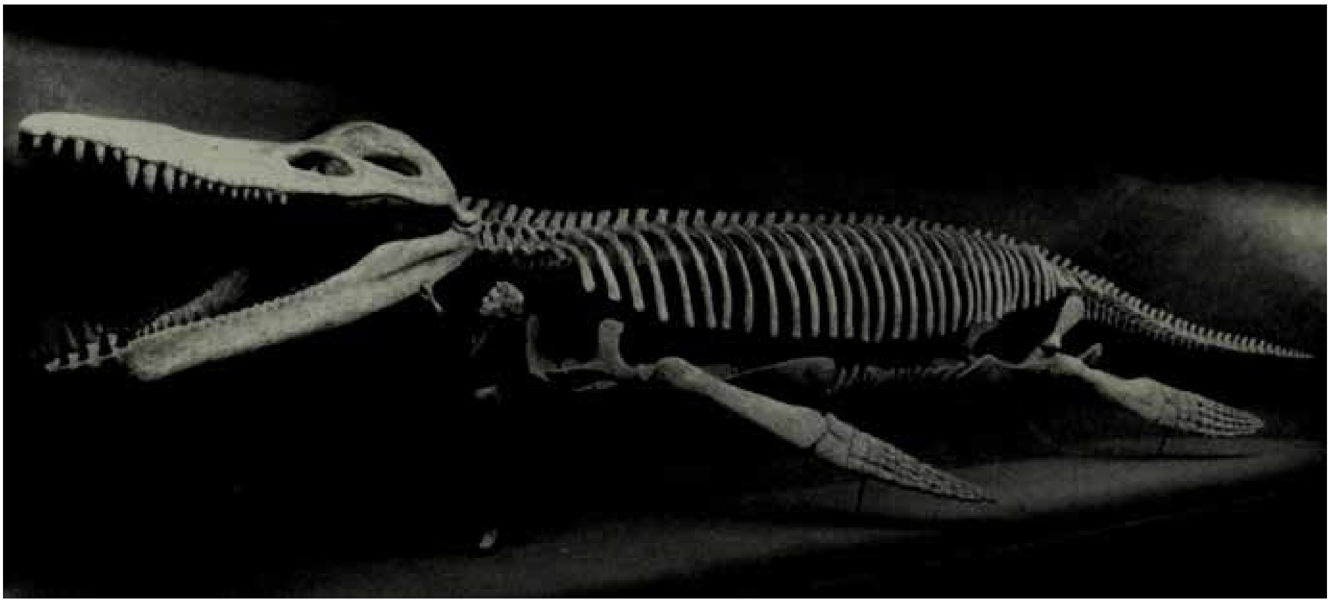
Kronosaurus (pronounced crow-no-sore-us) *queenslandicus* is named after the Greek Titan Kronos, who ate his own children. It was a fierce predator who ate other marine reptiles and is only found in Australia.

[Gabriel's illustration]

They grew up to 10-metres long, with huge two-metre long skulls and massive, powerful jaws.

The most complete fossil was found in 1932 on an outback property near Hughenden, Queensland. Its discoverers took it to America, where it's on display at the Harvard University Museum of Comparative Zoology.

One third of this Harvard display is made from plaster, leading to its nickname 'Plastersaurus'. They also added too many vertebrae to its spine, so it's over a metre longer than it should be.



Assistant Nelda Wright admiring the Harvard Kronosaurus in a photograph from the MCZ Annual Report 1957–1958. Thanks to the Ernst Mayr Library of the Museum of Comparative Zoology.

Krono nose

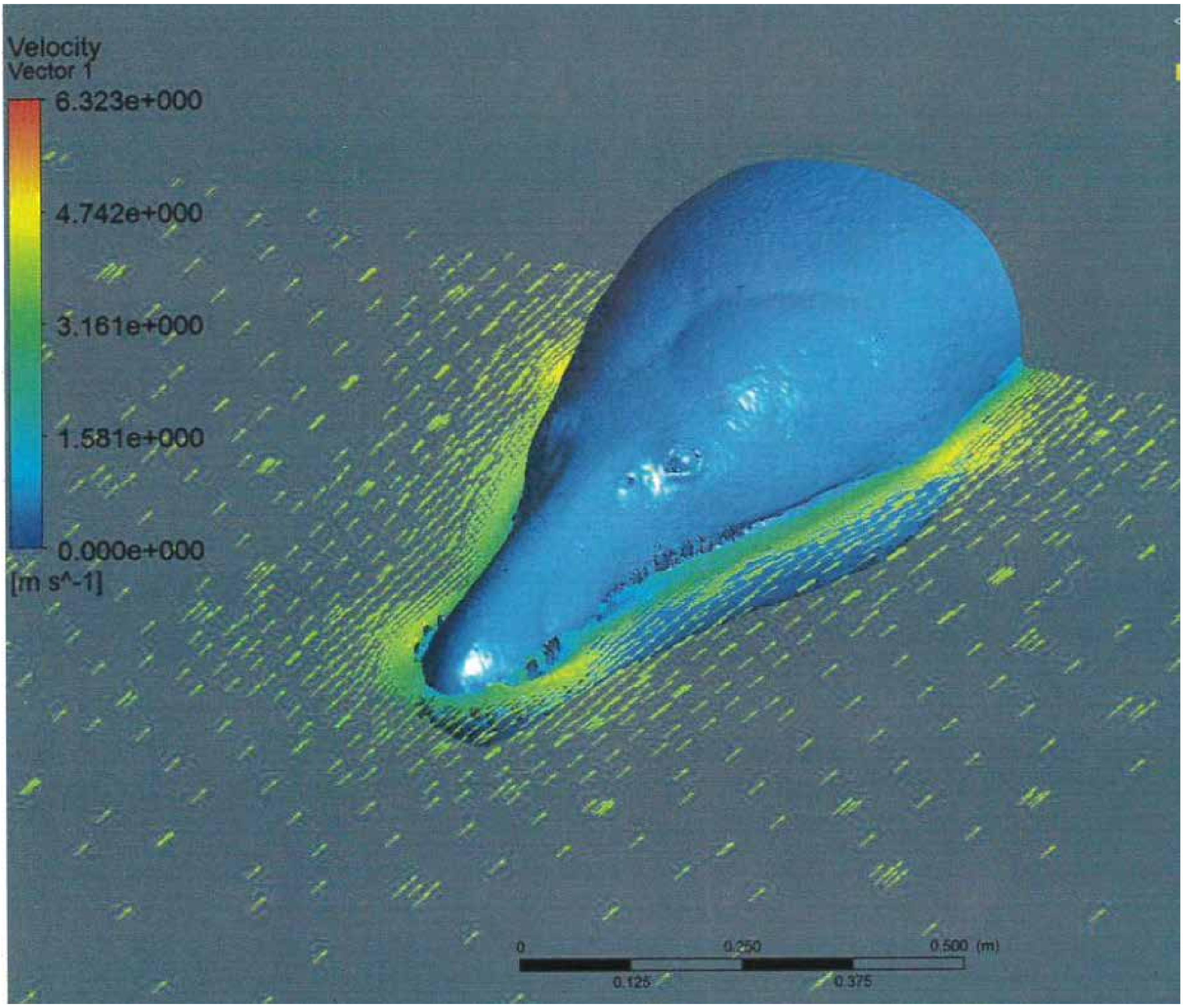
This cast of a Kronosaurus's snout is from a fossil found in Richmond, Queensland. It's on loan from the Kronosaurus Korner museum in Richmond.

