DINOSAURS: DAWN TO EXTINCTION TAKES VISITORS ON A JOURNEY 600 MILLION YEARS BACK IN TIME, INTO THE WORLD OF TERRESTRIAL REPTILES AND ANIMALS. FROM THE DEPTHS OF THE PRECAMBRIAN OCEANS, TO THE DRY LANDSCAPE OF THE TRIASSIC, AND THE LUSH FORESTS OF THE JURASSIC AND CRETACEOUS, THIS EXHIBITION TELLS A UNIQUE STORY OF THE PRE-, ACTUAL- AND POST-DINOSAUR PERIODS.

DINOSAURS
DAWN TO EXTINCTION

ArtScienceMuseum
MARINA BAY SANDS

EXCLUSIVE EDITION

DINOSAURS DAWN TO EXTINCTION

BY VICKERS-RICH, TRUSLER AND ALCOBER

DINOSAURS DAWN TO EXTINCTION

ArtScienceMuseum
MARINA BAY SANDS

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DINOSAURS
DAWN TO EXTINCTION

BY DR. PATRICIA VICKERS-RICH,
PETER TRUSLER AND DR. OSCAR ALCOBER

IMAGE: MARINA BAY SANDS PTE. LTD.

FOREWORD

Dinosaurs: Dawn to Extinction takes visitors on a journey 600 million years back in time, into the world of terrestrial reptiles and animals. From the depths of the Precambrian oceans, to the dry landscape of the Triassic, and the lush forests of the Jurassic and Cretaceous, this exhibition tells a unique story of the pre-, actual- and post-dinosaur periods.

The world was not an easy place to live in with the constant battles for survival. Visitors can venture into the dinosaurs' world to gain a deeper understanding of how these species evolved, adapted and braved the ever-changing landscape. While many are familiar with dinosaurs such as *Triceratops, Dinosaurs: Dawn to Extinction* aims to broaden visitors' knowledge on dinosaurs by introducing them to the lesser-known species that lived amongst the dinosaurs, as well as rarely seen creatures from the past. The collection, combining real fossils with original artworks and hands-on displays, is presented unlike any conventional museum display. Visitors will be able to explore a tree's roots like a small mammal-like reptile would have, and experience the beauty of diversity under the *aurora australis* (the southern lights), through a distinctly ArtScience lens.

For over 30 years, Dr. Patricia Vickers-Rich, paleontologist and curator of *Dinosaurs: Dawn to Extinction,* has collaborated and traveled around the world with artist Peter Trusler, in search of the remains of early life. These successful expeditions have allowed Peter Trusler to create vivid illustrations and document prehistoric life in exquisite detail. From the colours of the sky, to the fauna crushed beneath the depicted dinosaur's foot, every detail is backed by scientific research and intricately accounted for when creating these masterpiece images of the past.

Staying true to the mission of ArtScience Museum, the evergreen subject of dinosaurs is creatively put together by marrying art and science to create a special and unique visitor experience. *Dinosaurs: Dawn to Extinction* provides a one-of-a-kind experience that offers a new perspective into the world of dinosaurs. We invite you to travel back in time with us, be immersed amongst the fascinating fossils, specimens and artworks on display, and leave ArtScience Museum with a deeper and newfound understanding of dinosaurs.

Ross Leo
Associate Director, ArtScience Museum, Singapore

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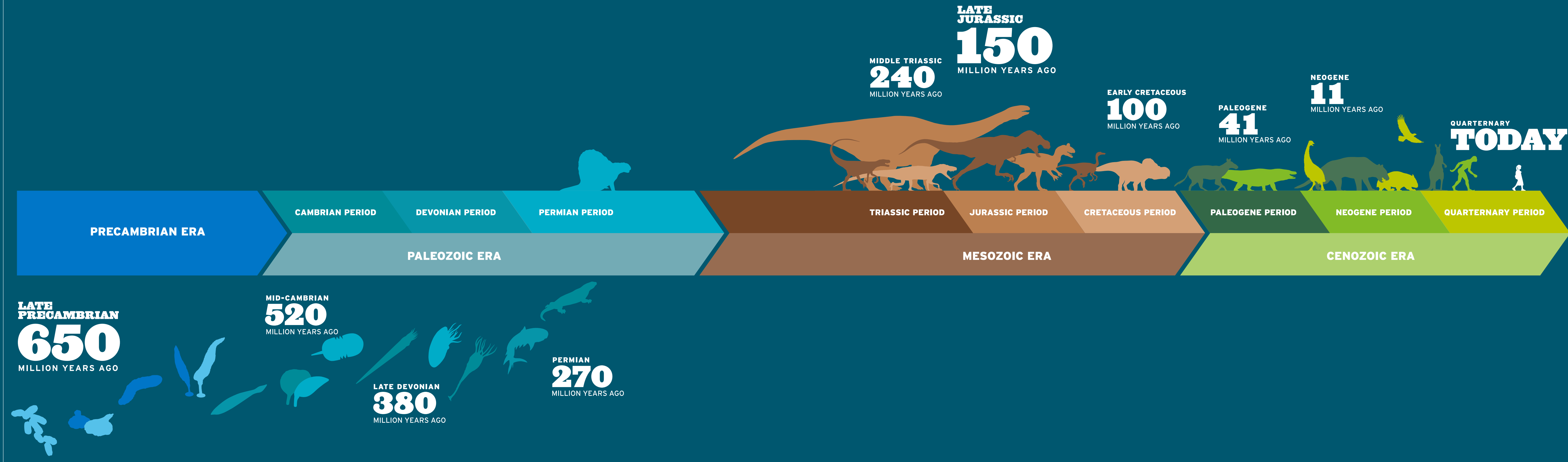
GEOLOGICAL TIMESCALE



INTRODUCTION

YORGIA IS IMAGINED IN THE CLOUDY MIST, BUT ITS FOSSILS LIE IN THE GRIP OF THE ROCKS ALONG THE CLIFFS. THESE DELICATE FOSSIL IMPRINTS WERE HIDDEN BETWEEN LAYERS OF ROCK FOR MILLIONS OF YEARS, UNTIL THE RAIN AND SEA BEGAN WASHING AWAY THE MUDSTONES OF THE TAIGA FORESTS.

ILLUSTRATION: PETER TRUSLER

DINOSAURS ARE PROBABLY THE BEST KNOWN FOSSIL GROUP ON THE PLANET, AS ANY FIVE-YEAR-OLD WILL TELL YOU. THEY HAVE CAPTURED OUR IMAGINATIONS EVER SINCE SIR RICHARD OWEN FIRST COINED THE TERM IN APRIL 1842 – THE "FEARFULLY GREAT LIZARDS."

Much was actually known about dinosaurs before this, but no one had actually put the puzzle together until Owen. His sharp eyes realized that the defining character of this group of reptiles was the full fusion of the backbone elements in the region of the hips (the sacaral vertebrae) – and this fusion was not a case of arthritis! Dinosaurs, though probably better known than any other reptilian group, have near relatives in a larger family grouping called the *Archosauria*. This includes the flying reptiles (the Pterosaurs), the crocodiles and a rag-tag group of other reptiles that first appear in the Triassic – a time that you will be visiting in this exhibition – more than 200 million years ago. Despite their popularity, dinosaurs were not the rulers of these times. They endured stiff competition from not only their close archosaurian relatives but from another group of saurians. One of these groups was the mammal-like reptiles, called the Synapsida, were our very own ancestors.

Dinosaurs: Dawn to Extinction follows the path taken by the dinosaurs and their feisty relatives: from the dawn of their existence in Triassic times, to their near-total disappearance some 66 million years ago, at the end of the Cretaceous. But don't worry. One resilient group did persist, and you will have to wait to find out just what group this is! This exhibition will take you through not just dinosaur times, but vast times before, when life was just beginning on Earth some 3.8 billion years ago. At this point, almost all life was still bubbling away in the sea. You will then travel to younger times, when life got complex, when it moved onto land, and finally when the dinosaurs hit the scene. The land was stark, and competition for the limited resources with other reptilian groups was fierce. Afterwards, you will travel to the near-end of this enigmatic, yet intriguing group, gaining some understanding of what finally led to their demise... or at least, the demise of most of them.

EXAERETODON WAS A MAMMAL-LIKE REPTILE ABUNDANT IN THE LATE TRIASSIC, THAT HAD A LARGE HEAD AND AN UPRIGHT STANCE. *(STEVE MORTON)*

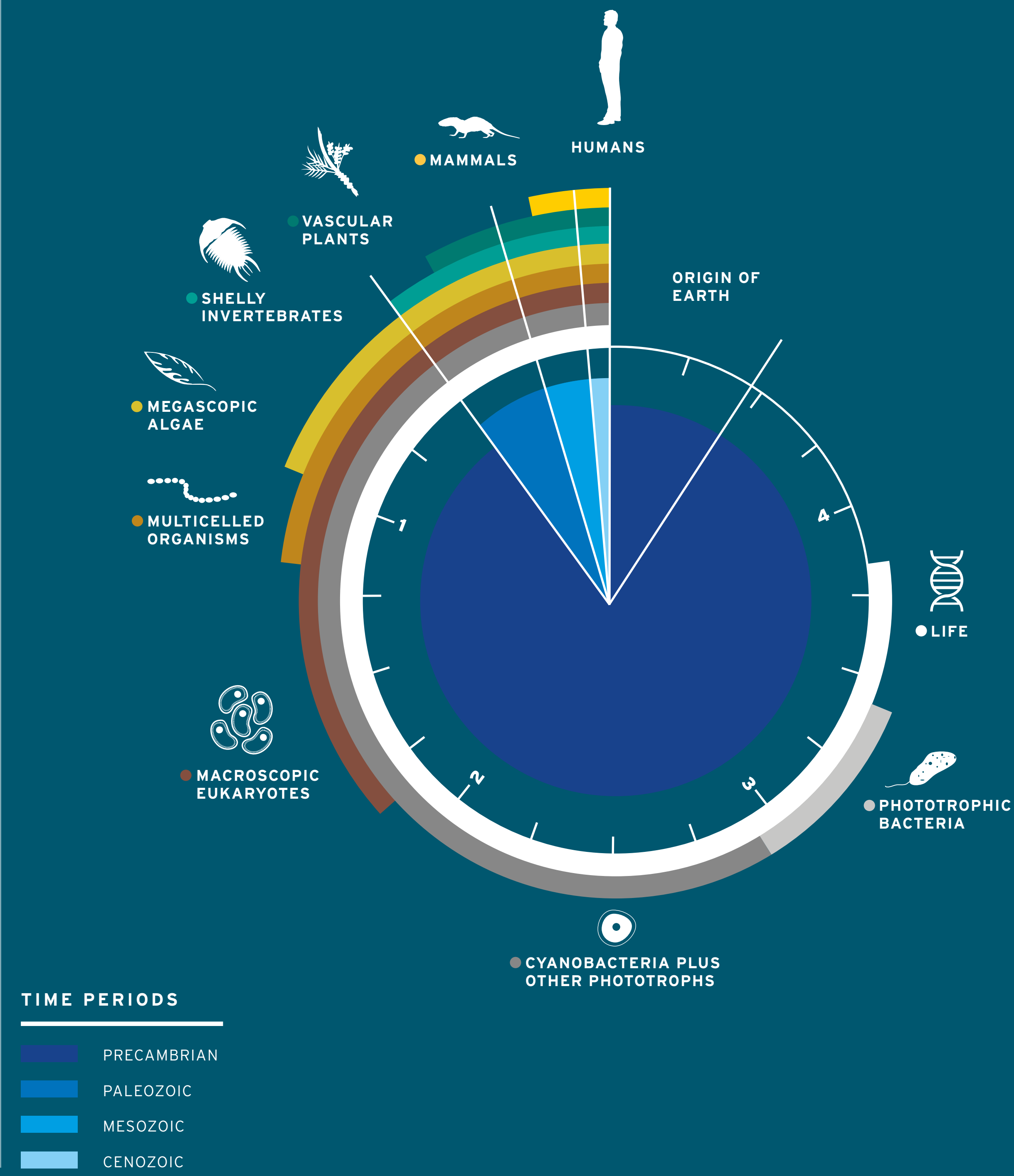
The journey through time is also a journey through space. Over time, the continents and ocean basins, and even the atmosphere and sea water, change. Massive continents, like Rodinia in ancient times and later Pangaea, first come together and then break apart – the last separation really being first the break up of Pangaea into the northern continents and the great southern continent Gondwana. When Gondwana began to fracture more than 200 million years ago, the world became a place more familiar to us today. Africa, South America, Australia, Antarctica began to bid each other farewell, and the ocean basins surged in between. But when the first dinosaurs appeared on the scene Pangaea was still a reality. As you move through the exhibition, you will experience the dynamics of drifting continents and discover just how the Earth really works. You'll discover the rules that govern plate tectonics and how it affects not only geography but the Earth's atmosphere, ocean circulation and ultimately the distributions of life itself.

On this journey, you will be able to look at, and even touch, some of the material that has allowed this story to be told. But much more is on offer. Side by side with the fossil specimens will be the engaging and meticulously precise reconstructions crafted by Melbourne's Peter Trusler. His imagery captures the best of science and art, turning bones, rocks and plant fossils into near-photographic pictures of the past. You'll get the inside scoop on how Trusler puts muscles and skin on bones, and forests on the hillsides of places that no longer exist – landscapes once haunted by dinosaurs.

EARTH HISTORY EVENTS OVER THE LAST 4,000 MILLION YEARS

The tale of the dinosaurs is one of successes and failures, followed by recovery, and finally near-extinction. They dominated the land for more than 160 million years. In the end, only a few small ones survived the famous Cretaceous-Tertiary extinction 66 million years ago, along with small mammals and other reptiles. Far from a weakness, being small was, in fact, paramount to their survival. The dinosaur survivors mainly took to the air – they became the birds we know today. After the dinosaurs, the mammals and birds became the vertebrate rulers of land and sky. Humans are part of this mix, and the next big question posed in this exhibition is: how are we to deal with the future? Can the dinosaurs give us some clues as to how we ourselves can avoid extinction? We, of all species ever to inhabit the Earth, can foresee the problems facing the world. Perhaps we can do something to avoid the same outcome faced by the dinosaurs 66 million years ago.

LIFE OVER BILLIONS OF YEARS AGO



GRAPH: FEDONKIN, ET AL., 2007; VASCULAR PLANT: SUKKOT DESIGNED BY GILAD FRIED FROM THE NOUN PROJECT, PLANT DESIGNED BY AARON P. BROWN FROM THE NOUN PROJECT, BACTERIA DESIGNED BY MAURIZIO FUSILLO FROM THE NOUN PROJECT

THE HERD IS WELCOMING YOU TO DINNER. *YOU ARE THE DINNER* FOR THESE AGILE REPTILES

IMAGE: UNIVERSITY OF SAN JUAN NATURAL SCIENCE MUSEUM

THE HERRERASAUR HERD

A herd of herrerasaurs immediately welcomes you into *Dinosaurs: Dawn to Extinction.* The herd is welcoming you to dinner – literally. You're the meal! These agile reptiles were top predators. These early "fearfully great lizards" with their steamlined, lightweight skeleton, manipulatable hands, teeth like serrated steak knives, and mobile jaws would have made them real meat-processing machines. These dinosaurs were an evolutionary breakthrough in the Triassic relative to the reptilian predators that came before – they were bipedal, agile and formidable predators which provided the blueprint for this branch of carnivorous dinosaurs for the next 160 million years.

Herrerasaurs were some of the very first dinosaurs to appear on the scene, and just who they were most closely related to is controversial – some paleontologists suggest that they were very primitive theropods, while others propose that they were part of the ancestral group which gave rise to both the theropods and sauropodomorphs. But herrerasaurs – including *Herrerasaurus, Sanjuansaurus* and *Frenguellisaurus* – are known from many skeletons that are complete, suggesting that some or all may have been pack hunters.

ONE PUTTING THE PIECES TOGETHER: PETER TRUSLER

FANCY A CAREER AS A PALEO-RECONSTRUCTIONIST? LEARN ABOUT WHAT IT TAKES FROM ONE OF THE BEST IN THE BUSINESS, THE ACCOMPLISHED PETER TRUSLER. MILLIONS OF YEARS AFTER DINOSAURS WALKED THE EARTH, HOW DOES THIS MAN PUT SKIN ON BONES, AND MAKE PEOPLE FEEL THAT EXTINCT BEASTS WALK AMONG US ONCE MORE?

ILLUSTRATION: PETER TRUSLER

PG.

19 **Trusler's work** How does one marry emotion and fact, particularly when dealing with a world millions of years old? Meet the man who puts the 'creation' in dinosaur recreation.

21 **Reconstruction drawings** From birdbrain to feathers for real. Observe as fossil skull fragments are reconstructed to give us the face of *Dromornis*.

ILLUSTRATION OF A HYPOTHETICAL BEHAVIORAL EVENT SHOWING THE OLDEST KNOWN SEXUALLY DIMORPHIC ANATOMICAL STRUCTURES THAT WOULD HAVE ALLOWED INTERNAL FERTILIZATION. FOSSILS OF THESE FISH ARE EXQUISITELY PRESERVED IN THE LIMESTONE NODULES OF WESTERN AUSTRALIA, ALLOWING DETAILED ANATOMY TO BE RECONSTRUCTED.