Head for figures

This is a scale model of a *Kronosaurus* head. It would have been three times bigger in real life!

Ben Thomas from the University of Newcastle used it to study how *Kronosaurus* was shaped to move through the water. He scanned it to create a 3D computer model, which he used in experiments that compared *Kronosaurus* to other species of plesiosaur and living crocodiles.

His results showed that the head of Kronosaurus was more streamlined than the head of living crocodiles.



Ben's computer model showing water flow around the model at 4m/s

Shrunken head

Model of a *Kronosaurus* head (a third of its actual size) made by Paul Stumkat, palaeontologist and artist. On loan from the University of Newcastle.

Sneaky necks

Sticking their necks out so their bodies don't, plesiosaurs may have had long necks so they could sneak up on schools of fish without frightening them with their large bodies.

Car crusher

A Kronosaurus could have eaten anything it came across. They've been found with the remains of other plesiosaurs in their stomachs. And plesiosaur skulls have been found with Kronosaurus bite marks on them.

Colin McHenry from the University of Newcastle studied Kronosaurus jaws and compared them to other animals'. He calculated that Kronosaurus had a bite force of 30,000 Newtons. That's three tons of crushing power – more powerful than a saltwater crocodile and more than enough to crush a car!

It wouldn't have taken that much force to crush other creatures. But the power would have been useful to snap shut its massive jaws against the resistance of water.

[cartoon of Kronosaurus crushing a car thinking 'I need more iron in my diet']

Jaw dropping

This real fossil is part of the lower jaw of a Kronosaurus. It was found by a private collector near Boulia in central Queensland and is now owned by Queensland Museum.

The teeth have been 3D printed to show how they would have looked. As part of the jaw bone is missing, the teeth are on clear plastic rods to show where they would have sat.

The teeth were 3D modelled by Queensland Museum's Senior Curator of Geosciences Dr Scott Hocknull and painted by Senior Technical Officer Debra Lewis.

Best in show

Meet the Richmond Polycotylid (pronounced polly-cot-eye-lid) – the most complete and best-preserved Australian plesiosaur specimen found so far. It's only missing a few tiny bones from the tips of its flippers, which may have been taken by scavengers.

It was found in 1990 during a cattle muster on a property near Richmond in northwest Queensland. It lived in Australia's ancient inland Eromanga sea, 100 million years ago, eating fish and turtles.

Healed injuries on its neck and back flipper show it survived some

battles, and it may have been quite old when it died as it had some osteoarthritis in its spine.

It has yet to get its official scientific name, but palaeontologist Dr Ben Kear hopes to announce it soon.

What would you call it?

Digging for days

World-class specimens like this take a lot of painstaking work to recover. It took two people over two years full-time to free its fragile bones from the rock.

Dr Mary Wade, palaeontologist and curator of geology at Queensland Museum loved fossil hunting in outback Queensland. As well as the Richmond Polycotylid, she also excavated dinosaur footprints at Lark Quarry and Kronosaurus fossils.

Mary Wade (left) and Cathy Mobbs uncovering the polycotylid. © Cathy Mobbs, Queensland Museum.

Name game

When scientists find a new species, they give it a scientific name. They're often named after where they were found or how they look. All names must be unique; they can't be rude and it's considered tacky to name things after yourself.

The names are translated into Latin but can still be fun. There's a mushroom called *Spongiforma squarepantsii*.

- Make a name for yourself:
- Spin the blocks to pick two English words.
- Lift the flap to see the scientific name you created.

Left-hand drum	
Visible text	**Hidden text**
Silvery	Argentea
Fat	Crassa
Jagged	Erosa
Giant	Giganteus
Common	Vulgaris
Smelly	Foetidus

Right-hand drum	
Hidden text	**Visible text**
saurus	Lizard
venator	Hunter
therium	Beast
ophis	Serpent
gnathus	Jaw
stomus	Mouth

Penny the plesiosaur

We borrowed this cast of the Richmond Polycotylid nicknamed 'Penny' from Kronosaurus Korner in Richmond, Queensland.

MOSASAURS

After the ichthyosaurs and plesiosaurs came the mosasaurs (pronounced mow-sa-sores). Mosasaurs were powerful swimmers with goanna-like bodies, long snouts and forked tongues. Their paddles were formed from soft tissue covering their long finger bones. They used them for steering as their tails pushed them through the water. Unlike ichthyosaurs and plesiosaurs, they kept their scaly skin.

Mosasaurs ate anything: ammonites, fish, turtles, plesiosaurs, mosasaurs and even sea birds. The only thing a mosasaur had to fear was a bigger mosasaur. Mosasaur skulls with bite marks from other mosasaurs suggest they might have fought each other for food, territory or mates.

Native Americans found mosasaur fossils in mid-western USA. They may have thought they were the remains of *Unktehila*, mythological water monsters.

Sauring to the top

Mosasaurs arrived five million years after the ichthyosaurs died out and soon replaced plesiosaurs at the top of the food chain. Their fossils show a steady sequence of changes as they evolved from small lizards living on the water's edge to the oceans' top predators.

Some reached enormous sizes; others lurked in the shallows ready to ambush whatever came by. Some developed heavy rounded teeth to crush the thick shells of their prey.

Mosasaurs dominated the world's oceans and inland seas for 30 million years until they went extinct, along with the plesiosaurs, at the end of the Cretaceous period. This extinction marked the end of the era when reptiles ruled the seas.

There are lots of fossils to help us understand how mosasaurs adapted to live in the sea.

Salty sneezes

If you live in the sea and eat seafood, you're going to absorb a lot of salt – more salt than your body can handle.

Many marine animals have developed salt glands, which help them get rid of excess salt. Sharks' salt glands are in their bottoms; but marine reptiles have them on their heads.

Turtles' glands are near their eyes so they cry very salty tears.

Marine iguanas' are in their noses so they do salty sneezes.

We don't know how all extinct marine reptiles dealt with excess salt. Some ichthyosaurs and nothosaurs (primitive relatives of plesiosaurs) appear to have had salt glands just in front of their eyes.

Push the button for another suggestion.

Reticulated pythons are the longest snakes in the world. They're native to South-East Asia. Photo from National Zoo and Aquarium, Canberra

Building a bulldog

This fearsome skeleton is the cast of a nine-metre *Prognathodon* (pronounced: prog-nath-o-don), a type of mosasaur. Its name means 'fore-jaw tooth'.

Prognathodons had strong, heavy jaws and blunt skulls, so are nicknamed the 'bulldogs' of the mosasaurs. But while their skulls were tough, the rest of their body was quite delicate. If they had lived on land, their spines would not have been strong enough to support their heads.

This is a cast of a fossil found in Colorado, USA. The original is in Brigham Young University in Utah.

It was assembled and painted by Gondwana Studios in Launceston, Tasmania.

It arrived in Launceston as individual resin bones, which had to be assembled like a giant jigsaw puzzle and mounted on a specially designed metal frame. The frame holds all the bits together and supports them in this life-like pose. Each replica bone had to be painted to look like the real thing.

Bro-sasaurs?

Eighty million years ago, five types of mosasaur swam in New Zealand waters, including *Tylosaurus* – the *T. rex* of the sea. We know about them thanks to Joan Wiffen – the 'dragon lady', a self-taught palaeontologist who found the first ever New Zealand dinosaurs in 1975.

Joan hunted and researched for more than 35 years, discovering many plesiosaurs and mosasaurs, as well as dinosaurs. She said: 'holding these ancient bones in my hands ... has enabled me to reach back in time, to touch the past'.

Joan Wiffen in 1983 holding the upper arm bone from a plesiosaur she found in Hawkes Bay. Photo from Wendy St George, GNS Science

Kiwi cast

Resin cast of a *Prognathodon* skull, found at Hawke's Bay, North Island, New Zealand, by Joan Wiffen.

The cast was made by Bootleg Design of Auckland.

Jaw mould ready for resin. Photo from Gareth Pugh, Bootleg Design.

Similar serpent

This is a replica skull from a modern reticulated python. (It's upside-down so you can see inside). It has some things in common with mosasaurs. Look closely. Can you see:

- the extra teeth in the roof of its mouth?
- the breaks part-way along its jaws?
- these same features on the mosasaur skulls?

Mosasaurs and most modern snakes have extra teeth in the roofs of their mouths to help grip their prey and stop it escaping. They're called pterygoid teeth. They're useful if you don't have claws to grab things with, or if your prey is slippery.

Snakes also have flexible jaws that can expand to help them swallow things bigger than their heads. You can see the hinge points on the lower jaw.

Stretchy skull

Try this to show how flexible lower jaws would help you swallow big prey.

1. Hold your arms out straight in front of you, with your fingers interlaced, and your elbows locked.
2. Imagine this is a lower jaw; it can swallow things as big as the gap between your elbows.
3. Now keep your fingers interlaced but bend your elbows outwards.
4. Your lower 'jaw' is now wider so you can swallow bigger prey.

Mosasaurs could stretch their mouths to swallow large prey such as turtles.

Python dinnertime. Large reticulated pythons have even eaten humans. Photo from Dan Fryer, www.reticulatedpython.info

Sound skulls

Mosasaur skulls reveal they had special adaptations for hearing underwater.

We have flexible ear drums which don't work very well underwater. Things sound funny when we're swimming or dunking our heads in the bath.

Mosasaurs had cone-shaped bones instead of ear drums. Bones are great at transmitting underwater sounds. Today's whales have similar structures in their ears. Maybe mosasaurs sang like whales, too, for long-distance communication.

[cartoon: dig site with mosasaur fossil skull wearing headphones. Palaeontologist uncovering it says 'it was listening to hard rock']

Head banging

Mosasaurs heard through bone conduction. We can use this method too. Some headphones, like these ones, transmit sound to the bones of your skull rather than your ear drums. See how their speakers are not covering the ears?

This keeps your ears free to listen for sounds, like traffic or warnings.

Hear here

Try hearing through your bones.

- B tapping louder?

The first time the sound was travelling through the air to your ear. The second time it was traveling through the bones of your arm, hand and skull.

'*T. rex* of the sea'

This is a replica tooth from a *Tylosaurus* (pronounced: tie-low-sore-us), the most well-known mosasaur since its starring role in the *Jurassic World* movie. It's known as the '*T. rex* of the sea' as it was also a fierce top predator. That's a cooler name that its real one – Tylosaurus means 'knob lizard'!

It gets its name from the lump of bone extending from the front of its jaw, similar to ones in modern killer whales. The whales' lumps protect their front teeth when they ram their prey. Tylosaurus might have hunted the same way, slamming into its prey from below, knocking them senseless so they could be devoured.

This would work well against other marine reptiles while they're at the surface breathing. Young Tylosaurs didn't have these bony lumps. Perhaps they didn't grow them until they were big enough to successfully ram prey.

Tylosaurus grew to a massive 15-metres long and even ate dinosaurs! Well, a Hadrosaur fossil was found with Tylosaur bite marks. The carcass had probably washed out to sea, providing a scavenged snack for a Tylosaurus.

T.rex on shore next to carcass looking at a Tylosaurus in the sea next to carcass thinking 'He's nothing like me']

Ripping ridges

Teeth from different marine reptile species can look quite different, but most have one thing in common – they have lines running up and down them, called apicobasal ridges.

Australian Museum palaeontologist Dr Matthew McCurry has researched the teeth of lots of ocean predators, both extinct and modern species. He found most of them have these ridges on their teeth; but the vast majority of land-based predators do not. The ridges make the teeth better at puncturing prey, which is useful for catching slippery fish underwater.

Teeth ridges may also make it easier for food to be removed from the teeth and swallowed. Prey can get stuck on predators' teeth. This is a big problem for ocean predators as most have flippers rather than claws so they can't use their 'hands' to help.

Photos of the plesiosaur and ichthyosaur teeth Matt McCurry used in his research. Can you see the apicobasal ridges? Can you see similar ridges on the mosasaur teeth in the case? Photo by Patrick Smith, Australian Museum.

Mosa munchers

These teeth are from two types of mosasaur. Can you guess what they ate from their shape?

The mushroom-shaped teeth are from *Globidens*. They're for crushing the shells of prey. *Globidens* ate shellfish.

The sharp teeth are from *Prognathodons*. They're for slicing the flesh of prey. *Prognathodons* ate fish and reptiles.

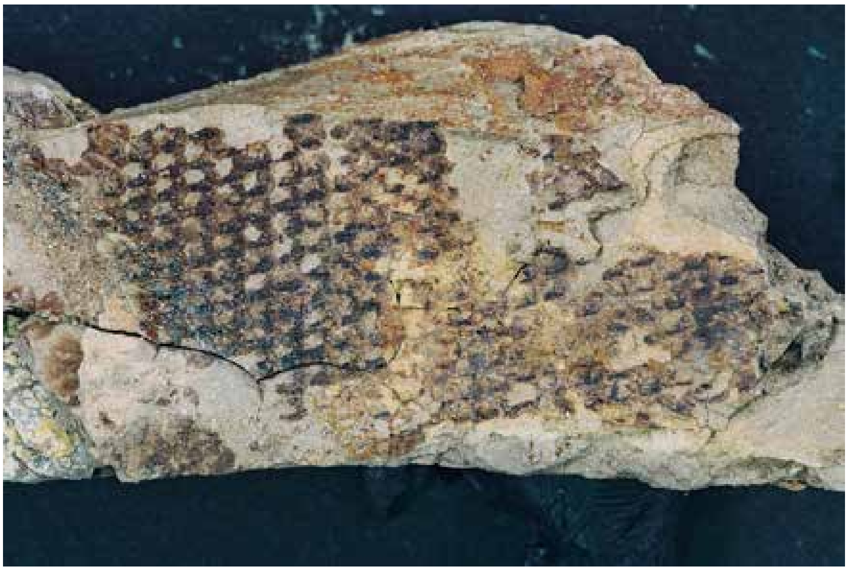
The cutting edges on the front and back of the teeth are called carinae. *T. rex* teeth have them too.

Shady characters

We used to have to guess about the colour of extinct creatures, based on similar modern animals. But scientists recently found some fossilised mosasaur scales and managed to extract and analyse their pigment cells to work out what colour they were.

They discovered mosasaurs were dark on top and light underneath, like great white sharks. This colour pattern is called counter shading, and helps many ocean predators hide from their prey.

If you're dark on top, prey above you can't see you against the dark of the deep water. If you're pale underneath, anything looking up can't see you against the bright sea surface.



Fossilised mosasaur scales. Thanks to Johan Lindgren, University of California Museum of Palaeontology and the State of California.