ILLUSTRATION: PETER TRUSLER

DINOSAUR ART ABOUNDS IN PRINT, IN THE MEDIA, IN DOCUMENTARIES, IN CARTOONS, JUST ABOUT EVERYWHERE. AND IT IS NOT ONLY CHILDREN WHO ARE FASCINATED – THERE ARE MANY "DINOSAUR ARTISTS" OUT THERE, WITH SOME STRIVING FOR ACCURACY, WHILE OTHERS ARE MORE FANCIFUL.

There are few who actually spend the time to truly understand the science that informs what a past world would have looked like, or smelled like. It takes detailed knowledge, in-depth research and true artistic talent to put such data into an image that most accurately reconstructs the past.

The paleo-reconstruction work of Melbourne artist Peter Trusler that graces this exhibition serves as a reality check. His work provides the most accurate view of the past possible, firmly based on scientific knowledge gathered over decades.

Trusler's art pieces are the result of the intimate collaboration of an artist (a scientist himself) in a number of projects with a broad scientific community over more than three decades – collaborations both multidisciplinary and international in nature. The art in *Dinosaurs: Dawn to Extinction* turns the spotlight on a special relationship. For decades, artists and scientists have worked together to craft reconstructive imagery that is as true to past life as possible. The exhibition investigates just how the attention to scientific knowledge is critical to producing a truly accurate reconstruction of the past.

The themes explored in this exhibition are varied and diverse. We'll be tackling the meaning behind art and illustration, the processes of investigation and discovery, the biodiversity of life through time, scientific enquiry, intimacy and understanding of the modern world. Our journey explains just how the synthesis of seemingly diverse matters can advance a realistic understanding of the complex processes of life – past, present… and maybe future. Trusler has spent his life putting his Biology degree to use. He has strived to understand how muscles work, how animals behave, the feel and smell of a desert, and is now working on his PhD. He understands the minute details of the varied environments on Earth. That knowledge has refined his understanding of art presentation, leading to breathtaking reconstructions of past reality.

You'll be taken through each stage of production of Trusler's reality, from preliminary concept drawings and design through to major paintings, in a variety of media. Illustrative pieces showcase detailed scientific recording of specimens and personal investigations of a variety of subjects. These include life sketches of habitats and landscapes, animals, birds and plants, through to detailed microscopic studies of fossil specimens – all leading to a final image, meticulous in its detail and emotive in its presentation.

"The multitude of variations and subjects in between these examples [on show] is of particular interest to me: I can dwell on the edge by sliding the aesthetic component of art in any direction. You will find considerable variation in the work featured throughout, which in turn represents a small, yet significant, part of my output. These works have been produced for, and generated by, science. The manner in which the scientists and I have collaborated has allowed our work to transcend boundaries, since we value communication, above all. My colleagues have appreciated not only my pictorial skills, but also the intellectual approach to my craft. This has led to a genuine fusion of our ideas and has given me the privilege of contribution as a scientist to the research process. I have personally valued our egalitarian relationships, and feel that it has extended each of us."

– Peter Trusler, 2013

RIGHT: *DROMORNIS* PRELIMINARY RECONSTRUCTION DRAWINGS AND SPECIMEN STUDIES. THE DRAWINGS DEPICT SOME OF THE STAGES IN THE STUDY, NAMELY THE RECONSTRUCTED OSTEOLOGICAL FORM OF A RESTORED SKULL (*BOTTOM RIGHT*), AND PROBABLE LIFE APPEARANCE (*TOP RIGHT*). STEPS NOT PICTURED INCLUDE SKETCHES OF THE FOSSIL SKULL FRAGMENTS, AND SOFT TISSUE ESTIMATES. IN FULL COLOUR IS TRUSLER'S TAKE ON WHAT THE BIRDS WOULD HAVE LOOKED LIKE IN THEIR NATURAL HABITAT (*ABOVE*).

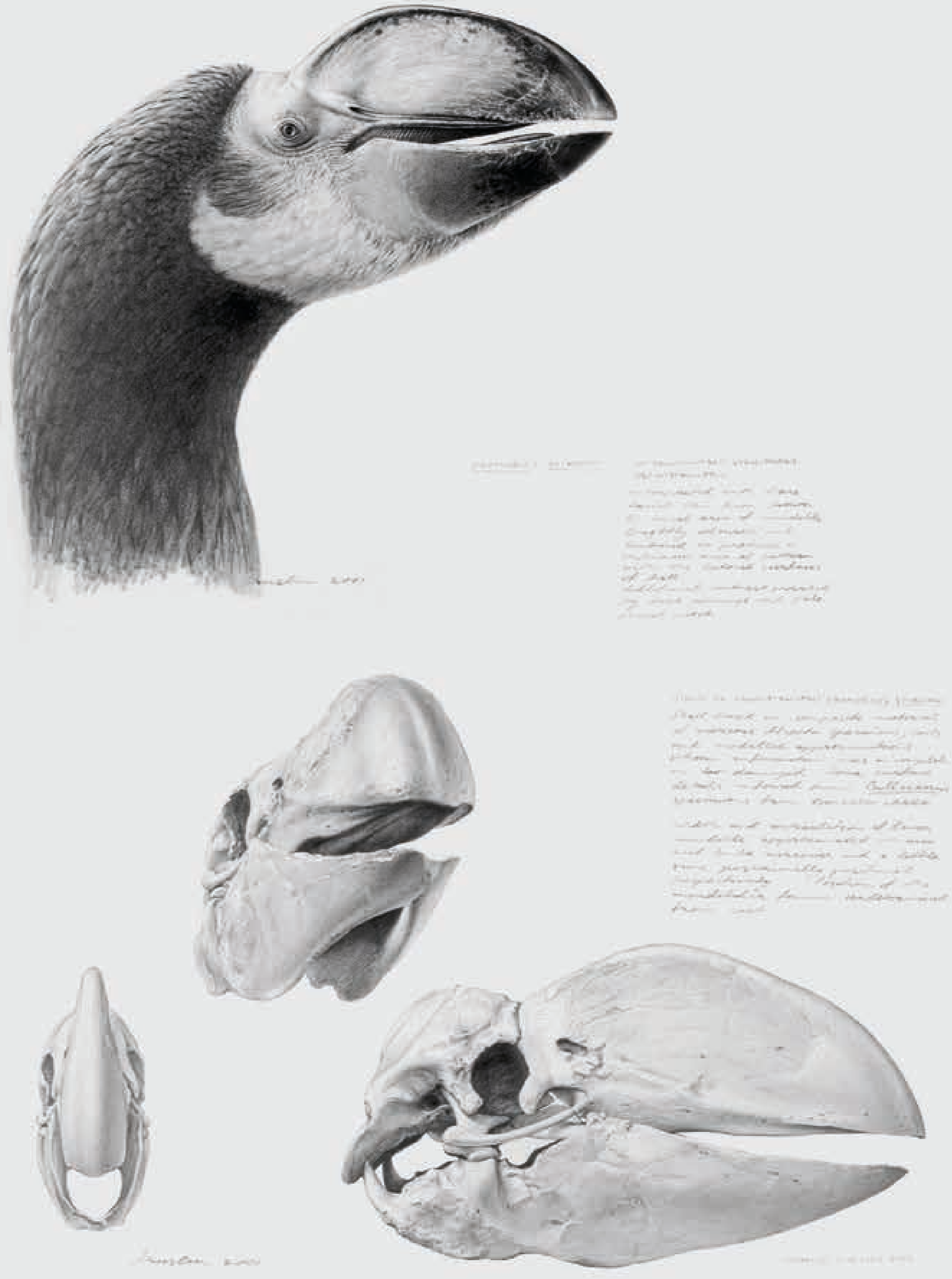
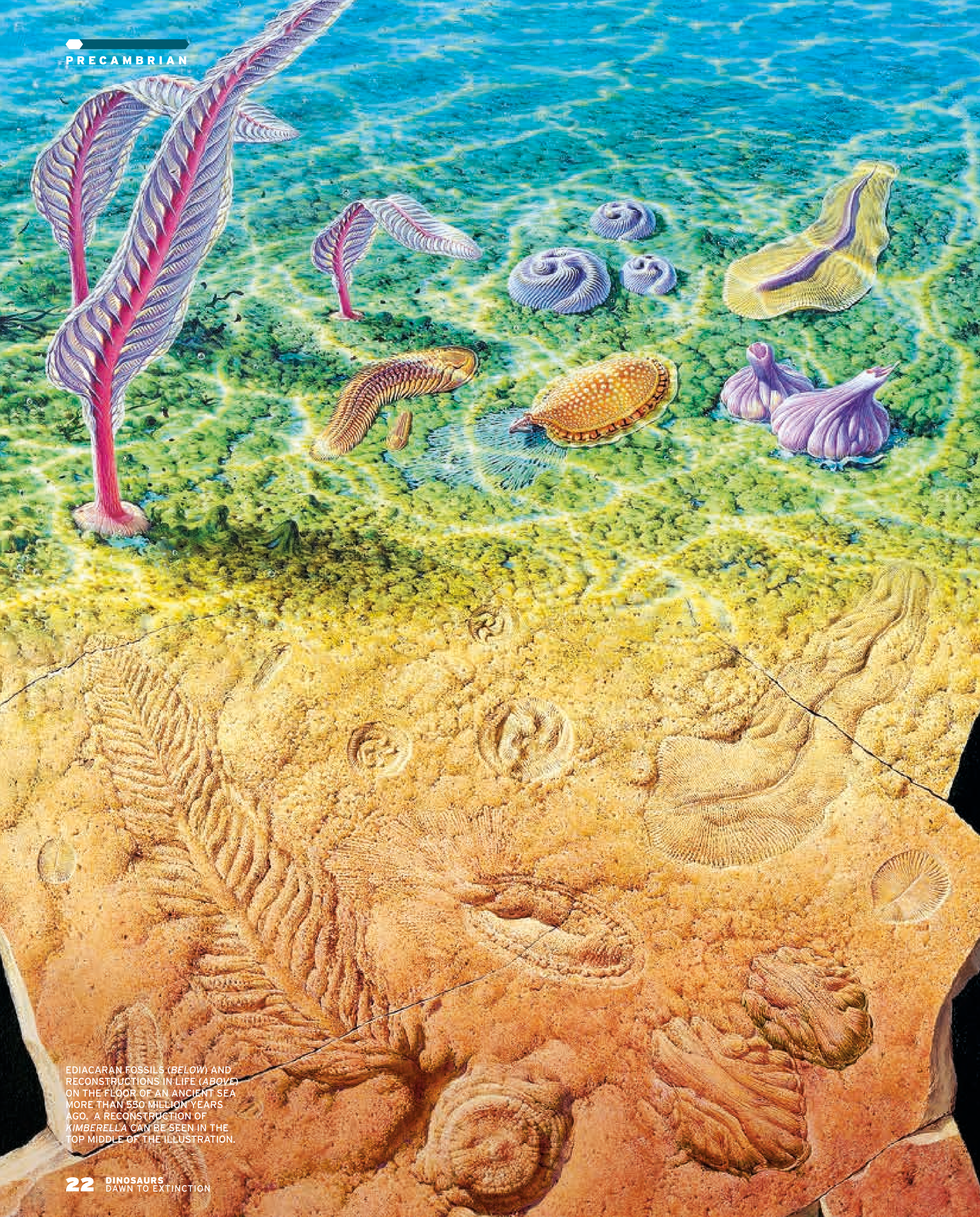


ILLUSTRATION: PETER TRUSLER



EDIACARAN FOSSILS (*BELOW*) AND RECONSTRUCTIONS IN LIFE (*ABOVE*) ON THE FLOOR OF AN ANCIENT SEA MORE THAN 550 MILLION YEARS AGO. A RECONSTRUCTION OF *KIMBERELLA* CAN BE SEEN IN THE TOP MIDDLE OF THE ILLUSTRATION.

TWO
BEFORE THE DINOSAURS

THANKS TO THEIR ABILITY TO LOOM LARGE IN POP CULTURE, MOST OF US KNOW SOMETHING ABOUT THE DINOSAURS. BUT HOW OFTEN DO YOU PONDER, "WHAT DID ANIMALS BEFORE THESE BEASTS LOOK LIKE?" LET US TAKE YOU INTO THAT WORLD, WHEN MUCH OF LIFE WAS A MERE BLUEPRINT FOR THE TANK-LIKE *T. REXES* AND PETRIFYING PTERODACTYLS THAT WOULD FOLLOW, AND WHEN BODIES WERE SOFT AND LIFE WAS HARD.

PG.

25
"Visions of Hell"
A dark sun, a looming blood-shade moon, punishing meteorite impacts and no sound at all. Welcome to Earth at its most unrecognisable, when life was young.

31
The big boom
What do we mean when we say 'the Cambrian explosion', and what does this momentous period have to do with the remains of long-dead medieval knights?

34
Chain of catastrophes
Volcanoes, methane, bacteria, oh my. This chain of disastrous natural events may well have spiked ocean temperatures to 40 degrees Celsius.

ILLUSTRATION: PETER TRUSLER

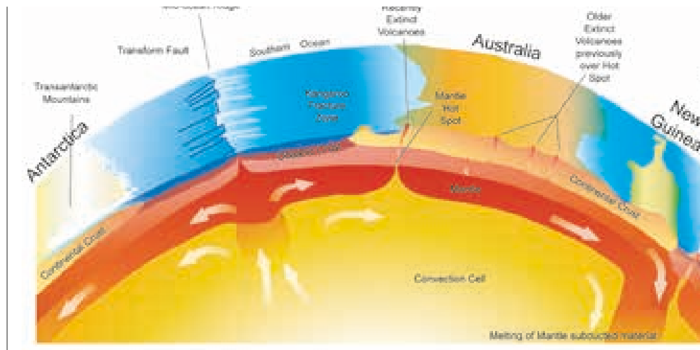
LATE PRECAMBRIAN **650** MILLION YEARS AGO

42.5%

LASTING NEARLY 2 BILLION YEARS, THE PROTEROZOIC ERA ACCOUNTS FOR 42.5% OF ALL GEOLOGIC TIME. THE PRECAMBRIAN IS DIVIDED INTO THREE MAJOR PARTS: THE HADEAN (FROM 4,500 TO 4,000 MYA), THE ARCHEAN (FROM 4,000 TO 2,500 MYA). AND THE PROTEROZOIC (FROM 2,500 TO 541 MYA).

THE FIRST TRACE OF LIVING THINGS ON OUR PLANET ARE THE REMAINS OF ONE-CELLED ORGANISMS AND THE STRUCTURES THEY BUILT: STROMATOLITES. THESE CAN STILL BE SEEN FORMING TODAY IN THE SALTY LAGOONS OF SHARK BAY ON THE WEST COAST OF AUSTRALIA.

Life at this time, more than 3.8 billion years ago, was all in the water – mainly in the seas – except perhaps for some microbes that might have been on land. The land was uninhabited for billions of years. But it was in much younger times that dinosaurs first moved onto the land. And they came after a number of major events that occurred to transform the land – the development of many-celled organisms from single cells, the spread of complex, multi-celled animals and plants, the appearance of eyes (and predators who used them), the rapid diversification in the seas with the development of skeletons and shells, the move onto land and finally the appearance of dinosaurs, mammals and humans. It was a long, long journey. In *Dinosaurs: Dawn to Extinction,* the visitor has a chance to follow life through all these times, using traces, soft impressions, bones, shells and art to capture the best estimate that science and art provide, allowing us all to unravel this traveler's tale.



ABOVE:
A CROSS SECTION OF OUR PLANET'S EXPLAINS WHY THE CONTINENTS ARE ALWAYS ON THE MOVE AND THE OCEAN BASINS COME AND GO – CONTINENTAL DRIFT DRIVEN BY PLATE TECTONICS. IT ALSO MAKES CLEAR WHY VOLCANOES ARE WHERE THEY ARE, AND WHY EARTHQUAKES HAPPEN WHERE THEY DO – THE INNER PART OF OUR EARTH IS HOT, MOBILE AND ACTS LIKE BOILING SOUP. *(PATRICIA VICKERS-RICH)*

"Visions of Hell would not be far removed from the pictures painted of earliest Earth by the theoretical constructs of geologists and astrophysicists. Reconstruction of the first moments of a solid Earth conjure up a most inhospitable place. There was no atmosphere. Round and round this early Earth circled a huge, reddish Moon, closer than it is today. A dim Sun, the Earth's nearest source of great energy, hung in a black, starry sky. Slicing thorough the darkness were hundreds, thousands of extraterrestrial visitors, meteorites that pummeled the Earth's dark surface, their impacts bright, fiery flashes that glowed, then dimmed into blackness... All was silent – for with no atmosphere, no air, there was no sound transmission."
– Fedonkin et al., 2007

WEIRD BEGINNINGS: THE DAWN OF ANIMALS AND PLANTS

THE PRECAMBRIAN

EVEN THOUGH THE OLDEST ROCKS ON EARTH CONTAIN TINY crystals of zircon, which have been dated at around 4,500 million years old, the first sign of life that most scientists agree on does not appear until around 3,800 million years ago. Stromatolites are structures that are built like towers or flat layers by single-celled bacteria and algae, trapping sediment or causing limestone to precipitate. These structures are still forming today in places like Shark Bay along the arid coast of Western Australia and in the Middle East – in very restricted and highly saline environments. These structures were widespread in the early history of Earth, as the planet's environments and inhabitants were much different from those of today.

There was, for example, much less oxygen in the oceans until bacteria and algae began producing oxygen. They turned sunlight into energy by a process called photosynthesis, which most plants do today. A byproduct of this chemical reaction is oxygen. The oceans in times past were often quite stratified, and so ocean bottoms often may have been anoxic – low in oxygen – even though the surface waters were likely quite full of this element. The seas may also well have been much more saline (salty).

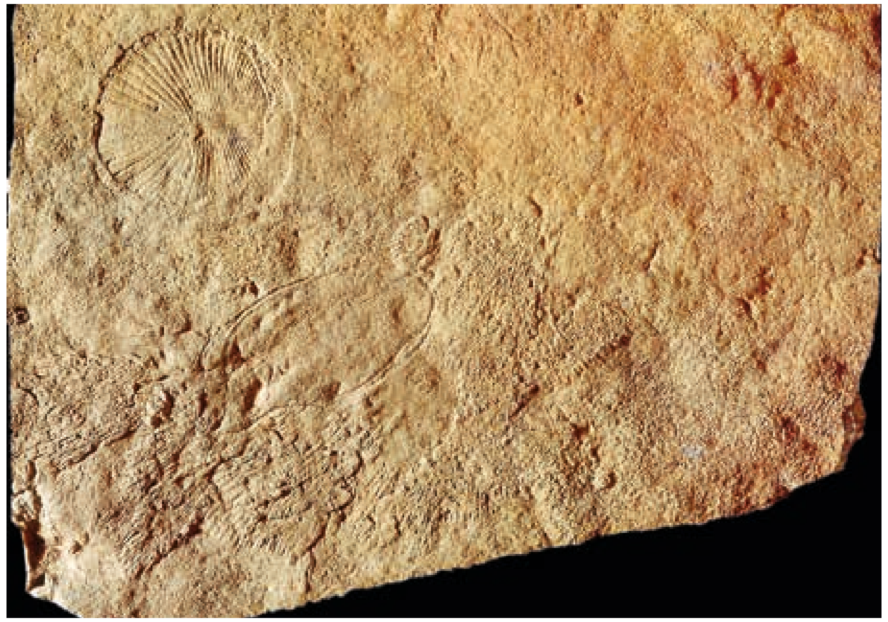
But there was one other factor that today makes the growth of stromatolites difficult – in Precambrian times more than 540 million years ago, there were few grazing animals that could feed on the algae or the bacteria, which either trap the sediments or cause the precipitation of the stromatolitic structures. But in the Cambrian and younger times, animals like snails and fish began to feast on such organisms – almost like sushi – and thus stromatolites today only survive in areas that these grazers do not frequent – like Shark Bay off the Western Australian coast, where lagoonal waters are so salty that snails and fish do not linger there.

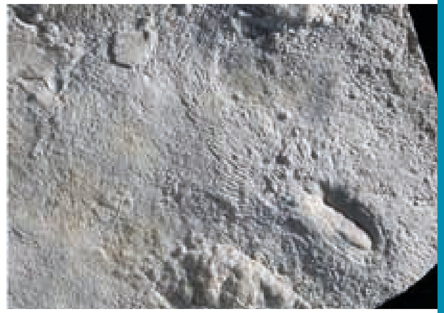
It was during these early days of our planet that many of the Earth's major ore deposits formed. Rich in lead, zinc and iron, they were critical to civilization as we know it. Many of these deposits are no longer forming

LEFT:
STROMATOLITES IN SHARK BAY, WESTERN AUSTRALIA, WHICH ARE STILL FORMING TODAY.

TOP:
ZIRCON CRYSTAL *(PATRICIA VICKERS-RICH)*

ABOVE:
TRUSLER'S RECONSTRUCTION OF *BRADGATIA*, AN ORGANISM THAT LIVED ATTACHED TO THE SEA FLOOR MORE THAN 565 MILLION YEARS AGO. *(PETER TRUSLER)*





in any quantity. The banded iron formations (BIFs) of North America, southern Africa and Western Australia are some examples, represented by the large heavy red-and-black striped rock in the Oculus. BIFs formed when there was a very limited supply of oxygen, but with oxgen levels increasing as single-celled organisms such as cyanobacteria and algae produced oxygen, the atmosphere began to change. For some organisms, it became toxic. For others, it was an opportunity and as oxygen levels rose, the first animals appeared – between 1,200 and 800 million years ago.

It was between 800 million and 600 million years ago that profound changes took place on Earth, ones that fundamentally affected life itself. The long dominance of microscopic, single-celled life forms was disturbed by massive glacial events, or Snowball Earth, and the build-up of oxygen in the atmosphere and oceans. The oxygen was toxic to the very organisms that had produced it. But some organisms developed antioxidants and survived this change. They then formed multicellular organisms – and bang! Life got big. And complicated.

Although future discoveries may uncover older evidence, at present

ABOVE:
EDIACARANS FROM THE LATE PRECAMBRIAN SHOW THE 'SYMMETRY OF GLIDING REFLECTION' – THEIR TUBULAR STRUCTURE IS SLIGHTLY OFFSET ON EITHER SIDE OF THEIR MIDLINES – UNLIKE THE BILATERAL SYMMETRY MOST COMPLEX ANIMALS HAVE TODAY. *PTERIDINIUM (ABOVE)* FROM NAMIBIA HAD STIFFENED BODY WALLS THAT MAY HAVE BEEN CONSTRUCTED OF CELLULOSE, A TOUGH MATERIAL USUALLY RESTRICTED TO PLANTS. *(FRANK COFFA AND PATRICIA VICKERS-RICH)*

ABOVE LEFT:
DICKINSONIA FROM SOUTH AUSTRALIA REACHED UP TO A METER IN LENGTH BUT REMAINED VERY THIN, AND *KIMBERELLA* (*LOWER LEFT OF SLAB*), WITH FEEDING TRACES. *(FRANK COFFA AND PATRICIA VICKERS-RICH)*

ABOVE RIGHT:
BANDED IRON FORMATION (BIF), REPRESENTING IRON-RICH SEDIMENTS THAT WERE DEPOSITED IN THE SEA WHEN THE WORLD'S OCEANS HAD LITTLE, IF ANY, OXYGEN. MOST WERE DEPOSITED BEFORE 2 BILLION YEARS AGO. HOWEVER, THE YOUNGEST-OCCURRING BIFs FORMED IN SMALL, OPENING OCEAN BASINS WHERE OXYGEN WAS SCARCE, MUCH LIKE THE RED SEA TODAY, AROUND 600 MILLION YEARS AGO IN PLACES LIKE NAMIBIA AND BRAZIL. *(STEVE MORTON)*

the first known animals are the Ediacarans. But they're enigmatic. All that remains of them are trails and impressions of these soft-bodied organisms. Most are squashed and deformed by the events and sediments that entombed them. These first animals did not produce any sort of protective hard parts or any internal support systems, such as shells and skeletons.

Imagine an animal's life without these structures: without eyes, a mouth, or even a stomach. This was not a major predicament at first, since there was no predation as we know it either. Microbial mats that covered the sea floors at that time were apparently one of the only options on the earliest menus. While those circumstances were about to irreversibly change, organisms had developed body forms ideal for exploiting the Ediacaran environment. The structure of many of the Ediacarns simply maximized the surface area of these organisms so that all 'food' could be absorbed across a membrane directly into the body of the chemotrophs, such as the rangeomorphs, which 'fed' by simply absorbing the chemicals in the water.

The rangeomorphs may even have had symbiotic algae living in their bodies, a bit like the jellyfish of Jellyfish Lake in Indonesia – which have lost all stinging cells and their guts. Instead, they get their energy from photosynthesizing algae in their bodies and by migrating at night down to the nitrogen-rich lake bottom. Here, they soak up the chemicals needed to run their physiological cycles.

Mathematicians describe the structure of this beautifully adapted feeding cycle as 'fractal'. This is a common branching system generated by motion, accumulation or by growth of particles in a two-dimensional or three-dimensional space, and can happen with abiotic materials – in mineral stains such as dendrites and in the way crystals grow.
This pattern is also employed in biology – in colonial growth of corals and lichens, fungi and large algal accumulations. Even the leaves of many plants show an abundance of this pattern. Such fractal patterns can also be observed in the organs of complex animals – in the arteries and veins of the blood system, in lungs and gills. It seems the genetic 'machinery' that could generate this sort of pattern was present early in the history of large life.

Not all Ediacarans had such a fractal pattern. Others boasted a structure of stacked tubules, but the arrangement of bits and pieces of their bodies did not follow the same pattern as that of most animals today. These days, most complex animals tend to have what is called bilateral symmetry, whereby one side is a mirror image of the other. In some Ediacarans the symmetry is offset, called by some the 'symmetry of gliding reflection'. The tubes in these animals are offset on either side of the midline – almost like looking into a trick mirror at the carnival!

ABOVE, CLOCKWISE FROM TOP:
RANGEA FROM 550-MILLION-YEAR-OLD SHALLOW SEA SEDIMENTS OF NAMIBIA, SOUTHWESTERN AFRICA. THESE LITTLE ORGANISMS, ONLY A FEW CENTIMETERS TALL, STOOD LIKE PUNCHING BAGS ON THE ANCIENT SEAFLOOR, TAKING ON, EVEN IN LIFE, SAND TO STEADY THEIR BASE AND HELP THEM KEEP AN UPRIGHT STANCE. *(MIKHAIL FEDONKIN)*

RANGEOMORPH FROM 565-MILLION-YEAR-OLD SEDIMENTS OF NEWFOUNDLAND. IT LIKELY FED BY ABSORBING CHEMICALS OUT OF THE WATER COLUMN ACROSS THE HUGE SURFACE AREA PRODUCED BY THE FRACTAL STRUCTURE OF ITS BODY PLAN. *(GUY NARBONNE)*

KIMBERELLA FROM THE LATE PRECAMBRIAN OF RUSSIA. ON THIS CLAYSTONE SLAB ARE PRESERVED ANIMALS AND THE TRACES THEY LEFT BEHIND AS THEY FED ON THE MICROBAL MATS COVERING THE SEA FLOOR. THIS LITTLE GROUP WAS OVERWHELMED BY A DOWNSLOPE AVALACHE. *(FRANK COFFA)*

THE TINY SHELLS (ABOUT 10 MILLIMETERS LONG) OF SOME OF THE FIRST ANIMALS TO DEPOSIT HARD SKELETONS: *CLOUDINA*, FROM THE LATE PRECAMBRIAN OF NAMIBIA. *(PATRICIA VICKERS-RICH)*

Even though most of the Ediacarans seem rather strange and had body structures very unlike those of animals today, there were some that were precursors of animals we know today. One of these is *Kimberella*, which seems to have had a soft protective shell, and left feeding traces similar to those of a snail. This little mobile animal had microbial mat on its menu – it liked sushi!

After more than 3,000 million years came a revolutionary change: many life forms began depositing hard skeletons and shells. This may well have been a reaction to greater availability of elements like phosphorus in the surface waters of the ocean, brought about by the ocean overturn during the glaciations of 'Snowball Earth'. The way life worked was about to alter forever.

EVIDENCE OF THE EARLIEST LIFE COMES TO US THROUGH VIOLENT EVENTS THAT BURIED ORGANISMS ALIVE. THEIR DELICATE YET RESILIENT FORMS PROVIDED SUFFICIENT PHYSICAL RELIEF TO BE MOLDED BY THE ENTOMBING SANDS. THIS EDIACARAN RECONSTRUCTION SHOWS THE BURIAL EVENT OF A RECENTLY DESCRIBED FOSSIL, *BURYKHIA HUNTI.*

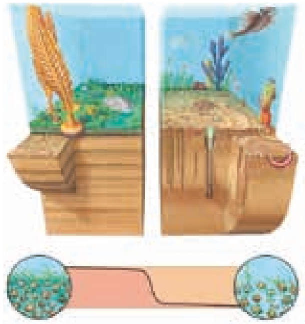
ILLUSTRATION: PETER TRUSLER

THE CAMBRIAN EXPLOSION: DIVERSITY BLOSSOMS IN THE PALEOZOIC

A TIME BEFORE THE DINOSAURS

THE MOMENTUM OF LIFE'S INTERACTIONS DRAMATICALLY increased in complexity during the Cambrian, which began around 541 million years ago. Or so it seems – once living things began depositing hard parts, shells and skeletons, the fossil record exploded in variety, mainly because hard parts were much more effectively preserved than soft-body impressions. At this time the competition between organisms was fierce! All sorts of combinations were found to gain strength and protection.

Some life forms began secreting minerals around or within their tissues. Others developed strong, resilient protein structures or tough carbohydrates. The introduction of these new body-building materials offered survival advantages by either affording better protection or by providing a more efficient means to procure and process food. It also enabled architectural advantages. Multicellular organisms could become structurally more complex, more efficient, and in maximizing body size an individual would not be so easily edible. Luckily for us, they would not decay so easily after death either. There was a tendency to become mineralized further once buried in sediments. And so the fossil record blossomed. These new developments were to the paleontologist like relics left behind by some long-dead valiant knight; his armour and other tools of his trade, scattered amid the ruins of the castle or battlefield, became beacons of his past existence, offering clues as to the world he inhabited.



ABOVE: OBSERVE THE MARKED DIFFERENCE BETWEEN PRECAMBRIAN TIMES (*LEFT*) AND CAMBRIAN AND YOUNGER TIMES. BEFORE THE CAMBRIAN EXPLOSION, ANIMALS DID NOT BURROW, MICROBIAL MATS WERE WIDESPREAD ON THE OCEAN FLOORS AND WERE A MAJOR SOURCE OF FOOD. IN ADDITION, ANIMALS DID NOT HAVE HARD PARTS AND LACKED EYES, AND PREDATORS WERE ABSENT. EVERYTHING CHANGED IN THE EARLY PART OF THE CAMBRIAN. *(PETER TRUSLER)*

This was the commencement of a new era: the Paleozoic. During its earlier phases, life was still largely confined to aquatic environments: lakes and streams on the continents and islands, and in the sea. Photosynthetic microorganisms continued to provide the base of the food chain, as they still do today, but this was increasingly augmented by aquatic plants, which moved steadily onto land from the Late Silurian and Devonian periods onward. Life for animals quickly turned into a game of hide and seek, just as it is in the present.

It seems that the food options for metazoans (animals) rather quickly expanded from Cambrian times onwards. Self-controlled movement had been 'invented'. Many animals could now actively seek out food, find partners, take shelter or escape predators by writhing, swimming, crawling or burrowing. The process was facilitated by and required increasingly sophisticated sensory systems to co-ordinate, to feel, to taste, to smell, and to see the world. These revolutions in sensing the world around them may have begun during the closing stages of the Precambrain, but the major consequences did not become clear until the Paleozoic.

And from then on it was a race to invade every possible niche the world offered. Animals developed jaws and sophisticated locomotory systems leading them onto land, and eventually some of these gave rise to dinosaurs... but not without another major disaster!