Mosasaur scales also had slight ridges or keels which made them more hydrodynamic, helping them slip through the water.

Crash of the titans

Ichthyosaurs suddenly disappeared at the end of the Cretaceous, 90 million years ago. We're not sure exactly why. Possibly an event starved the oceans of oxygen, and therefore the ichthyosaurs of their prey.

Then, 66 million years ago, a 10-kilometre-wide asteroid smashed into the Earth, triggering earthquakes, tsunamis and volcanic eruptions. Dust and smoke blocked the sun and the climate changed dramatically. This led to the extinction of nearly half the life on Earth and famously

brought an end to the dinosaurs (except some of those that had evolved into birds). Nearly three quarters of ocean species died out, including the plesiosaurs and the mosasaurs.

The reign of the reptiles was over.

But one group of marine reptiles survived – the turtles.

Shelled survivors

Turtles had been swimming alongside the other marine reptiles for millions of years, evolving harder shells in response to their ever more terrifying predators.

They survived the extinction event. In fact, they're the only fully aquatic marine reptiles to do so and are still with us today – just. There are seven species of marine turtles in our oceans today, but most are endangered.

[Cartoon: turtle visits underwater graveyard with 3 headstones 'ichthyosaurs', 'plesiosaurs' & 'mosasaurs'. Thinking "it's not the same without you"]

Going mouldy

This replica of a turtle skull fossil was made in this mould by Debra Lewis at Queensland Museum. The original fossil is from a Notochelone turtle found near Boulia, central Queensland.

Here's how Debra built the mould. (The fossil pictured is the jaw of an ancient marsupial):

1. Make a flat base from plasticine.
2. Put the fossil on the base and build the plasticine up to form walls.

3. Apply layers of silicone rubber inside the walls until it's one cm thick.

4. When the silicone has set, remove the walls.

5. Apply plaster over the silicone and plasticine base to create a firm outer shell.
6. When the plaster is set, flip the whole thing over and repeat the steps on the other side. A release agent stops the two lots of plaster sticking together.

7. When that plaster is set, open the mould and remove the fossil.

8. Fill the mould with a casting agent (resin).
9. When the resin has hardened, remove it from the silicone. The cast is now ready to paint.

Turtle power

This is a replica Archelon (pronounced arch-ell-on) skull. Its name means 'early turtle'.

Archelons are the biggest turtles to ever live. The largest found was

4.6 metres head to tail – as long as two and a half adult humans. They had very strong jaws and could easily bite through fish, squid and even shellfish.

Their upper shells were made from skin stretched over a framework of bones – like today's aptly named leatherback turtles.

One Archelon was 100 years old when it died. It had been hibernating on the sea floor and was fossilised in its sleep. Was he too 'hard' to wake up?

Our Archie

This replica Archelon skull was made by Dinosaur Valley Studios in Canada based on specimens and advice from Dr Don Brinkman from the Royal Tyrrell Museum of Palaeontology.

[Caption: Face painting at Dinosaur Valley Studios, Canada. Photo thanks to Frank Hadfield]

Early turtles

These are fossils from an Australian turtle species, called *Notochelone (pronounced No-toe-chee-lone)*. The name means 'back turtle' in Greek.

They lived about 100 million years ago in the Eromanga Sea, which covered much of ancient Australia. Their shells were less than a metre long – similar in size and shape to modern green sea turtles, who are distant relatives. They ate shellfish from the sea bed.

Turtles were the most common marine reptiles in Australia's inland sea, and their fossils are found quite often.

Nice Notos

Fossil Notochelone turtle shell or carapace. Found at Flinders River, North Queensland. On loan from Queensland Museum.

Fossil Notochelone turtle skull. Found near Richmond, Central Queensland. On loan from Queensland Museum.

Tom's turtle

Tom Hurley found this fossil turtle in 2008 on a property in western Queensland and loaned it to us. He was looking for ichthyosaurs but he found this stunning turtle and a fossilised conifer cone instead. This shows how unpredictable fossil hunting can be, and how landscapes can change over millions of years.

Tom is a great fossil finder. He discovered the *Kronosaurus* jaw featured in the plesiosaur section. His discoveries are so important that he's even had a new species of extinct fish he discovered named after him: *Australopachycormus hurleyi*. This was a three-metre long fish with a head like a swordfish.

Top turtle

Leatherbacks are the largest turtles around today. The biggest have two-metre-long shells – taller than most people.

Their throats are lined with spines to help them swallow slippery jellyfish, which is all they eat. Sadly, they sometimes swallow floating plastic bags by mistake.

Photo of jelly-fish-like plastic bag

Leatherbacks swim huge distances from where they nest on tropical beaches to where they feed in cold water. Scientists tracked one leatherback that swam 20,000 km from a beach in West Papua, Indonesia, to the United States. That's half way around the world. It took 647 days.

Turtle top

This is a replica skull from a modern leatherback turtle. Do you think it looks similar to the Archelon skull? Leatherback turtles are either descendants or close relatives of Archelon.

Leatherbacks have skylights in their skulls! An area of thin bone directly above the pineal glands on the top of their heads allows them to detect sunlight and measure day lengths. This help them know when to migrate.

Today's terrors

Ichthyosaurs, plesiosaurs and mosasaurs are long gone; now other predators stalk the seas. The extinction of these marine reptiles made way for sharks and whales to flourish, and some evolved into huge, terrifying hunters. We may think today's great white sharks and killer whales are scary, but they're nothing compared to their ancient cousins.

[Gabriel's illustration of Megalodon]

Next in brine

There's a new reptile taking to the seas. In the last eight million years, iguanas on the Galapagos Islands have been swimming and diving to feed underwater. They're not fearsome predators though. They eat algae from submerged rocks. But who knows how they'll evolve in the next few million years?

Iguanas are one of about 40 species of marine reptiles living in today's oceans. Most of the others are sea snakes.

Big tooth

After the huge reptiles, came the huge sharks. Megalodon (pronounced mega-luh-don) grew up to 19 metres long, over three times as big as the biggest great white shark. It was one of the largest fish that ever lived. Its name means 'big tooth', which is all we've ever found of them.

Like all sharks, Megalodon had a skeleton made of cartilage (like our ears) rather than bone. Cartilage is lightweight and springy, which is great for swimming, but not for fossilising.

Luckily teeth fossilise well and sharks have lots of teeth. Megalodon could have had about 276 teeth in five or six rows (adult humans only have 32 teeth). Sharks also lose and replace their teeth throughout their lives, so a single Megalodon could have had grown thousands.

Sharp tooth

Today's biggest predatory shark is the great white. The largest reliably measured was six-metres long. Its scientific name, *Carcharodon*, means 'sharp tooth'. It is a top predator in today's oceans, eating everything from small fish to seals and dolphins. Its only threats come from humans and, occasionally, killer whales.

Real tooth

This is a real fossil Megalodon tooth. It was found in Georgia, USA. A replica great white shark tooth sits on top of it to show the size difference. Great white sharks are a protected species. We didn't want to encourage their illegal hunting by including a real tooth.

Touch tooth

Touch this replica Megalodon tooth. Imagine a massive mouth with over 270 teeth like these!

We're lucky they're extinct!

Whopping whales

After the huge reptiles, and alongside the huge sharks, came equally huge whales.

Livyatan (pronounced Livvy-a-tan) matched Megalodon's massive size and had even bigger teeth. In fact, *Livyatan* had the biggest teeth of any creature ever (except for tusks).