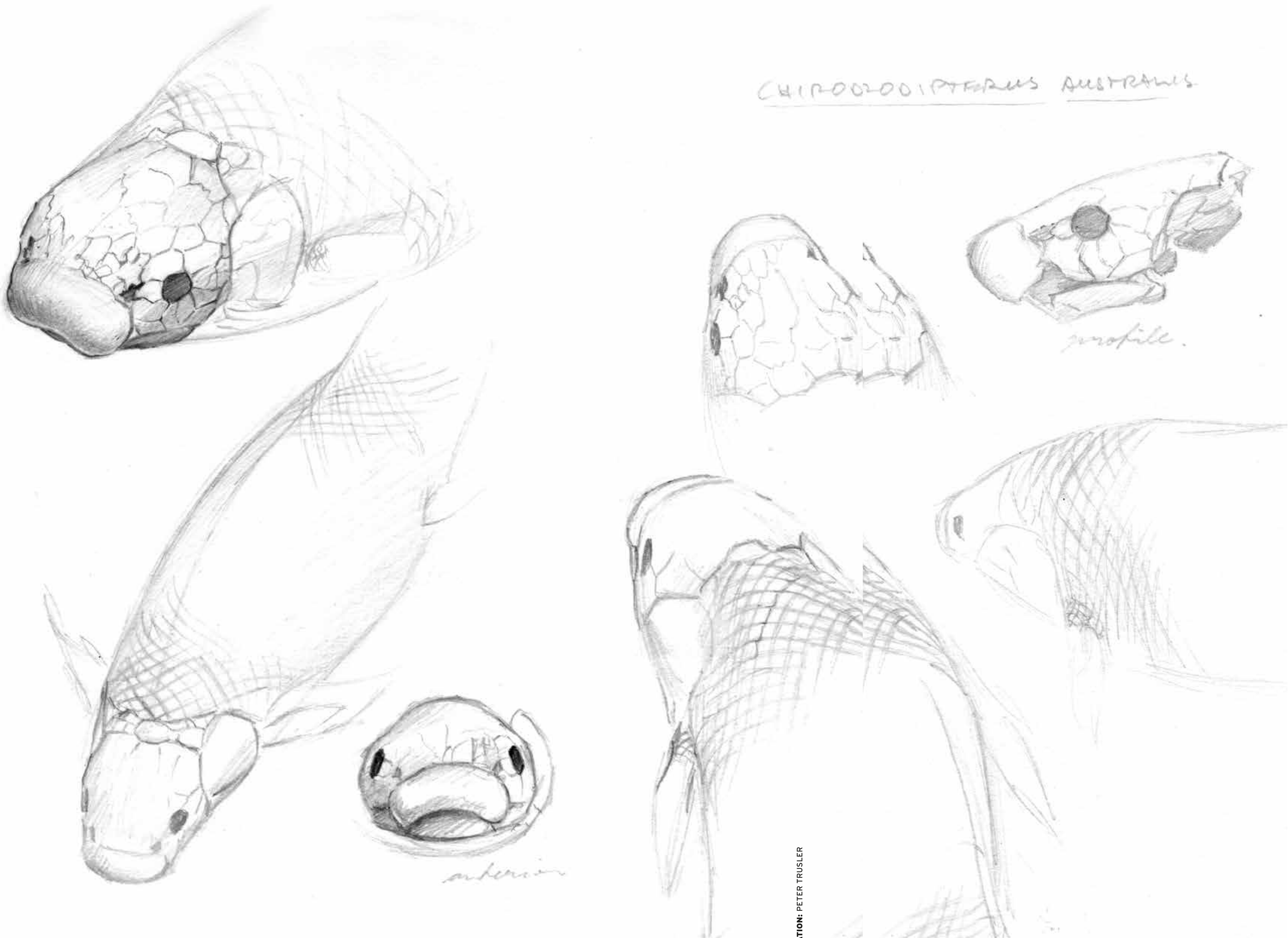


ILLUSTRATION: PETER TRUSLER

PRELIMINARY RECONSTRUCTION OF THE LUNGFISH *CHIRODIPTERUS*

THE EARLY PALEOZOIC WAS A TIME OF GREAT OPPORTUNITY AND LIFE RADIATED INTO MANY DIFFERENT AREAS. THE SEA FLOOR BRISTLED WITH ANIMALS THAT EVENTUALLY LED TO CURRENTLY LIVING FORMS, SUCH AS THE TRILOBITES, RELATIVES OF JOINT-LEGGED ANIMALS LIKE CRABS; NAUTILOIDS, RELATIVES OF THE LIVING *NAUTILUS*; EVEN A VARIETY OF FORMS RELATED TO STARFISH, SAND DOLLARS AND SEA LILIES; AND CORALS. THE WORLD WAS MODERNIZING. *(FEDONKIN, ET AL., 2007, COURTESY OF THE PALEONTOLOGICAL INSTITUTE, RUSSIAN ACADEMY OF SCIENCES, MOSCOW)*

ARCHAEOCYATHIDS WERE AMONG THE FIRST ANIMAL REEF BUILDERS – THEY ARE FIRST KNOWN IN THE EARLY CAMBRIAN, BUT BY THE MIDDLE OF THIS TIME PERIOD THEY DISAPPEAR, GIVING WAY TO PRIMITIVE CORALS, WHICH LATER GAVE RISE TO THE CORALS WE KNOW TODAY. *(STEVE MORTON)*

ALTHOUGH GRAPTOLITES MAY NOT LOOK FAMILIAR, THIS GROUP INCLUDED OUR CLOSEST ANCESTORS IN THE CAMBRIAN AND WERE EXTREMELY SUCCESSFUL AT COLONIZING THE SEA FLOORS AS WELL AS THE OPEN WATERS FOR MANY MILLIONS OF YEARS IN THE PALEOZOIC ERA. *(STEVE MORTON)*

RIGHT AFTER THE BEGINNING OF THE CAMBRIAN ANIMALS BEGAN TO BURROW. THESE FOSSIL BURROWS, CALLED SKOLITHOS, ARE THE REMINDERS OF THIS BEHAVIOR, GIVEN THE NAME VERDUN SYNDROME AFTER THE FAMOUS BATTLEGROUND IN WORLD WAR I, WHERE THE ONLY WAY TO SURVIVE WAS BY DIGGING TRENCHES AND PUTTING ON ARMOUR – PRECISELY WHAT HAPPENED IN THE EARLY CAMBRIAN, IN THE FORM OF BURROWING AND SKELETONIZING. *(STEVE MORTON)*

TRILOBITES FROM THE CAMBRIAN. THESE COMPLEX ANIMALS HAD EXTERNAL SKELETONS, EYES, AND WERE QUITE CAPABLE OF MOVING ABOUT. THEIR LIVING RELATIVES INCLUDE THE CRABS AND SHRIMP. *(STEVE MORTON)*

THE BOTTOM-FEEDING *GRIPHOGNATHUS* PROBES ABOUT LIKE A PLATYPUS IN THE ORGANIC RICH MUD DURING THE LATE DEVONIAN OF AUSTRALIA. THE LARGE PLACODERM *EASTMANOSTEUS (PICTURED RIGHT)* IS CONSIDERING WHAT MIGHT BE ITS NEXT MEAL. BOTH THESE FISH, THE FORMER OF WHICH GAVE RISE TO THE LUNGFISH WE KNOW TODAY, ENJOYED THE PROTECTION OF THE CLEAR MARINE WATERS IN THE VICINITY OF THE GREAT GOGO REEF, WHICH IS WELL EXPOSED IN WEST AUSTRALIA TODAY. *(PETER TRUSLER)*

THE WORST OF DISASTERS: THE PERMO-TRIASSIC DEBACLE

THE SCENE IS SET FOR DINOSAURS

LIFE HAD ITS UPS AND DOWNS THROUGHOUT THE PALEOZOIC Era from the Cambrian to the Permian, from around 541 million to about 252 milion years ago. There were glaciations and greenhouse times, some causing a number of extinctions. But the big one was to come right at the end of this time. Clocking in between 253 million and 252 million years ago, it was a series of major events that defined the Permo-Triassic boundary – the line between the Paleozoic and the Mesozoic eras.

Researchers estimate that upwards of 96% of all marine species, 70% of land-dwelling vertebrates and upwards of 57% of all families and 83% of all genera of insects were wiped out at the end of the Permian. This is the only mass extinction known in the fossil record of insects! With such a loss of biodiversity, recovery of life took much longer than after any other global disaster since. It required at least 10 million years, if not longer, for the many lost 'jobs' (ecological niches) to be repopulated. And many of the new 'employees' were from very different groups than had populated the 'workforce' in the late Paleozoic. Different organisms moved into the niche space that had been left open by the extinction of many other organisms before the major event at the end of the Permian.

What caused this debacle is a major topic of discussion in scientific circles. It is clear that different groups were affected by extinction at different times during the latest Permian. Life in the marine realm was nearly entirely wiped out, except perhaps for microbes. On land, insects were profoundly affected, and the flora of the Paleozoic scarcely survived this mass destruction. The gymnosperms that had so dominated the later Paleozoic were replaced by the lycopods, the club mosses; only later do the gymnosperms make a comeback. The seed-ferns, such as *Glossopteris*, took a major hit. And close to two-thirds of the labyrinthodont amphibians as well as the reptiles, including the mammal-like reptiles, disappeared forever. The larger woodland plants were chronically stressed, and these assemblages did not recover lost ground for more than 5 million years, well into the Triassic. The mammal-like reptiles, which had long dominated the terrestrial landscapes, did survive this disaster, but only a few. They then reinvented themselves in the Triassic, and were major competitors for eco-space, rubbing shoulders with the first dinosaurs and other more primitive reptiles at that time.

AT THE END OF THE PERMIAN MAJOR DISASTER STRUCK LIFE. IT WAS IN LARGE PART BROUGHT ABOUT BY MASSIVE VOLCANIC ACTIVITY IN WHAT IS NOW SIBERIA, PRODUCING THE SIBERIAN TRAPS.

And what caused all this? The current theory is that it was a series of catastrophes, the combination of which brought about this major demise of life – in the sea and on land. The huge volcanic outpourings of the Siberian Traps eruptions, which occurred near large accumulations of coal and a continental shelf, may have set off large emissions of carbon dioxide and methane. Global warming, not long after the cessation of major worldwide glaciation, likely led to very low oxygen levels in the oceans, which could have been great encouragement for expansion of bacteria that could live in low oxygen conditions – especially a group called the sulphur-reducing bacteria. This would then lead to a massive production of toxic hydrogen sulphide. In short, it was an environmental mess, especially toxic to those organisms which required oxygen, and ocean surface temperatures may well have reached as much as 40 degrees Celsius. It would certainly have been a Greenhouse Earth. With we humans introducing more and more carbon dioxide to the atmosphere thanks to the burning of fossil fuels, can we learn something from this story today?

LIFE IN THE BEGINNING

THE FIRST ANIMALS LIVED IN THE SEA AND HAD SOFT BODIES. OVER SEVERAL HUNDRED MILLION YEARS, THEY DEVELOPED FEATURES THAT IMPROVED THEIR CHANCES OF SURVIVAL. TO PROTECT THEMSELVES FROM PREDATORS, THEY DEVELOPED EYES, SHELLS, SKELETONS AND BURROWING CAPABILITIES. WHEN PLANTS BEGAN TO GROW ON LAND, THERE WAS A MOVEMENT OUT OF THE SEA AND ANIMALS NEEDED TO ADAPT TO A NEW LIFE ON LAND. THESE CREATURES DEVELOPED LIMBS TO SUPPORT THEIR WEIGHT, MOVE AROUND, GRIP AND BALANCE ON HARD SURFACES. THEY ALSO NEEDED LUNGS TO HELP THEM BREATHE, SKIN TO KEEP THEM FROM DEHYDRATING, AND EGGS THAT THEY COULD LAY ON LAND. THEY EVEN HAD TO DEVELOP NEW WAYS TO EAT. ANIMALS BEGAN TO LOOK VERY DIFFERENT.

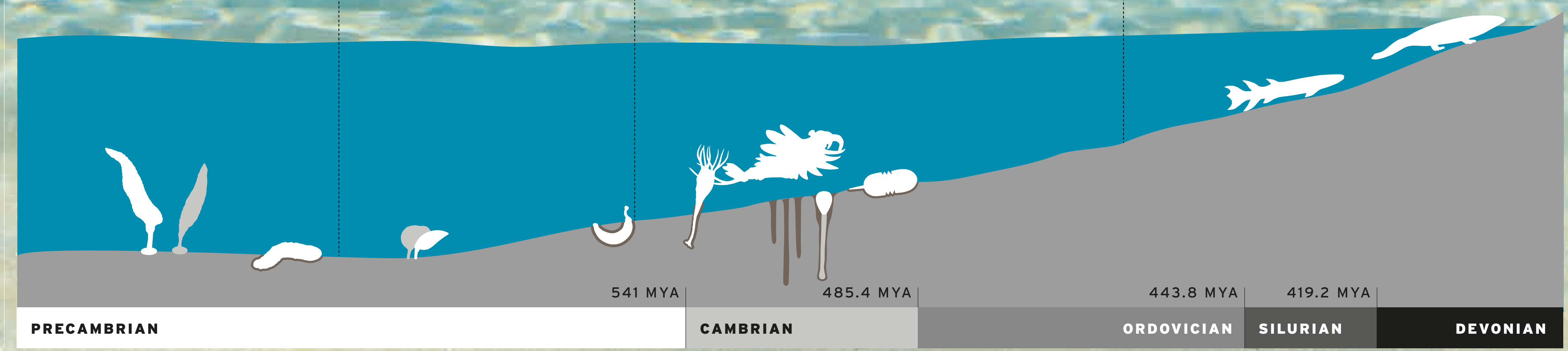
SOFT AND HARD SHELLS

As the cold of the glaciations at the end of the Precambrian caused the upwelling of phosphorus-rich bottom waters, animals first developed hard shells, though exactly why is still not understood. When eyes developed and true predators came onto the scene, shells were a source of protection.

ELEPHANT SKIN
DURING THE PRECAMBRIAN, MICROBIAL MATS WERE WIDESPREAD ON THE SEA FLOORS, AND THESE MATS LEFT THEIR IMPRESSION IN THE OVERLYING SEDIMENTS THAT BURIED THEM. THEIR IMPRINTS RESEMBLED THE SKIN OF AN ELEPHANT – THUS THEIR NAME.

TRILOBITES
TRILOBITES WERE ARTHROPODS, OR JOINT-LEGGED ANIMALS WITH EXTERNAL SHELLS. CERTAIN TRILOBITES COULD GROW QUITE LARGE, UP TO 70 CENTIMETERS IN LENGTH. SOME SPECIES OF TRILOBITE WERE PLANT-EATERS, WHILE OTHERS WERE CARNIVORES.

AMMONITE
AMMONITES WERE SHELLED SEA CREATURES, RELATIVES OF TODAY'S SQUID, CUTTLEFISH AND OCTOPUSES. AN AMMONITE COULD RISE OR SINK IN THE WATER BY CONTROLLING HOW MUCH AIR IT ALLOWED INTO CHAMBERS IN ITS SHELL.

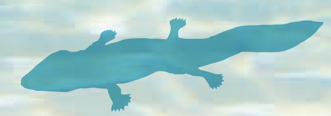


THE RISE OF EYES

In the early days of life on Earth, no animals, which all inhabited the seas at the time, had eyes. The first eyes developed at the beginning of the Cambrian and many animals had compound eyes. That means they had not just one eye, but many, so they could see from many different angles. Once eyes appeared, predators arose. Today, there are still animals with compound eyes, such as the fly and grasshopper.

THE DEVELOPMENT OF BURROWING

With the birth of predators, to avoid becoming a meal animals developed new strategies; one was burrowing, and the other, the development of shells. The constant churning of the sediments as animals dug deep to find safety introduced oxygen into ocean sediments, and food began to grow there. Thus, the bottom of the sea was no longer covered by microbial mats.



THE DEVELOPMENT OF LIMBS

In the early Paleozoic, fish developed fins that allowed them to move about, but it was not until the Late Devonian that they began to venture out on land. As they did, some species developed terrestrial limbs through natural selection. Modifications in the shoulder and pelvic girdles and the way limbs articulated led to a variety of new types of locomotion. The land had finally been conquered.

ILLUSTRATION: PETER TRUSLER

THREE
FROM DISASTER COMES OPPORTUNITY: THE EARLY TRIASSIC

SOMETIMES, SMALL CLUES CAN LEAD TO MONUMENTAL DISCOVERIES. SUCH WAS THE CASE WHEN PALEONTOLOGISTS USED AN INNOCUOUS-LOOKING, SHEEP-SIZED REPTILE TO GAIN AN INSIGHT INTO THE GEOLOGIC HISTORY OF OUR ENTIRE PLANET. THOUGH THE DINOSAURS MADE THEIR ENTRANCE WHEN THE PLANET WAS STILL RECOVERING FROM MASSIVE TRAUMA, BY THE END OF THE TRIASSIC, THINGS WERE LOOKING UP.

PG.

41

Four-way fight

We tend to think of them as canny, ruthless survivors, but the dinosaurs had their work cut out for them, with not one but three rival groups of animals vying for domination. But who would emerge victorious?

44

Kill or be killed

Following the major extinction event that wiped out the vast majority of species in existence at the time, many ecological niches lay empty. Living in this fiercely competitive world, it paid to keep one's guard up – and to stay sharp.

EARLY TRIASSIC **252–247** MILLION YEARS AGO

COURTESY OF VRIELYNCK, B. AND BOUYSSE, P., 2003. THE CHANGING FACE OF THE EARTH, UNESCO PUBLISHING/ COMMISSION FOR THE *GEOLOGICAL MAP OF THE WORLD*, PARIS

8.5 HOURS

WHEREAS YOU USED TO BE ABLE TO WALK FROM WHAT WOULD BECOME ANTARCTICA TO FUTURE AUSTRALIA, IT WOULD NOW TAKE YOU AT LEAST EIGHT AND A HALF HOURS TO FLY BETWEEN THE TWO.

"The dinosaurs arose in the Triassic, and probably during the Early to Middle Triassic. They enter a world far different from the typical Age of Dinosaurs scenes, a world in which the dominant herbivores were synapsids (dicynoldonts and chiniquodontids) and rhynchosaurs, and carnivores were cynodonts and basal archosaurs of various kinds, previously called thecodontians. Into this world came the dinosaurs, initially small bipedal carnivores. They rose to dominance at some point during the second half of the Triassic. Certainly, by the end of the Triassic Period, dinosaurs were abundant and reasonably diverse, and all the major lineages had emerged and diversified."
– Benton in Brett-Surman, et al., 2012

The Early Triassic was stark, and the world did not fully recover its late Paleozoic biodiversity until the Mid to Late Triassic, the time when dinosaurs first appeared. But there were some survivors that prospered. One of these was the mammal-like reptile *Lystrosaurus*, a plant-eater, along with a third group of primitive reptiles, including such forms as procolophonids and the crocodile-like thecodonts. Add to this labyrinthodont amphibians, which had also been successful in the Permian, but were mainly water-dwellers. These intrepid reptiles and amphibians expanded in number but did not reach the biodiversity that they had previously achieved in the Permian. So before the dinosaurs made their appearance there were really three groups that were to be their competitors: the mammal-like reptiles (our ancestors!); a group of more primitive reptiles, some closely related to the living crocodiles; and the labyrinthodont amphibians. Finally, the dinosaurs appeared in Middle Triassic times and by then, their immediate reptilian and amphibian competitors were well tooled up to give them a run for their money.

Lystrosaurus, one of the survivors of the Permian crisis, was a mammal-like reptile. It was a sheep-sized mammal-like reptile, one which once lived all across the ancient supercontinent Pangaea. Its teeth were reduced to a pair of tusks. Its nostrils and eye sockets were located near the top of the skull, the snout turned down at the tip suggesting that it was an amphibious feeder, much in the fashion of the living hippopotamus. *Lystrosaurus* was quite closely related to the Permian mammal-like reptile *Dicynodon*, a member of the late Paleozoic terrestrial fauna that had

ABOVE: *LYSTROSAURUS* FROM THE EARLY TRIASSIC OF RUSSIA, MORE THAN 247 MILLION YEARS OLD. ONCE THOUGHT TO BE RESTRICTED TO GONDWANA, THIS SUCCESSFUL MAMMAL-LIKE REPTILE WAS SPREAD ALL OVER THE SUPERCONTINENT OF PANGAEA, ONE OF THE FIRST SURVIVORS TO MOVE INTO THE VACANT SPACES LEFT BY THE PERMO-TRIASSIC EXTINCTION EVENTS. REPLICA. *(FRANK COFFA)*

IMAGE: UNIVERSITY OF SAN JUAN NATURAL SCIENCE MUSEUM

"THE VALLEY OF THE MOON" OF ISCHIGUALASTO NORTH OF SAN JUAN IN WESTERN ARGENTINA IS A PARADISE FOR PALEONTOLOGISTS - IT HAS PRODUCED OVER THE YEARS ONE OF THE MOST BIODIVERSE VERTEBRATE ASSEMBLAGES ON EARTH RANGING FROM THE MIDDLE TO THE LATE TRIASSIC.

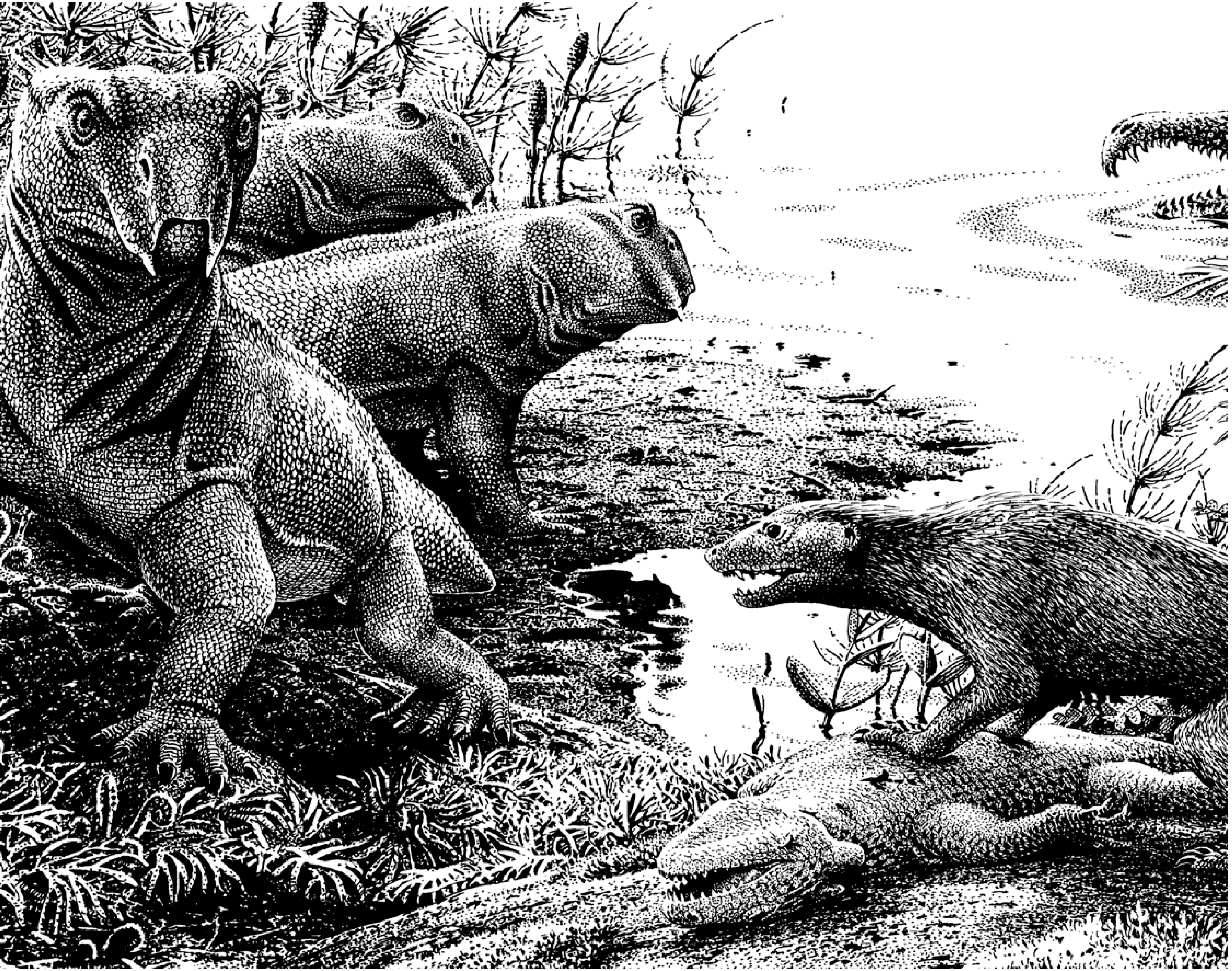


ILLUSTRATION: PETER TRUSLER

LEFT:
EARLY TRIASSIC LAND ANIMALS WERE DOMINATED BY THE MAMMAL-LIKE REPTILES AND ANOTHER PRIMITIVE REPTILIAN GROUP CALLED THE THECODONTS. IN THE FOREGROUND A PREDACEOUS MAMMAL-LIKE *THRINAXODON* TEARS INTO A MORE PRIMITIVE SCALED PROCOLOPHONID. A HERD OF TUSKED *LYSTROSAURUS* STANDS VIGILANT ON THE WATER'S EDGE. IN THE BACKGROUND THE CROCODILE-LIKE *CHASMATOSAURUS* BIDES ITS TIME, PROTECTED SOMEWHAT BY THE POND THAT IS ITS HOME.

been very successful. *Lystrosaurus* is of particular interest as it is known to have lived in many places on the supercontinent Pangaea – and its presence there led paleontologists to use the common occurrence of fossil animals and plants to help reconstruct past supercontinents. South America, Africa, Australia, and even Russia are now very far apart, but in the Triassic they were connected as a supercontinent. *Lystrosaurus* is known on all of these continents. It was one of the keys to putting the pieces back together, along with such plants as *Glossopteris* – useful in reconstructing the great southern continent Gondwana.

When dinosaurs finally appeared on the scene, developing from more primitive reptilian stock, they faced a rather bleak planet. Not only had it been devastated environmentally, but the land masses were "glued" together into one enormous supercontinent, Pangaea. But Pangaea was on the cusp of breaking apart. Much of this huge continental mass, particularly the interior, was an immense desert. Only around the edges had the woodlands begun to recover. One of these places, which fostered the beginnings of dinosaurs as well as the reinvention of the labyrinthodont amphibians, mammal-like reptiles and the other odd-bod reptilian groups, was Ischigualasto, now situated in the northwestern part of Argentina. The great variety of new, intrepid survivors that appeared during the Triassic competed fiercely for ecospace. Understanding their varied lifestyles is just one of the exciting discoveries you have ahead of you during this exhibition. So it's worth taking a close look at the actors on this Triassic stage, one by one.

ABOVE:
THE OUTCROPS IN THE "VALLEY OF THE MOON" OF ISCHIGUALASTO HAVE PROVIDED AN ABUNDANCE OF FOSSIL REPTILES THAT DOMINATED THE FAUNAS OF SOUTH AMERICA. THE FACT THAT THESE ROCKS ARE EXPOSED IN A NOW-DESERT AREA MAKES THIS ONE OF THE RICHEST TRIASSIC FOSSIL SITES ON EARTH. *(UNIVERSITY OF SAN JUAN NATURAL SCIENCE MUSEUM)*

THE CO-EXISTENCE OF REPTILES

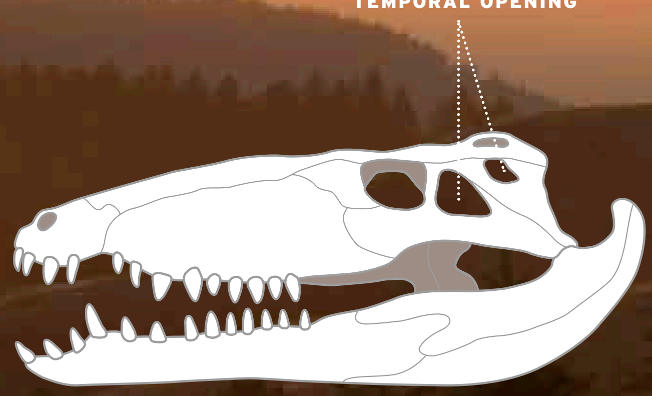
MIDDLE TO LATE TRIASSIC
247-201 MILLION YEARS AGO

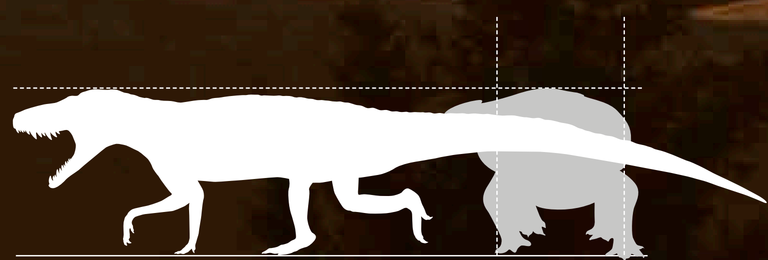
ANIMALS THAT MOVED FROM THE SEA TO LAND FOUND WAYS TO ADAPT TO THEIR NEW ENVIRONMENT. MANY GROUPS DEVELOPED DIFFERENT BODY TYPES AND ALTERNATIVE FEEDING STYLES. WHEN DINOSAURS APPEARED IN THE MIDDLE TRIASSIC, THEY HAD TO LIVE ALONGSIDE CROCODILE-LIKE REPTILES, SOME TRUE CROCODILES, MAMMAL-LIKE REPTILES, AND EVEN SOME AMPHIBIANS. EACH TYPE OF ORGANISM WAS DISTINCT FROM THE OTHER AND HAD DIFFERENT ECOLOGICAL "JOBS", OR NICHES. COMPETITION WAS FIERCE FOR LIMITED RESOURCES AND NOT ALL OF THEM SURVIVED.

BONE STRUCTURES OF THE SKULL

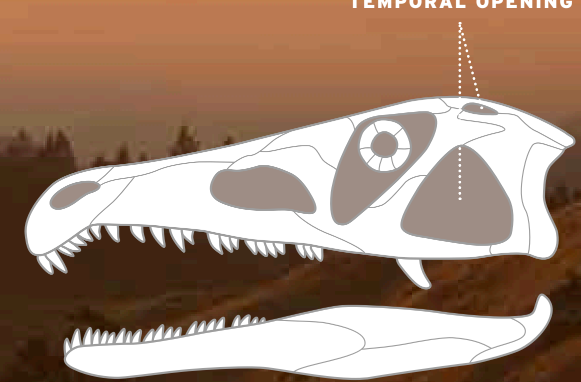
Different reptiles had a varying number of holes – 'temporal openings' – in their skulls. These temporal openings allowed for the expansion of muscle masses operating the lower jaw and a more complex attachment area – as well as lightened the skull itself. These temporal openings are extremely useful in the classification of reptiles.

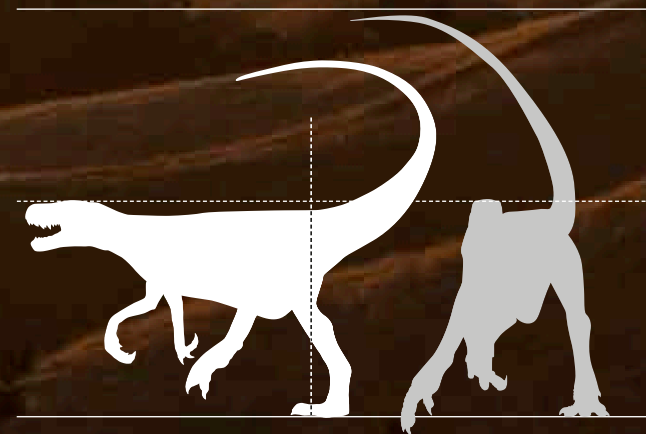
CROCODILE-LIKE REPTILES



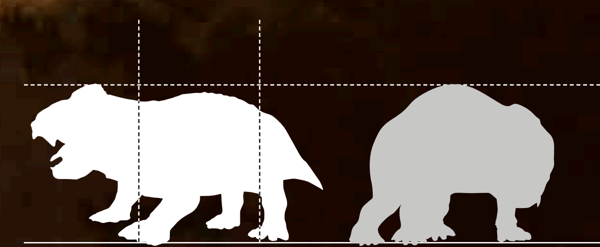


DINOSAURS





MAMMAL-LIKE REPTILES



POSTURES OF REPTILES

You can distinguish between types of reptiles by looking at their posture. Most dinosaurs had an upright posture with their limbs under the body. Many crocodile-like reptiles had legs that spread outward. Most mammal-like reptiles had hind legs that stood upright and front legs that were spread out to the sides, but others had an upright stance.

FOUR
THE MIDDLE AND LATE TRIASSIC: ENTER THE DINOSAURS, AND THE WAR OF THE REPTILES

HAVING ESTABLISHED A FOOTHOLD, THE ANIMALS THAT WERE TO BECOME THE DINOSAURS NOW SET ABOUT DIVERSIFYING, HELPED BY AN EXPANSION IN PLANT LIFE. BUT THAT DOESN'T MEAN LIFE IN PLACES LIKE THE VALLEY OF THE MOON, OR ELSEWHERE ON THE PLANET, WAS EASY FOR OUR REPTILIAN ANCESTORS.

PG.

52
Reptilian odd-bods
Not only does *Aetosauroides* have a mouthful of a name (don't worry, there's a pronunciation guide) - it also came festooned with clumsy-looking feet and the teeth of an anteater.

56
The amphibians
Meet an early amphibian that isn't going to win any beauty contests anytime soon. This beast's strange upward-looking eyes were built for sneaky spying while lying in the water, not for looks.

58
The mammal-like reptiles
Sneak a peek at an expert working on a replica of one of our ancestors, one that is so lifelike it looks like he could playfully nip her fingers at any moment!

64
The dinosaurs
The earliest identified dinosaur didn't look like you would expect - not in size, anyway. Much like cartoon character Speedy Gonzales, *Marasuchus* was a fast critter – and also mouse-sized.

ILLUSTRATION: PETER TRUSLER

LATE TRIASSIC **237-201** MILLION YEARS AGO

COURTESY OF VRIELYNCK, B. AND BOUYSSE, P., 2003. THE CHANGING FACE OF THE EARTH, UNESCO PUBLISHING/ COMMISSION FOR THE *GEOLOGICAL MAP OF THE WORLD*, PARIS

THIS MAP FROM THE LATE TRIASSIC IS NOT MUCH DIFFERENT THAT THE EARLY TRIASSIC, FOR THE CONTINENTAL MASSES DURING THIS PERIOD FORMED ONE MEGACONTINENT - PANGAEA.

2,600KM

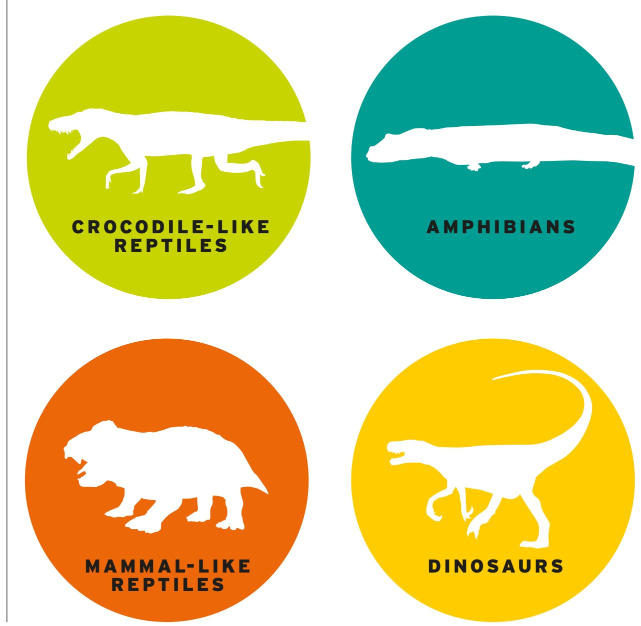
THE CLOSEST DISTANCE BETWEEN SOUTH AMERICA AND AFRICA IS NOW BETWEEN SENEGAL AND BRAZIL, A SPAN OF NEARLY 2,600 KILOMETERS.