As a giant sperm whale, it was probably a top predator. It ate sharks, seals, dolphins and other whales.

Its full name, *Livyatan melvillei* comes from the biblical sea monster 'leviathan', and Herman Melville, who wrote of the terrifying whale Moby Dick. Scientists originally called it Leviathan, but discovered that name was already an outdated scientific name for the mastodon, an extinct relative of elephants, so switched to the Hebrew spelling.

Jaw-normous

This is a replica of the biggest tooth ever found in Australia. It was found in 2016 on Beaumaris Beach, east of Melbourne. It's five million years old and from a close relative of *Livyatan*.

The replica was made by Museum Victoria from the original fossil in their collection.

[Photo of Erich with original tooth]

Caption:

Vertebrate Paleontology curator Erich Fitzgerald holding the original fossilised tooth.

Photo by Benjamin Healley, Museum Victoria.

Top teams

These giants are extinct, but their relatives are today's top ocean predators.

Though not as big, today's killer whales, or orca (from their scientific name *Orcinus orca*), take on modern giants such as humpbacks and even blue whales.

They're able to tackle huge prey because they're social – they work in teams and help each other to find and kill their prey.

Killer Whales off the coast of Eden, New South Wales, even used to team up with human whalers, alerting them to passing whale prey and helping herd them to shore. In return, the humans would throw the orca the prized tongues.

Orcinus rather morbidly means 'of the kingdom of the dead'.

[Cartoon: Killer whale dressed as sports fan (striped scarf, beanie) holding banner saying 'Go Team Orca']

Current killer

This is a replica killer whale tooth. See how much smaller it is than the Livyatan tooth? Killer whales use teamwork to make up for their smaller size when tackling large prey.

Ocean ambush

This film shows killer whales hunting humpback whale calves off Ningaloo Reef, Western Australia.

The film runs for 1 minute.

It may be upsetting for some viewers.

This footage was filmed by John Totterdell, founder and principal researcher at CETREC WA (Cetacean Research Centre), which has been studying whales off the coast of Western Australia for the past 14 years.

These killer whales are a family group of three siblings led by their mother, called 'Hook' after the shape of her fin. When killer whales approach a humpback, they first check to see if it has a calf. If not, they move on.

Humpback mothers try to protect their calves by shielding them with their five-metre-long flippers and, if possible, escaping to shallow water. Sometimes other whales help drive off the attackers. Nevertheless, 60 per cent of recorded attacks by Hook's family are successful.

The attackers usually try to ram the calf to disable it or kill it outright. The battle shows the conflicting needs of two whale mothers trying to care for their young – if the humpback saves her calf, the young killer

whales will go hungry. Migrating humpback calves are a vital winter food source for Western Australia's killer whales. In fact, they may be the key to their survival.

Early in 2019, John managed to record a group of killer whales attacking and killing an adult blue whale – the first known successful attack on a mature blue whale anywhere in the world. Here are some of his pictures:

Monster movie

After you've seen the exhibition and met the monsters, come and see them swim.

With water supporting their bodies, even huge creatures can be graceful and fluid...but they're still scary!

Blue whale back bones

yearling calf

Balaenoptera musculus

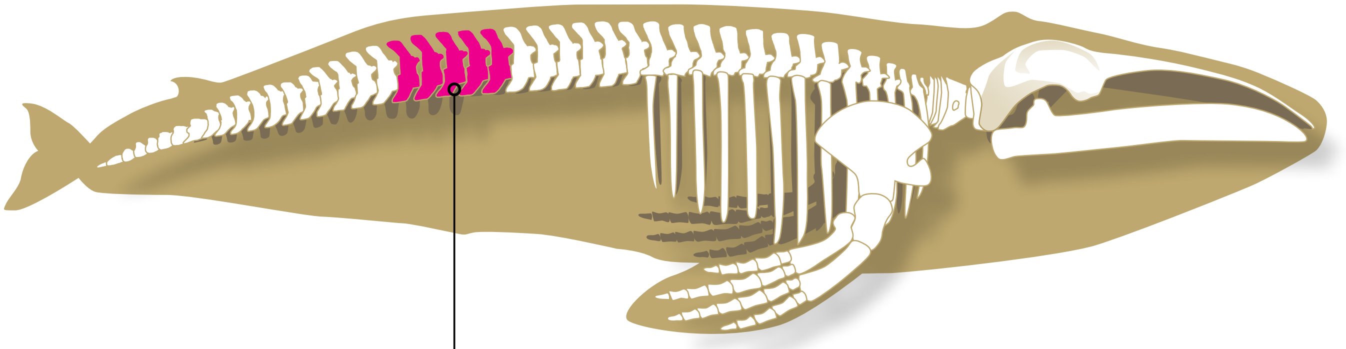
Locality: Found on a beach at St Lawrence, south of Townsville (22° 19'S, 149° 38'E)

Stranded: 24 February 1994

These whale vertebrae (back bones) from a blue whale are part of a large collection of cetacean skeletons in Queensland Museum Network's mammal collection. Scientists use these specimens for research on the species that occur off the Queensland coast.

The heaviest blue whale ever measured weighed approximately 173 tonnes. It was 29.5 metres long.

A blue whale that landed in Namibia in 1924 yielded 52 tonnes (305 barrels) of oil, illustrating why this species was once hunted as a rich resource (Best, 2007).



The five bones on display are from the lumbar (lower back) region.

QUEENSLAND MUSEUM NETWORK RESEARCH

FROM DIG TO DIGITAL

Discover Queensland's extinct Sea Monsters with Dr Espen Knutsen, Queensland Museum Network palaeontologist.

Giant marine reptiles swam in the shallow inland seas of Queensland during the time of the dinosaurs. This animation shows the discovery and excavation of the skeleton of a long necked plesiosaur in the field, and subsequent preparation, followed by detailed reconstruction and animation.

The *Eromangasaurus* skeleton featured in this animation is based on an actual specimen found in the Boulia Shire and currently on display at the Boulia Heritage Complex. The skeleton is known as 'Percy' after a competition to name it was won by a local schoolgirl, Chaquille Spoof, in 2017.

Platypterygius (Plat-Ip-Ter-Id-Ge-us) and *Eromangasaurus* (Ero-Manga-Saw-Rus)

Queensland Museum Network acknowledges Boulia Shire Council and Boulia Heritage Complex for their ongoing support. The 'Percy' specimen was collected by Tom Hurley and the late Dick Suter. The skeleton was prepared by Dick Suter.

Queensland Museum Network's Geosciences collection spans over 4.5 billion years of history—from meteorites from the outer solar system to ancient minerals formed deep in the Earth's crust, and 1.65 billion years of fossilized lifeforms.

Our collections, some acquired more than 160 years ago, and our associated research studies define Queensland in time and place. These collections document our unique biodiversity and help us understand Queensland's changing environment.

The Museum's Geosciences research team is internationally acclaimed for their expertise; and includes Dr Andrew Rozefelds, Dr Scott Hocknull and Dr Espen Knutsen.

In the Early Cretaceous Period (140-100 million years ago), much of inland Queensland and northern New South Wales was inundated by a global rise in sea levels. Known as the Eromanga Sea, this inland marine habitat was home to a variety of ichthyosaurs, plesiosaurs, turtles, crocodiles, fish and molluscs. Fossil remains of these animals can be found in the rocks now outcropping in central and northern Queensland.