AS THE WORLD RECOVERED FROM DISASTER, PLANTS CHANGED FROM ONE SEED FERN TO ANOTHER, THE PERMIAN *GLOSSOPTERIS* FLORA GIVING RISE TO THE NEWLY APPEARING *DICROIDIUM* FLORA. TRUE FERNS CONTINUED AND THE MAIDENHAIR TREES, THE GINKGOPHYTES, ALONG WITH THE PALM-LIKE CYCADS, HORSETAILS AND EVENTUALLY THE EVERGREEN CONIFERS EXPANDED.

This biodiversity growth provided more and more opportunities for the land animals. The mammal-like reptiles took full advantage of it, as did some of the newcomers – the first dinosaurs. And although early in the Middle Triassic, the non-dinosaurian reptiles were essentially in charge, their dominance was challenged in Late Triassic times when dinosaurs pushed into the territories dominated by other groups. The rivers and streams were still held by the labyrinthodont amphibians, but even they began to lose ground towards the beginning of the Jurassic. Only two sorts managed to cross the line into this new period, one last survivor being *Koolasuchus*, which persisted into the Early Cretaceous. There were also other reptilian groups around who joined in the fray, some crocodile-like in appearance, but from many different backgrounds. So began a time of stiff competition. Reptiles, start your engines.

EXAERETODON WAS A MAMMAL-LIKE REPTILE ABUNDANT IN THE LATE TRIASSIC, THAT HAD A LARGE HEAD AND AN UPRIGHT STANCE. *(STEVE MORTON)*

ANIMAL CLASSIFCATION



REPTILIAN ODD-BODS: CROCODILE-LIKE REPTILES

CROCODILE-LIKE REPTILES

AETOSAUROIDES

EAGLE LIZARD

The aeotosaurs (*Aetosauroides*) were heavily armoured reptiles. They walked on all four legs, splayed out to the side. They had a long snout, like that of a pig, and teeth shaped like chisels, like those in living ant-eating animals. Their armor was made up a mosaic of interlocking plates that protected their back, sides, belly and even their tail.

A VARIETY OF REPTILES FROM DIFFERENT LINEAGES ABOUNDED in the Triassic, ones that were neither mammal-like nor dinosaurs. Many were called "crocodiles," but they were not. Some were aquatic, others fully terrestrial. Either way, they were all part of the war for resources.

Although many of these Middle and Late Triassic reptiles outwardly resembled living crocodiles, there was really only one that was on the way to being a real croc - *Paeudohesperosuhus*. Most of the others belonged in different groups and in some classifications are all placed in the Order *Thecodontia*, whereas crocs have their own Order - *Crocodilia*. *Scaphonyx* is really an odd-bod - having its own unique order - the *Rhynchosauria!*

SCAPHONYX WAS ONE OF THE CROCODILE-LIKE REPTILES THAT WOULD HAVE BEEN A MAJOR CONTESTANT IN THE WAR OF THE REPTILES - IT WAS A HIGHLY ADAPTED HERBIVORE AND WAS PRESENT IN GREAT NUMBERS - LIKELY THE BASE OF THE FOOD PYRAMID OF THE TIME. IT WOULD NOT HAVE BEEN A FAST RUNNER, AS IT HAD A SPRAWLING STANCE, AND THIS MAY HAVE BEEN ONE OF THE FEATURES THAT LED TO ITS DEMISE - AS THE AGILE CARNIVOROUS DINOSAURS AND OTHER CROC-LIKE REPTILES DEVELOPED AND DIVERSIFIED. *(UNIVERSITY OF SAN JUAN NATURAL SCIENCE MUSEUM)*

PRONOUNCED
a-EAT-oh-SORE-oid-ees

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Thecodontia, Aetosauria (crocodile-like reptile)

ERA
Late Triassic, 228 million years ago

DIET
Meat and plants, an omnivore

SCALE
2 to 3 meters (7 to 10 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

IMAGES: UNIVERSITY OF SAN JUAN NATURAL SCIENCE MUSEUM

VENATICOSUCHUS

HUNTING CROCODILE

Pseudosuchians (*Venaticosuchus*), known from a single specimen in the Ischigualasto collection, had an ankle that was constructed precisely *reverse* to that of true crocodiles. The lower jaw of this crocodile-like reptile was much shorter than the upper, so that the upper teeth in front did not touch the lower. The teeth further back in the jaw were serrated, making them good slicing tools for this large, dog-sized carnivore. Both its front and hind limbs were about equal length, making this reptile a quadruped. Some other pseudosuchians walked on their hind legs, like humans.

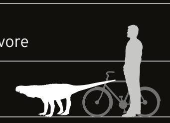
PRONOUNCED
veh-nat-teh-ko-SOOK-us

CLASSIFICATION
Reptilia, Archosauria (Archosauriformes), Pseudosuchia, Ornithosuchidae

ERA
Late Triassic, 228 million years ago

DIET
Meat, a highly specialized carnivore

SCALE
1.4 meters (5 feet) in length



COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

LATE TRIASSIC

PSEUDOHESPEROSUCHUS

FALSE HESPEROSUCHUS, WESTERN CROCODILE

The sphenosuchians (*Pseudohesperosuchus*) were primitive relatives of the crocodiles of today. *Pseudohesperosuchus* was lightly built, with an ankle constructed very similarly to that of modern crocodiles. But contrary to today's crocs, *Pseudohesperosuchus* was fully terrestrial. It had many small backward-curving teeth, perfectly adapted to hold onto squirming prey. With its upright, four-legged stance and lightly built skeleton, it was a fast, agile predator. Speedy, too: it may well have galloped!

PRONOUNCED
su-do-hes-purr-oh-SOOK-us

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Crocodylia, Sphenosuchia

ERA
Latest Triassic, 210 million years ago

DIET
Meat, a carnivore

SCALE
1.3 meters (4 feet) in length

COUNTRY
Northwestern Argentina, La Rioja Province, Talampaya Park

IMAGES: UNIVERSITY OF SAN JUAN NATURAL SCIENCE MUSEUM; ICON: FAN DESIGNED BY RICARDO MOREIRA FROM THE NOUN PROJECT

SAUROSUCHUS

LIZARD CROCODILE

The rauisuchians (*Sillosuchus, Fasolosuchus, Saurosuchus*) were reptiles with a mixture of crocodilian and dinosaurian characteristics. Their hind legs and ankle bones were like those found today in crocodiles, but many other parts of their skeletons were constructed of bones like those in dinosaurs – for example, the pelvis. *Saurosuchus (pictured)* had large, elongated, serrated teeth and a short neck. In comparison, *Sillosuchus,* a relative, had hollow, thin bones, no teeth and a long neck. It's likely they were speedy runners though, ideal for escaping predators or even catching a bit of prey themselves – maybe a cockroach or two!

PRONOUNCED
sawr-oh-SOOK-us

CLASSIFICATION
Reptilia, Diapsida, Archosauromorpha, Archosauria, Thecodontia, Rauisuchia

ERA
Late Triassic, 228 million years ago

DIET
Meat, a carnivore

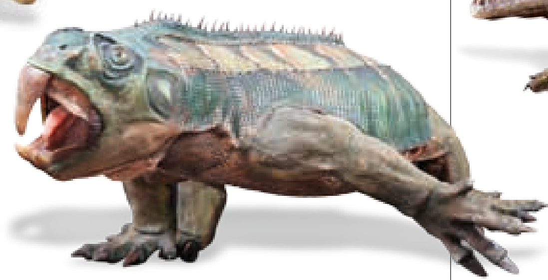
SCALE
6 meters (20 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

SCAPHONYX

UNKNOWN

The rhyncosaurians (*Scaphonyx*) were the most abundant terrestrial animals in the Ischigualasto region – hundreds of skeletons of *Scaphonyx* alone have been found. *Scaphonyx* was an herbivore, with a powerful beak and a broad skull hosting powerful jaw muscles connected to a deep jaw – a perfect design for slicing and dicing tough vegetation, abundant at the time *Scaphonyx* lived. *Scaphonyx* had hind feet with massive claws, perhaps for digging up roots and tubers. Sadly, this successful group became extinct quite suddenly around 228 million years ago, perhaps related to a dramatic change in climate or even the arrival of the dinosaurs.



PRONOUNCED
ska-FON-ix

CLASSIFICATION
Reptilia, Diapsida, Archosauromorpha, Sauropterygia, Rhynchosauria

ERA
Late Triassic, 228 million years ago

DIET
Plants, an herbivore

SCALE
2 to 2.3 meters (7 to 7.5 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

PROTEROCHAMPSA

UNKNOWN

The proterochampsians (*Proterochampsa*) were primitive reptiles with a lifestyle much like that of modern crocodiles, though they existed more than 50 million years before real crocs appeared. They had terrestrial ancestors, but recolonized freshwater rivers, developing a low, broad snout with eyes on the top of the skull, as in aquatic animals. They adapted to snaring prey too, largely thanks to their teeth, which were conical and recurred, allowing them to better hold onto struggling prey. They would have been in direct competition with the labyrinthodon amphibians, which also had a major adaptive radiation in the Triassic.

PRONOUNCED
pro-tehr-oh-CHAMP-suh

CLASSIFICATION
Reptilia, Diapsida, Archosauromorpha, Archosauria, Thecodontia, Proterosuchia

ERA
Late Triassic, 228 million years ago

DIET
Meat, a carnivore

SCALE
2.5 meters (8 feet) in length

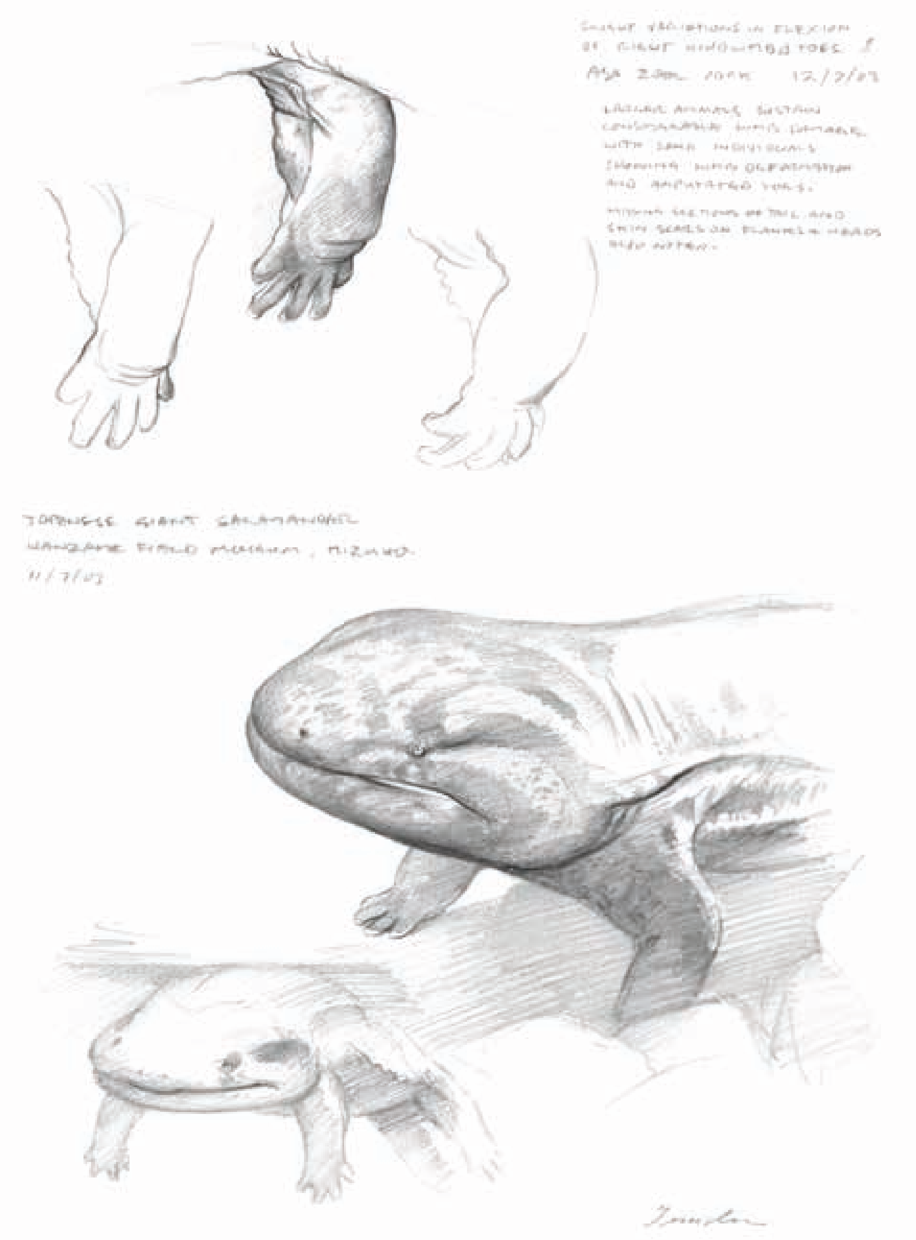
COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

THE AMPHIBIANS

AMPHIBIANS

THE TEMNOSPONDYLS WERE AN EXTREMELY SUCCESSFUL GROUP of small to giant amphibians that were diverse and lasting, during the Carboniferous through the Triassic, with rare survivors as late as the Early Cretaceous. Although early in their history they were mainly terrestrial, in Permian and Triassic times they invaded the rivers and lakes and became the dominant predators there.

Near the end of the Triassic the planet experienced another pinch point, but it seems to have affected the marine realm far more than the terrestrial. There is debate about what caused it: some suggest there might have been significant climate change and a rise of sea levels due to volcanic activity. The volcanic activity seems associated with the beginning of fragmentation of the great supercontinent Pangaea – leading to rising air temperatures, super-greenhouse conditions and acidification of the oceans. These rising temperatures could also have brought about a melting of permafrost near the poles. This would have released methane, further stoking greenhouse conditions – methane is one of the more dangerous greenhouse gases. All these may have worked in concert to worsen the situation. Whatever the cause, the dinosaurs seem to have coped while many of their Triassic competitors did not. As a result, the Jurassic and Cretaceous periods that lay ahead were paradise for these reptilians, and they diversified, some reaching the largest size ever for terrestrial inhabitants.



RIGHT:
IN ORDER TO MAKE AN ATTEMPT TO RECONSTRUCT ANIMALS THAT ARE NO LONGER AROUND, ARTIST AND SCIENTIST ALIKE SEEK OUT THE CLOSEST LIVING THING - USING THE IDEA THAT THE PRESENT IS THE KEY TO THE PAST. TO MAKE AN ATTEMPT TO UNDERSTAND THE ANCIENT LABYRINTHODONTS, THE CLOSEST ANALOGUE IS THE GIANT JAPANESE AND GIANT CHINESE SALAMANDERS. TRUSLER AND HIS SCIENTIFIC COLLEAGUES TRAVELED TO THE COLD MOUNTAIN STREAMS OF JAPAN IN PURSUIT OF THE GIANT SALAMANDER, AND THEY FOUND THEM LIVING IN BURROWS - ONCE THEY COAXED SOME OUT, THEY WERE ABLE TO OBSERVE AND USE THIS AS A MODEL FOR THE PAST. *(PETER TRUSLER)*

PROMASTODONSAURUS

MASTODON-SIZED LIZARD (THE MASTODON IS AN ANCIENT ELEPHANT)

Promastodonsaurus was a temnospondyl amphibian that lived in the rivers and lakes of the Triassic. Like most well-adapted water-dwelling animals, this amphibian would have had upward-looking eyes, so that it could lie near-submerged but still be able to search for its dinner. It had a weak backbone and stubby legs, so was clearly not able to walk about on land effectively. Its head was very large, while its body and tail were relatively stunted. It likely captured its prey by opening its mouth suddenly and sucking its victim in. Its meal would have no chance of escaping from the huge number of ensnaring conical teeth.

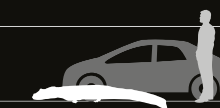
PRONOUNCED
pro-mast-toe-don-SAWR-us

CLASSIFICATION
Amphibia, Labyrinthodonta, Temnospondyli

ERA
Late Triassic, 228 million years ago

DIET
Fish and other animals, just about anything in the water

SCALE
2.5 meters (8 feet) in length



COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

IMAGES: UNIVERSITY OF SAN JUAN NATURAL SCIENCE MUSEUM

THE MAMMAL-LIKE REPTILES: OUR ANCESTORS

MAMMAL-LIKE REPTILES

THE MAMMAL-LIKE REPTILES WERE ONE OF THE COMPETING teams in the Middle and Late Triassic. They were a diverse group that filled both carnivore and herbivore niches in the late Paleozoic. Many were later wiped out by the events in the Late Permian. Some forms, such as the offspring of the dicynodonts, were able to recover and re-establish themselves in the early parts of the Triassic. That is until other reptilian groups and the dinosaurs began the battle for resources. Much of the Middle and Late Triassic was truly a war for resources, and in the end, the new kids on the block won. But the dinosaurs didn't win without a fight. A quick survey of the variety of different mammal-like reptiles will give some idea of just how much diversification took place amongst this group during their second, and last, major adaptive radiation. Although they did not triumph in the end against the dinosaurs, they did give rise to the mammals!

One of the best places on our planet where fossils of all of these major competitors occur in abundance is in "The Valley of the Moon". Known as Ischigualasto, this site in northwestern Argentina is one of the most stunning displays of fossils on the planet.