Much of our current research focuses on uncovering the fascinating secrets hidden for millions of years within this ancient sea floor. With this research we hope to reveal more about Queensland's ancient past and add to our ever-increasing knowledge of the State's unique geological and palaeontological history.

Australia, 110 million years ago. In the Early Cretaceous Period, Australia was much further south than today and connected to Antarctica. Much of Queensland was covered in a shallow sea, called the Eromanga Sea.

Globe image: © 2016 Colorado Plateau Geosystems Inc

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Queensland Museum Network
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Central Queensland University

Dr Scott Hocknull

Senior Curator of Geosciences,
Queensland Museum Network
Honorary Research Fellow, University of Melbourne

Dr Espen Knutsen

Senior Curator of Palaeontology,
Queensland Museum Network
Research Fellow, James Cook University

ANCIENT MARINE REPTILE RESEARCH

The ancient marine reptile research at Queensland Museum Network is led by Senior Curator, Dr Espen Knutsen. Dr Knutsen's early research focused on 145 million-year-old marine reptiles from the Arctic Archipelago of Svalbard in Norway. Dr Knutsen spent six field seasons digging for fossils in this polar bear-rich region near the North Pole. His team discovered and collected more than 40 marine reptile skeletons, resulting in eight new species, including one of the world's largest plesiosaurs.

Working for Queensland Museum Network, Dr Knutsen has changed his fieldwork location from one of the coldest places on Earth to one of the warmest. Despite the different climate and hemisphere, the extinct animals he finds in Queensland are similar to those that lived tens of millions of years earlier on the other side of the planet.

Many questions remain unanswered about the Cretaceous marine reptiles of Queensland. How many species were there? How did they evolve over time? Did they ever migrate from the Eromanga Sea?

Collecting new specimens and studying museum collections may hold the answers.

Main image: Fossil remains of a hind limb of a long-necked plesiosaur in Svalbard, Norway.

Fieldwork camp on Spitsbergen Island, Svalbard, Norway.
The two white kitchen tents are a long way away from the sleeping tents. Keeping food separate from the sleeping site lowers the risk of polar bears snacking on the crew.

RECENT DISCOVERY

JULY 2020

Dr Knutsen's most recent research find was in July 2020. The fossil remains of an elasmosaurid (long-necked) plesiosaur were discovered at a cattle station east of Hughenden in western Queensland. The fossil was excavated in September 2020 and is now being prepared and stabilized at Queensland Museum Network - Museum of Tropical Queensland, Townsville - so it can be further studied.

Main image and above: The site of the new plesiosaur fossil remains. The yellow arrows indicate bone fragments (mainly neck fragments) that have eroded out of the rock. The red arrow shows where parts of the neck and body are still preserved within mudstone.

1. Eroded fragments of the neck

2. Rib still in the rock

3. Eroded fragments of the neck and shoulder

4. Shoulder and neck still in the rock

Dr Knutsen undertaking field work on a newly discovered plesiosaur.

PALAEONTOLOGY IN THE FIELD

FINDING FOSSILS

Fossils are found where certain types of rock (sedimentary) of the right age have been exposed on the Earth's surface.

Geological maps help palaeontologists locate sedimentary rocks of the right age. This information can be used along with aerial images to locate areas to investigate and look for fossils.

Fossils are found in exposed rocks of the right type and age. The green on the map shows exposed Cretaceous rocks that were formed from sediment either in rivers and lakes or the inland sea that covered much of Queensland.

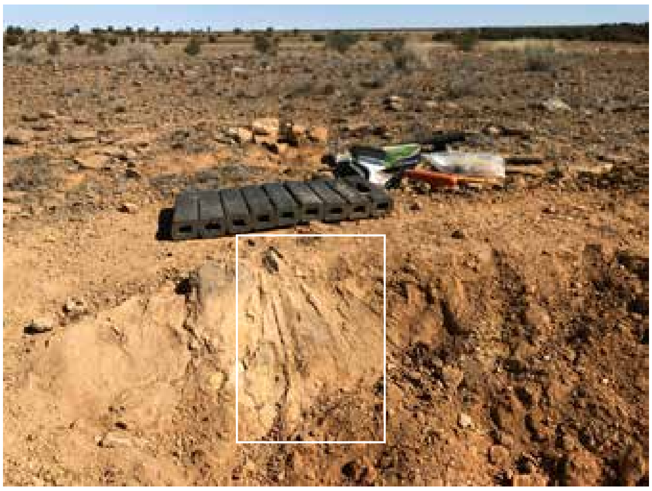
COLLECTING FOSSILS

Once a fossil has been discovered, its location is marked on a GPS and excavation can begin.

Nearly all the overburden (dirt and rock covering the fossil) is removed before carefully brushing down to the rock layer preserving the fossil.

Once uncovered and documented, the fossil is encased in a plaster jacket to provide a safe cocoon for its transport back to the museum.

Ichthyosaur excavation at Boulia, central Queensland.



The overburden has been removed to expose an ichthyosaur skull.

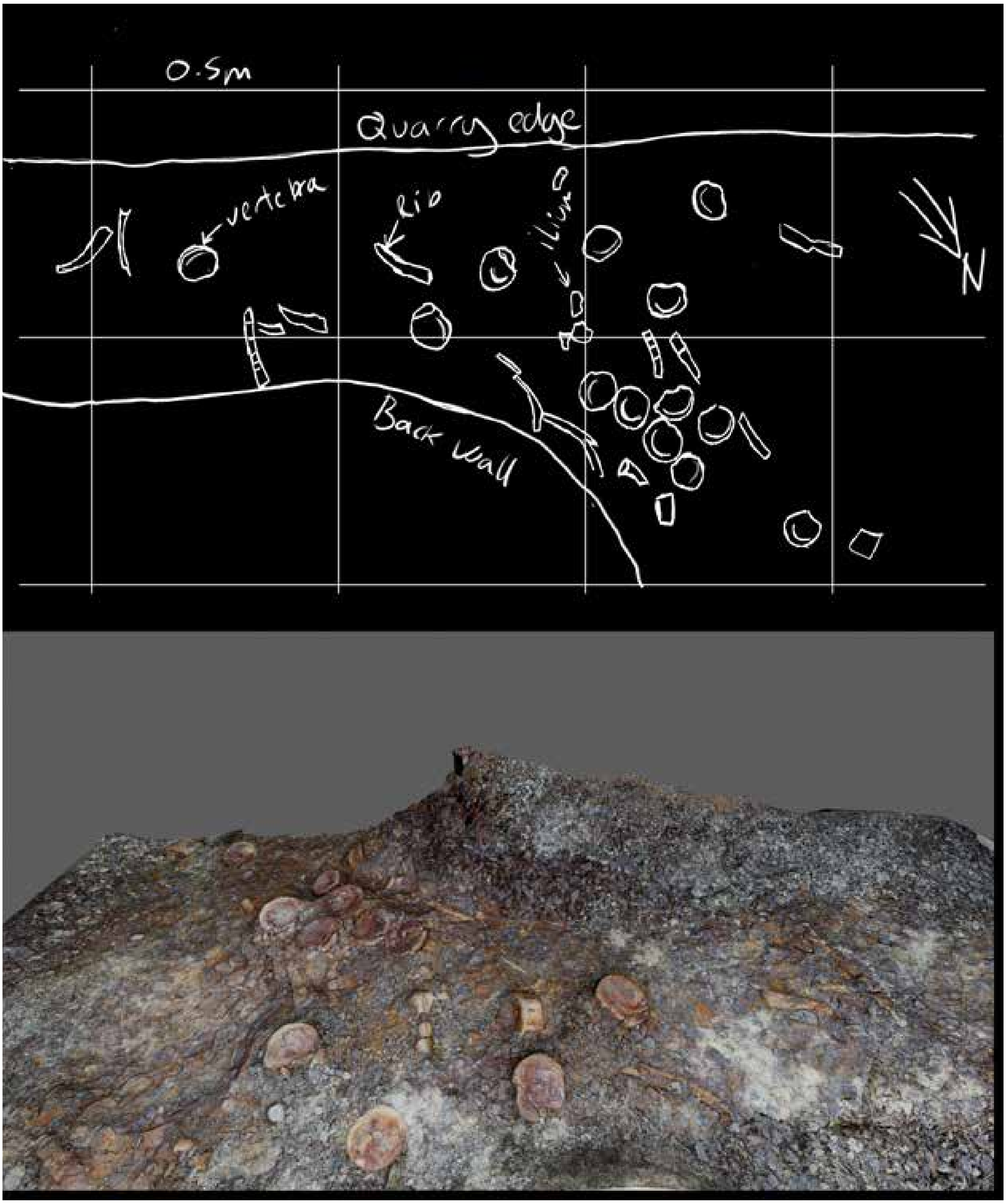
The fossil is first covered in a layer of wet toilet paper to ensure the plaster layer does not stick to the fossil. Layers of plaster-soaked hessian are then applied to make a plaster jacket.