ISCHIGUALASTIA

ANCIENT REPTILE FROM ISCHIGUALASTO

Ischigualastia, a dicynodont, had a unique skull with large openings at the back to accommodate massive jaw muscles. It was toothless in all but the most primitive forms, and likely had a horny beak like that of a turtle. It could pull its lower jaw backwards when chewing and slice tough vegetation like a saw blade. Its back legs were nearly straight, but the front ones more sprawling, bending at the elbow. These reptiles were the largest herbivores of the time, reaching up to a meter in length, and were replaced by the sauropod dinosaurs by the end of the Triassic.

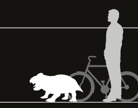
PRONOUNCED
is-chee-gua-LAS-tee-ah

CLASSIFICATION
Reptilia, Synapsida , Therapsida, Dicynodontia

ERA
Late Triassic,
228 million years ago

DIET
Plants, an herbivore

SCALE
0.7 meters to 1 meter
(28 to 39 inches) in length



COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

IMAGES: UNIVERSITY OF SAN JUAN NATURAL SCIENCE MUSEUM

CHINIQUODON

PRIMITIVE MAMMAL FROM CHINQUA, BRAZIL

Chiniquodon was a cynodont, quite similar to mammals, with a mouthful of different kinds of teeth: incisors, huge stabbing canines and broad, sharp-edged cheek teeth – good for slicing. It chewed its food before swallowing and so developed a bony palate that separated the mouth from the nasal passage, so it could breathe while eating, just like us. As with mammals, the lower jaw of this reptile was made up of mainly one bone, the dentary. A close relative of *Chiniquodon* was *Probelesodon*, one of the last mammal-like reptiles to survive. At the end of the Triassic, the mammal-like reptiles were pushed aside by the dinosaurs, which moved into their role; the only surviving progeny of this successful group are modern mammals.

PRONOUNCED
chin-EE-kwo-don

CLASSIFICATION
Reptilia, Synapsida , Therapsida, Dynodontia

ERA
Late Triassic, 228 million years ago

DIET
Meat, a carnivore

SCALE
Up to 1 meter (39 inches) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

ECTENINION

UNKNOWN

Ecteninion, a eucynodont, was a close relative of mammals, known only from parts of the skeleton and skull. It may have been partly warm-blooded, but we know it had flattened teeth that could easily slice up food – flattened side to side, acting like a pair of scissors. It had a long, slender skull with large canines for stabbing prey, ideal for cracking insect bodies.

PRONOUNCED
ek-teh-NIN-ee-on

CLASSIFICATION
Reptilia, Synapsida, Therapsida, Cynodontia

ERA
Late Triassic, 228 million years ago

DIET
Carnivore, likely dining on insects

SCALE
0.5 meters (20 inches) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

EXAERETODON

UNKNOWN

Exaeretodon, one of the last survivors of the cynodont mammal-like reptiles, was abundant in the Late Triassic. Its dentition was quite similar to those of mammals, with many different kinds of teeth: incisors, canines and molars. Its diet may have been like that of wild boars today. The head was extremely large, and it would have been a scary animal to meet. Armed with an upright stance, it stood with legs directly underneath its body – not sprawled out to the side – and thus was most probably swift on its feet.

PRONOUNCED
x-air-ET-oh-don

CLASSIFICATION
Reptilia, Synapsida, Therapsida, Cynodontia

ERA
Late Triassic, 228 million years ago

DIET
Plants and animals, an omnivore

SCALE
Adults up to 2.4 meters (8 feet) in length, juveniles as small as 0.4 meters (16 inches)

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

CHALIMINIA

UNKNOWN

Perhaps almost forgotten because of its small size was the tiny *Chaliminia*. This diminutive mammal-like reptile was very similar to true mammals – and was highly specialized for insect eating, though it may have been rather greedy, eating whatever plants or animals it came across. It was a member of the most advanced mammal-like reptile group, the cynodonts. These soon gave rise to primitive mammals, complete with mammalian specializations – a reduced number of bones in the lower jaw (eventually only one) – and incorporating two of the lower and upper jaw bones into the ear. Not only could this little mammal-like reptile see very well, but it was on its way to crafting a sharp sense of hearing too. And, as so often happened in the times of great biological crises on planet Earth – the tiny size of *Chaliminia* likely had something to do with its offspring surviving and giving rise to primitive real mammals.

PRONOUNCED
chal-ah-MEN-ee-ah

CLASSIFICATION
Reptilia, Synapsida, Cynodontia

ERA
Late Triassic, 210 million years ago

DIET
Insects and other small prey, insectivore

SCALE
0.3 meters (12 inches) in length

COUNTRY
Northwestern Argentina, La Rioja Province, Talampaya Park

IMAGES: UNIVERSITY OF SAN JUAN NATURAL SCIENCE MUSEUM; **ICON:** FAN DESIGNED BY RICARDO MOREIRA FROM THE NOUN PROJECT

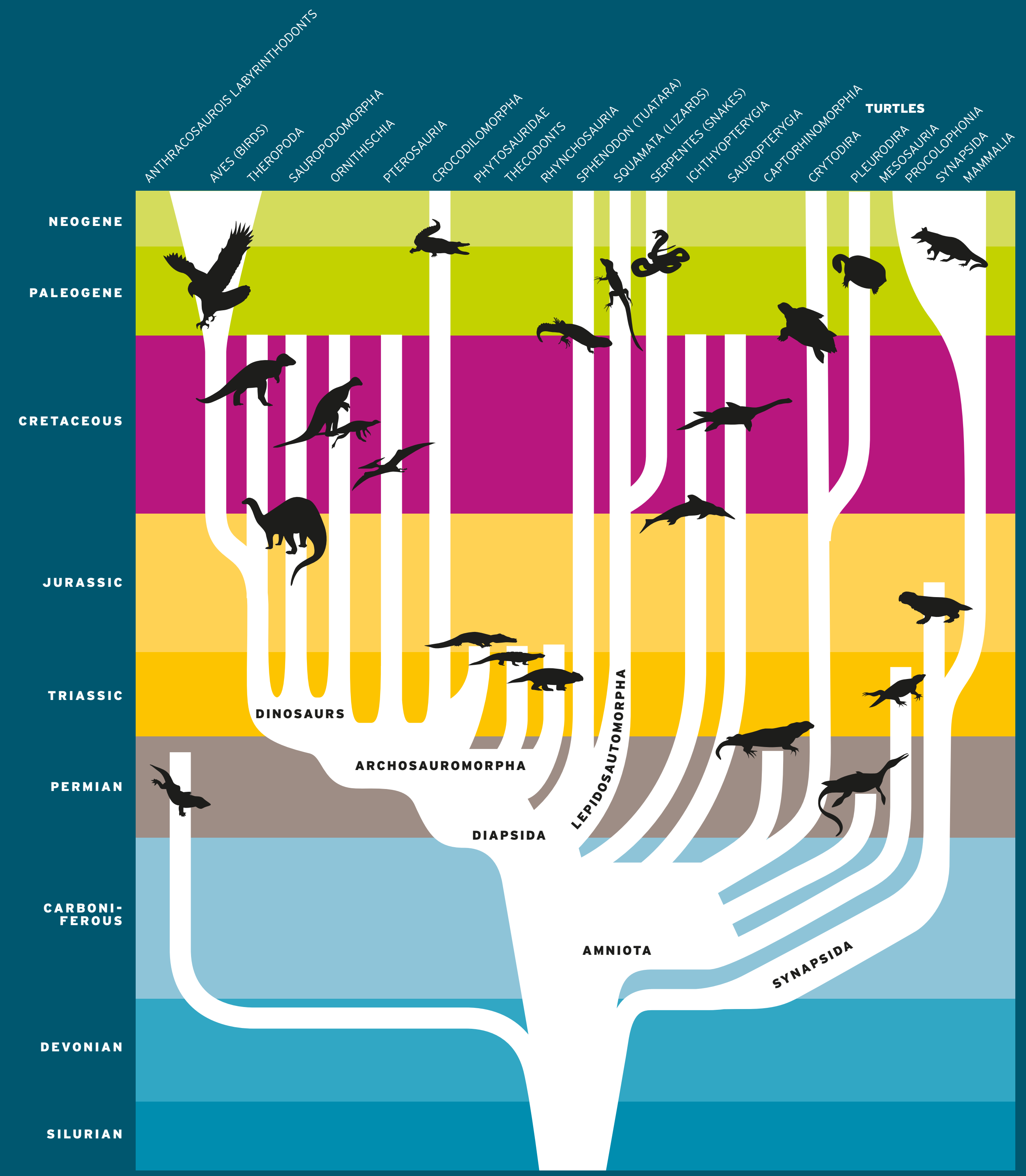
THE DINOSAURS

DINOSAURS

DINOSAURS FINALLY MADE THEIR APPEARANCE IN THE MIDDLE Triassic. It's likely the very oldest is a critter close to the base of the family tree, the tiny *Marasuchus*, no larger than a mouse! It had short arms, long, slender legs and well-developed feet. These enabled it to move upright like us humans, and quickly, to avoid predators, running like we do on the balls of its feet. It was definitely not flat-footed! But in addition to its speed, its small size and ability to hide in the undergrowth away from predators may well have been its greatest defences. Time and time again in the history of life, small forms seem to have the advantage in times of great stress.

Once dinosaurs came onto the scene, their family tree split in two different directions. Sir Richard Owen, who proposed the name 'Dinosauria' (terrible lizards) in 1842, had used the bones in the region of the pelvis to define this group, the fused sacral vertebrae. Similarly, the pelvis became the defining structure in determining which group a dinosaur belonged to: those with a pelvic structure like that present in birds (the ornithischians – thus the name) and the lizard-hipped (the saurischians). Those groups continued right up to the near-demise of the terrible lizards. Surprisingly, it was the lizard-hipped saurischians that gave rise to birds, the relatives of *T. rex!*

FAMILY TREE OF REPTILES



LATE TRIASSIC

PISANOSAURUS

PISANO'S LIZARD

Pisanosaurus is the oldest known bird-hipped dinosaur (ornithischian), based on just a single specimen from Ischigualasto. It was small, and stood up on its two hind legs. It had very large canines, along with cheek teeth adapted for scissor-slicing vegetation. It had large eyes and a skull with a bone unique to the ornithischians. This bone is known as the predentary, at the front of the lower jaw. This predentary likely supported a part of the beak. *Pisanosaurus* had long arms, spanning nearly 70% the length of its lankier hind legs. That seems to be a clue that this was a speedy runner. It certainly needed to be, with all the carnivores on the prowl in the ancient Valley of the Moon, the beautiful Ischigualasto.

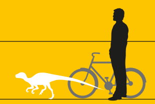
PRONOUNCED
peh-san-oh-SAWR-us

CLASSIFICATION
Reptilia, Diapsida, Archosauromorpha, Archosauria, Ornithischia, Ornithopoda

ERA
Late Triassic, 228 million years ago

DIET
Plants, an herbivore

SCALE
1 meter (39 inches) in length



COUNTRY
Northwestern Argentina, La Rioja Province, Talampaya Park

IMAGES: UNIVERSITY OF SAN JUAN NATURAL SCIENCE MUSEUM

SKELETON OF *HERRERASAURUS* (*UNIVERSITY OF SAN JUAN NATURAL SCIENCE MUSEUM*)

HERRERASAURUS

HERRERA'S LIZARD

The herrerasaurids (*Herrerasaurus, Sanjuansaurus*) are among the oldest known dinosaurs. They had hollow bones, like those of birds; a short, straight neck; long five-toed feet, with the middle hind toe bearing the animal's weight; and a long, stiff tail for balance. They were swift, bipedal runners with knife-like serrated teeth that would easily have sliced and diced prey. Their hip structure was typical of lizard-hipped dinosaurs, and this morphology held right up to the time of *T. rex* in the Late Cretaceous – persisting into the time of early birds.

PRONOUNCED
he-rare-ah-SAWR-us

CLASSIFICATION
Reptilia, Diapsida, Archosauromorpha, Archosauria, Saurischia, Theropoda

ERA
Late Triassic, 228 million years ago

DIET
Meat, a carnivore

SCALE
Approximately 3 meters (10 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

EODROMAEUS

ANCIENT RUNNER

Eodromaeus was a small theropod. One of the latest discoveries at Ischigualasto, the specimen was first collected in 1996, but only recently studied. It had highly curved teeth, indicating it was likely a carnivore, and a long, lightweight neck, with vertebrae filled with air spaces. It is the oldest theropod known, pushing dinosaur origins back to the Middle Triassic.

PRONOUNCED
ee-oh-DRO-mee-us

CLASSIFICATION
Reptilia, Diapsida, Archosauromorpha, Archosauria, Saurischia, Theropoda

ERA
Late Triassic, 230 million years ago

DIET
Meat, a carnivore

SCALE
About 0.7 meters (28 inches) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

EORAPTOR

DAWN HUNTER

Eoraptor was a small sauropodomorph, and though it looked outwardly like a theropod, this dinosaur was an omnivore. Its teeth were not those of a predator, but more leaf-shaped, adapted for nipping plants. It was an agile little reptile, weighing in at around 10 kilograms. Its hollow bones made it lightweight. Although it had five toes, it ran using just one, though each had a sharp claw that could have been used for digging, or grabbing bits of meat from carcasses. It wasn't specialized for carnivory, unlike many of the later dinosaur predators.

PRONOUNCED
EE-oh-rap-tor

CLASSIFICATION
Reptilia, Diapsida, Archosauromorpha, Archosauria, Saurischia, Sauropodomorpha

ERA
Late Triassic,228 million years ago

DIET
Omnivore, plants and animals

SCALE
1 to 1.4 meters (3 to 5 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

IMAGES: UNIVERSITY OF SAN JUAN NATURAL SCIENCE MUSEUM; **ICON:** FAN DESIGNED BY RICARDO MOREIRA FROM THE NOUN PROJECT

PANPHAGIA

ALL EATING

Panphagia was a small, hollow-boned biped that looked a little like a carnivore, but the form of its teeth and hands fell somewhere between those of the meat-eating early dinosaurs and the plant-eating sauropods. It is thought it gladly ate both plants and insects, and was a swift runner that could escape small predators.

PRONOUNCED
pan-FAGH-ee-ah

CLASSIFICATION
Reptilia, Diapsida, Archosauromorpha, Archosauria, Saurischia, Sauropodomorpha

ERA
Late Triassic, 228 million years ago

DIET
Omnivore, plants and animals

SCALE
1.2 meters (4 feet) in length

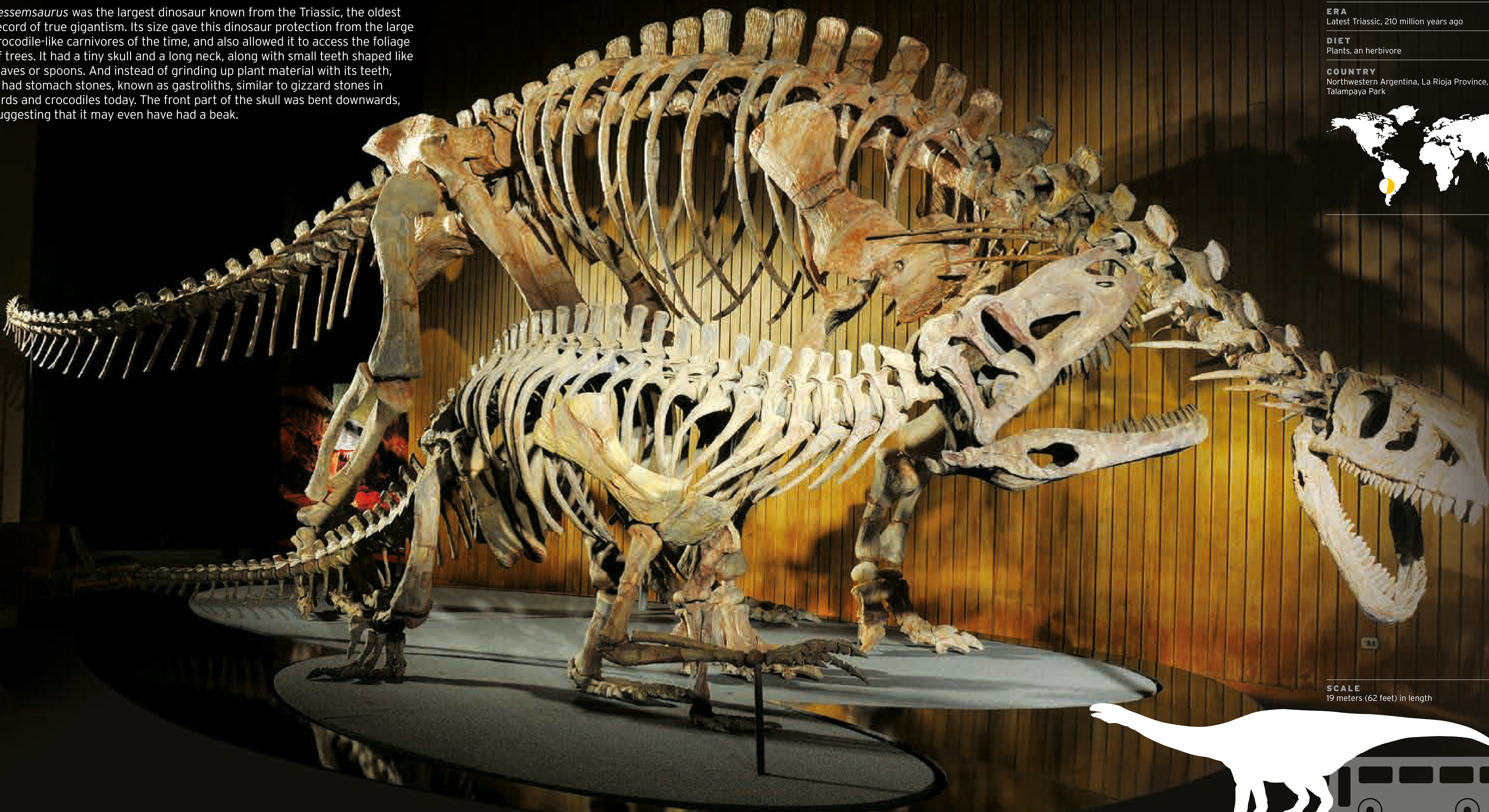
COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

LATE TRIASSIC

LESSEMSAURUS

LESSEM'S LIZARD

Lessemsaurus was the largest dinosaur known from the Triassic, the oldest record of true gigantism. Its size gave this dinosaur protection from the large crocodile-like carnivores of the time, and also allowed it to access the foliage of trees. It had a tiny skull and a long neck, along with small teeth shaped like leaves or spoons. And instead of grinding up plant material with its teeth, it had stomach stones, known as gastroliths, similar to gizzard stones in birds and crocodiles today. The front part of the skull was bent downwards, suggesting that it may even have had a beak.