Soil and rocks are removed by digging under (undercutting) the fossil, so the plaster jacket can be flipped to expose the underside. Sometimes the jacket is so heavy that it requires mechanical assistance to be moved.

The flipped plaster jacket is ready to be plastered on the other side and transported to the museum.

MAPPING FOSSIL SITES

While many of the methods used to collect fossils are similar to those used over 100 years ago, palaeontologists now use an array of modern tools and techniques to record and map the excavation site fragments. Knowing exactly where all the fragments of a fossil were found helps palaeontologists understand the story of the organism—from when it died to when it was found as a fossil. It also provides information about the environment it was buried in.



Example of gridded field sketch and 3D model of a plesiosaur excavation site.

CAMERAS, DRONES AND 3D MAPPING

Before a fossil is removed from its site, its exact position and orientation is recorded. This involves drawing gridded field sketches and taking hundreds of photos. Palaeontologists also use drones and photogrammetry (a series of overlapping photographs taken from different angles) to make detailed 3D maps of excavation sites and whole localities.

Dr Knutsen preparing to use a drone to capture imagery of a fossil's field site. These photographs are used to generate 3D maps.

PALAEONTOLOGY AT THE MUSEUM

PREPARING FOSSILS

Once fossils within their plaster jackets arrive at the museum, they need to be extracted from the rock matrix. Brushes, tweezers, dental tools, acid and adhesives are all used to prepare and consolidate the fossils.

Main image: Dr Knutsen uses an air scribe (mini jack hammer) to carefully remove the matrix (dirt and rock) attached to the fossil.

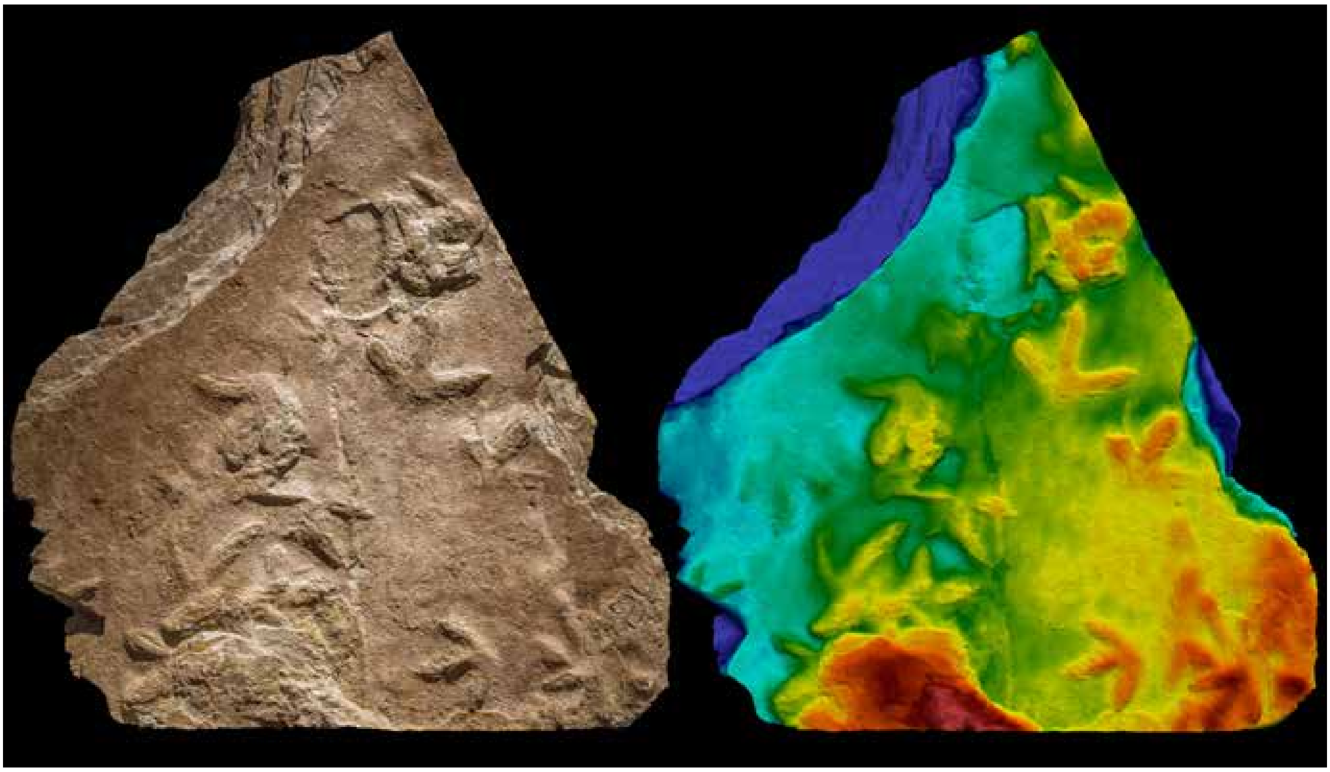
Mild acid is often used to extract fossils from carbonate-rich rocks. The acid dissolves the rock without affecting the fossil. This fossil-bearing rock is submerged in acetic acid.

Fossil fish bones and teeth that were extracted from the rock.

VIRTUAL FOSSILS

Palaeontologists often make an accurate replica (or cast) of a fossil. These casts mean that a unique or delicate fossil can be studied by many people, while the original is kept in protective storage. Many of the specimens in this exhibition are casts made from moulds of the originals.

More recently, new digital imaging technologies such as photogrammetry and 3D laser scanning are creating 3D models of fossils. These models not only give palaeontologists a permanent virtual record of the specimen, they can be easily sent to colleagues all over the world, allowing fossils to be studied in new and different ways.

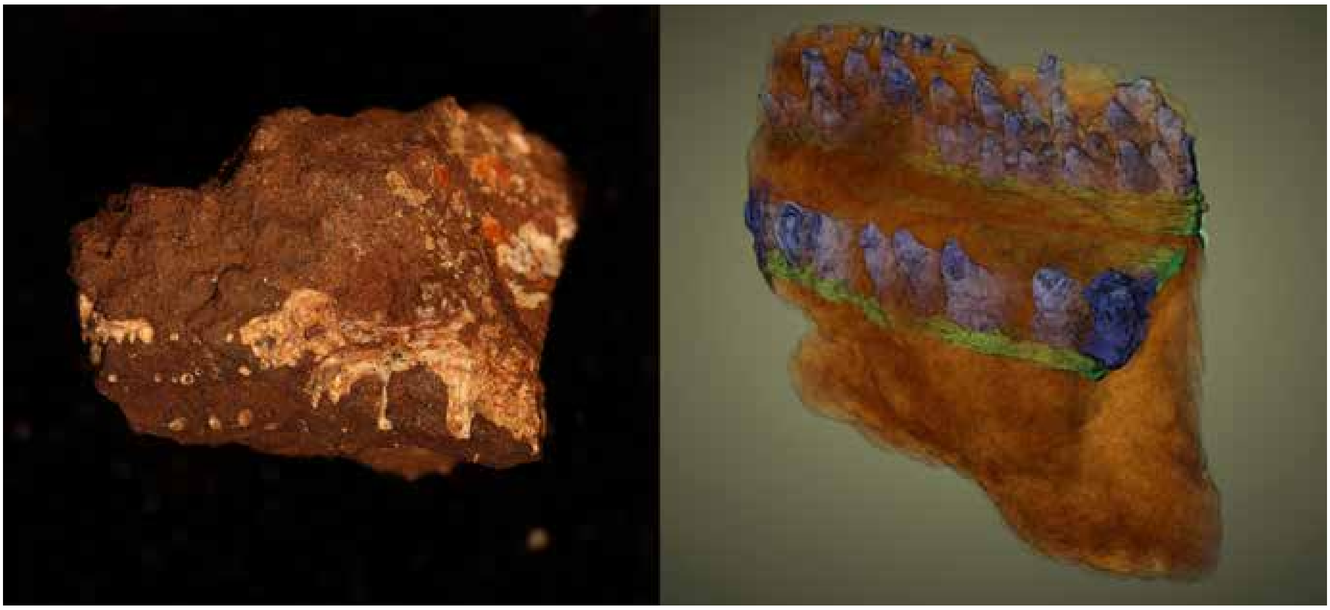


A 3D model was created of these Jurassic dinosaur footprints and then visually enhanced (coloured) so the tracks are easier to see and study.

COMPUTERISED TOMOGRAPHY

X-ray computerised tomography (CT) allows palaeontologists to study the internal structures of the fossil, or even study fragile fossils still entombed inside rock.

Particularly important to palaeontological research is the Australian Synchrotron facility in Victoria. The Synchrotron produces electromagnetic radiation (light) as bright as one million suns, capable of penetrating dense fossil specimens.



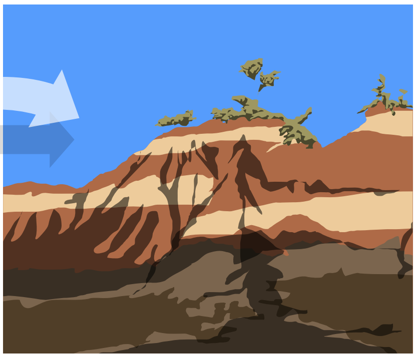
A tiny early Triassic amphibian skull embedded in rock (left) has been scanned using X-ray CT (right). The rock is shown in brown, the bone in green and the teeth in blue. The fossil features can be digitally extracted using this process then printed in 3D.

DATING FOSSILS

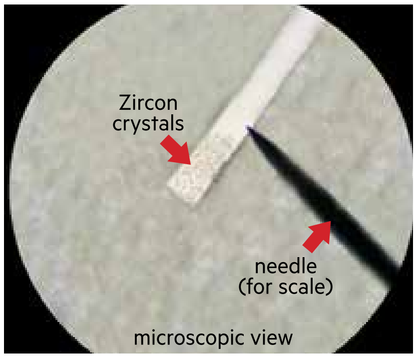
Minerals, such as zircon, preserved in the rock surrounding a fossil can tell us the age of the rock, and therefore the age of the fossil. Zircons form in magma from volcanoes. When they form, zircons trap uranium in their crystal lattice, which gradually decays into lead at a known rate (half-life). By measuring the relative amount of uranium and lead in zircons, we can calculate how old a fossil is. This is called radiometric dating.

1. Zircons form and deposit across the landscape.

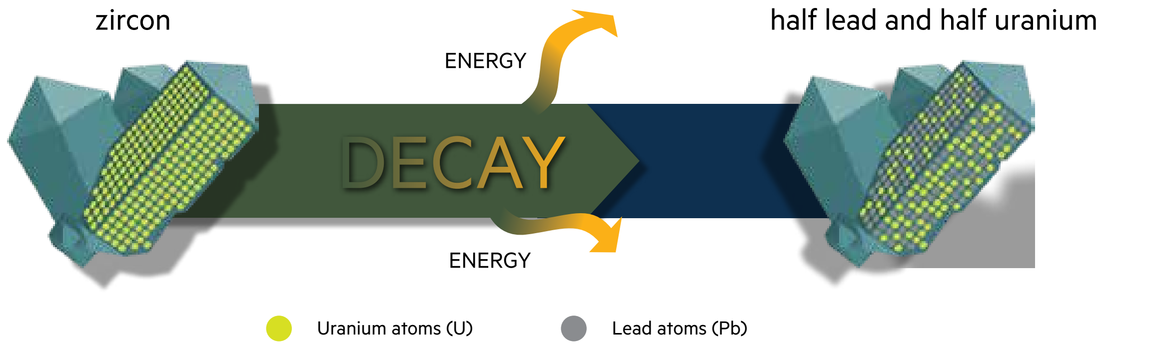
2. Zircons then become part of the sedimentary deposits.



3. Millions of years later, zircons can be extracted from sedimentary rock.



4. The age of zircons is measured by the relative amount of uranium and lead it contains.



QUEENSLAND MUSEUM NETWORK GEOSCIENCES TEAM

Queensland has the most comprehensive fossil heritage in Australia, dating back 1.65 billion years.

Meet Queensland Museum Network Geosciences research and collections staff. They are committed to telling the stories of the past by studying the vast rock and fossil records from across Queensland.

PROJECT DIG

DIGITAL INFRASTRUCTURE GROWTH

Queensland Museum Network has been collecting and documenting the natural and cultural history of our state, surrounding waters and near neighbours for nearly 160 years.

Today, we are custodian of the State Collection – comprised of 1.2 million cultural objects and natural history specimens and more than 14 million research items.

These objects and specimens remind us of events that have befallen us, of greatness achieved, of those we have loved, those we have lost and the unique environments we call home.

The sheer size of the State Collection means that only a small portion can ever be displayed publicly.

Project DIG (Digital Infrastructure Growth) is helping to address this challenge.

This five-year collaboration between Queensland Museum Network and global resources company BHP combines state-of-the-art scanning, imaging and 3D technologies, allowing us to dig deeper, to reveal the stories beyond the surface, and digitally share this knowledge with communities no matter where they are in the world.

Examples of Project DIG initiatives are showcased within Sea Monsters: Prehistoric Ocean Predators and the Lost Creatures gallery on level two.

Want to know more?

projectdig.qm.qld.gov.au