PRONOUNCED
less-im-SAWR-us

CLASSIFICATION
Reptilia, Diapsida, Archosauromorpha, Archosauria, Saurischia, Suropodomorpha

ERA
Latest Triassic, 210 million years ago

DIET
Plants, an herbivore

COUNTRY
Northwestern Argentina, La Rioja Province, Talampaya Park

SCALE
19 meters (62 feet) in length

LATE TRIASSIC

RECONSTRUCTED LANDSCAPE OF THE TIME OF CHANGE FROM THE ISCHIGUALASTO FORMATION TO THE LOS COLORADOS FORMATION IN ARGENTINA. THE WIDE, SEMI-ARID BASIN CONTAINED A RIVER SYSTEM THAT WAS NOURISHED BY WETTER SEASONAL CONDITIONS AND SUPPORTED FLORA OF GINKGOITES AND CONIFERALES TREES. HERE, THE PREDATORY CROCODILE-LIKE REPTILE *FASOLASUCHUS TENAX* ATTACKS AN EARLY SAUROPOD, *LESSEMSAURUS SAUROPOIDES*. BEFORE *DINOSAURS: DAWN TO EXTINCTION* PETER TRUSLER HAD NOT WORKED MUCH WITH THE TRIASSIC, SO THE CHALLENGE WAS TO CREATE SOMETHING UNIQUE FOR THE EXHIBITION. TRUSLER SPENT MONTHS CONSULTING PALEONTOLOGISTS AND ASSESSING RESEARCH PAPERS TO MAKE THIS IMAGE POSSIBLE.

ILLUSTRATION: PETER TRUSLER

SURVIVAL OF THE SMALLEST

AS THE SUPERCONTINENT OF GONDWANA SPLIT APART, THE OCEANS BEGAN DEVELOPING BETWEEN ONCE-CONNECTED LANDS. SHORELINES INCREASED ALONG WITH THE TYPES OF VEGETATION AND ANIMAL LIFE AS FLORAS AND FAUNA BECOME ISOLATED FROM ONE ANOTHER. DURING THIS TIME, THE FIRST PRIMITIVE MAMMALS APPEARED. ALONG WITH THE SMALLER MAMMAL-LIKE REPTILES SUCH AS THE *CHALIMINIA* - OUR DISTANT ANCESTOR - THESE LOW-PROFILE, HARD-TO-SEE CREATURES FED ON INSECTS AND PLANTS, AND COULD ALSO EAT MEAT. THEY COULD SCURRY UP TREES OR DIG TUNNELS TO AVOID BECOMING A MEAL AND GETTING STOMPED ON BY LARGER ANIMALS.

TEETH AND DIET

The teeth of reptiles were shaped and sized according to the jobs they performed. The meat-eaters (carnivores) usually had large and long jagged teeth. Animals with broad and flat teeth, such as *Lessemsaurus*, were plant-eaters (herbivores). Mammal-like reptiles had different types of teeth, suggesting that some species were omnivores, eating plants, insects and small mammals.

TOP: THIS BEAUTIFUL LITTLE TOOTH IS FROM LEAELLYNASAURA AND IS TYPICAL OF AN HERBIVORE'S TOOTH THAT SLICES AND DICES LIKE A PAIR OF SCISSORS *(STEVE MORTON)*

CARNIVORES

ANIMALS THAT ATE MEAT ARE CALLED CARNIVORES AND USUALLY HAD LARGE AND LONG JAGGED TEETH. THEY COULD TEAR THEIR PREY APART AND SWALLOW THE MEAT WITHOUT MUCH CHEWING.

OMNIVORES

SOME MAMMAL-LIKE REPTILES, SUCH AS *CHALIMINIA*, AND DINOSAURS, HAD DIFFERENT TYPES OF TEETH. THIS SUGGESTS THEY MAY HAVE HAD A VARIED DIET OF PLANTS, INSECTS AND SMALL MAMMALS.

HERBIVORES

MANY ANIMALS HAD TEETH THAT WERE BROAD AND FLAT. THESE ANIMALS WERE LIKELY HERBIVORES, EATING ONLY PLANTS, AND NEEDED BROAD TEETH TO GRIND UP PLANTS SO THEY COULD BE DIGESTED.

CHALIMINIA

Chaliminia was a tiny mammal-like reptile that lived alongside the dinosaurs. Its small size enabled it to burrow and hide. Although perhaps preferring insects, this clever reptile may have been an omnivore, taking whatever sort of food was available. Perhaps this was its survival strategy. These tiny animals may have lived in the shadows of the dinosaurs, but they were the ones that survived the major extinctions and are about as close as one gets to the ancestry of mammals.

GOOD THINGS COME IN SMALL PACKAGES

There were benefits to being a small animal. These included:

Small size usually came with agility, allowing a quick and easy escape from large predators.

Small size allowed an animal to more easily hide in foliage, keeping out of the way of harsh or changing weather conditions.

ILLUSTRATION: PETER TRUSLER

FIVE JURASSIC-CRETACEOUS: THE DINOSAUR TAKEOVER!

FINALLY, THE DINOSAURS STARTED TO COME INTO THEIR OWN, STRUTTING AROUND THE PLANET AND SPREADING THEIR WINGS. BUT IT WASN'T ALL FUN AND GAMES. MANY OF THEM HAD A VERY COLD TIME OF IT. STILL, IF YOU HAD THE HIPS OF A BIRD AND A HEAD LIKE A ROCK, IT WAS AN EXCITING TIME TO BE ALIVE. ALL THE MORE SO WHEN, IN THE LATE JURASSIC, RELATIVES OF THE MOST FAMOUS PLAYER STEPPED ONTO THE STAGE... *TYRANNOSAURUS REX*.

PG.

77
Head of a rock star
Find out why this animal was very much the Elvis of its time. But for one specimen, the good times ended with one ill-fated meal. The lesson? Chew carefully, boys and girls.

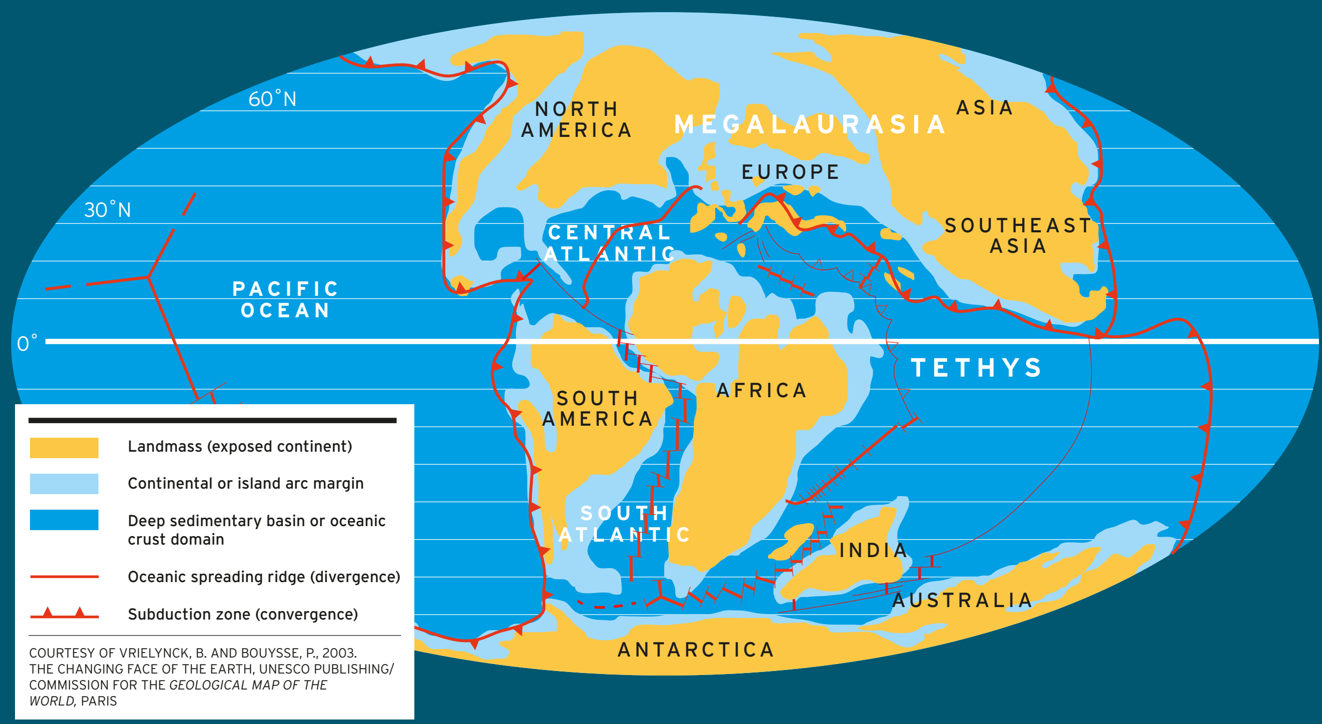
81
The *T. rex* family
This relative of *T. rex*, one of the most famed and fearsome hunters of the era, did not look as you would expect. Unless you were expecting an ostrich, that is.

82
A tank with legs
Ankylosaurs could walk with a bit of a strut, as their armor gave them protection from practically everyone. No wonder this one seems to be smiling.

84
Keeping it cool
Have a care for these poor dinosaurs, who had to live without sunlight three months of the year. But at least they could enjoy stunning views of the aurora australis.

LATE CRETACEOUS **96–92** MILLION YEARS AGO

THE MEGACONTINENTS PANGAEA AND GONDWANA HAD CLEARLY BEGUN TO FRAGMENT. TOWARDS THE END OF THE REIGN OF DINOSAURS, WHEN MAMMALS BEGAN TO TAKE CENTRE STAGE WITH BIRDS, THE SEPARATION CONTINUED, GRADUALLY RESULTING IN THE WORLD WE KNOW TODAY. THIS FRAGMENTATION LED TO DISTINCT FAUNA AND FLORA TO DEVELOP IN QUITE INDEPENDENT WAYS. THUS WE HAVE TODAY THE UNIQUE KOALAS AND KANGAROOS OF AUSTRALIA, THE LLAMAS AND SLOTHS OF SOUTH AMERICA AND THE PANDAS OF ASIA.



COURTESY OF VRIELYNCK, B. AND BOUYSSE, P., 2003. THE CHANGING FACE OF THE EARTH, UNESCO PUBLISHING/ COMMISSION FOR THE *GEOLOGICAL MAP OF THE WORLD*, PARIS

38 METERS

THE CENOMANIAN ERA SAW THE BIRTH OF ONE OF THE LARGEST DINOSAURS EVER DISCOVERED, *ARGENTINOSAURUS*. IT TOWERED TO A HEIGHT EQUIVALENT OF A THREE-STOREY BUILDING, AND WAS 38 METERS IN LENGTH.

AS THE TRIASSIC CAME TO AN END, WITH SOME FAUNAL OVERTURN, THE JURASSIC DAWNED, AROUND 200 MILLION YEARS AGO. BY THIS TIME ALL MAJOR GROUPS OF DINOSAURS HAD MADE THEIR APPEARANCE. UNLIKE THE MAP OPPOSITE WHICH SHOWS THE BREAK-UP AT THE END OF THE ERA, WITH THE CONTINENTS STILL VERY MUCH CONNECTED INTO THE SUPERCONTINENT PANGAEA, TERRESTRIAL ANIMALS WERE ABLE TO MOVE ABOUT WITH FEW BARRIERS – THE WORLD WAS INTERCONNECTED.

At first the diversity of dinosaurs seemed limited, though this observation could perhaps be due to the fossil record itself. If the skeletons of once-living forms are not preserved as fossils for some environmental reason, then the true diversity will not be recorded. We must be careful to understand just how many treasures from each time period have been found before drawing conclusions about true diversity in times past.

The move from the Late Triassic into the Early Jurassic was a boom time for dinosaur diversity. Dinosaurs "went from being a significant minority in many environments to near dominance" (Sues, in Brett-Surman, 2012). On the contrary, groups that had been in charge before – such as the mammal-like reptiles and a range of other reptiles – declined in diversity, many disappearing forever. Was this gradual or abrupt? And what caused it to happen? As we speak, scientists around the world are still debating this enigma. Regardless, the dinosaurs took over the land and held onto it for more than 160 million years!

During the Jurassic, large and small theropods moved up in the world, gaining top predator status. The smaller predatory and insectivorous roles were shared with other lizard-like reptiles, crocodilians, some amphibians (such as *Siderops*) and even mammals, which had now developed out of mammal-like reptile stock. *Cryolophosaurus* was one of the top pursuit predators of the Early Jurassic, while the sauropods were growing larger and larger. This was due in part to predator pressure, but their bigger size also allowed them to snack on taller vegetation. Meanwhile in the lower-growing vegetation, bird-hipped ornithischians competed for resources, developing more and more sophisticated ways of processing the vegetarian menu. There were also still a few sphenodont reptiles as well as rare mammal-like reptiles lurking in the undergrowth, still clinging to existence. Competition among all these reptiles for resources was still fierce, just as it had been in the Triassic, but it was a game with different players.

Late Jurassic and Cretaceous landscapes hosted an increasing variety of all sorts of dinosaurs, more and more finely dividing up the available resources. The first dinosaurs that eventually gave rise to the fearsome tyrannosauroids, including relatives of the A-list *T. rex*, appeared on the scene in the Late Jurassic. Along with the sauropods, they continued to get bigger, some species achieving truly monumental sizes. Diversification continued too, including the debut of the plated stegosaurs, the armoured tank-like ankylosaurs, and the frill-necked protoceratopsians.

ABOVE: *CRYOLOPHOSAURUS* WAS A SPEEDY THEROPOD DINOSAUR THAT LIVED DURING THE JURASSIC IN THE THEN POLAR ANTARCTICA. IT HAD A DISTINCTIVE FORWARD-FACING CREST ON ITS SKULL *(PICTURED)* THAT HAS LED TO IT BEING INFORMALLY CALLED 'ELVISASAURUS', AFTER THE FAMOUS POP SINGER. LIKE THE HORNS OF ANTELOPES TODAY, THIS FEATURE WAS PROBABLY A SIGNAL TO OTHER DINOSAURS IN ITS GROUP OF ITS IDENTITY. THE SPECIMEN FEATURED IN THIS EXHIBITION LIKELY CHOKED TO DEATH AS IT WAS TRYING TO SWALLOW THE RIBS OF A GIANT SAUROPOD DINOSAUR, WHICH APPEARED TO BE STUCK IN ITS THROAT WHEN ITS BONES WERE COLLECTED IN THE FIELD. *(STEVE MORTON)*

The Late Jurassic and Cretaceous periods were an era of peak success for the dinosaurs. It was a time when the world was sweltering under greenhouse conditions. The end of their golden age came at the close of the Cretaceous, just before the Earth was pummelled by meteorites and continued cooling into modern times. Only then did the birds and mammals pull the same trick on the dinosaurs that they had on mammal-like reptiles, moving into the roles vacated when the Earth's climate changed. The small became the rulers of the world, crossing into the Cenozoic and again radiating into niches held by their predecessors. The birds moved on from the dinosaurs and the mammals from the mammal-like reptiles.

THE LAST SURVIVOR OF THE TEMNOSPONDYL LABYRINTHODONT AMPHIBIANS, IN THE COLD WATERS OF EARLY CRETACEOUS SOUTHERN AUSTRALIA. *KOOLASUCHUS* AMIDST THE LEAF FALL IN THE AUTUMN OF THESE POLAR REGIONS. THE COLD WATERS MAY HAVE EXCLUDED THE TRUE CROCODILES, WHOSE POPULATIONS WERE EXPANDING AT THIS TIME, ALLOWING THE SURVIVAL OF THESE AMPHIBIANS TO CONTINUE THEIR SUCCESSES OF THE LATE PALEOZOIC AND TRIASSIC.

ILLUSTRATION: PETER TRUSLER

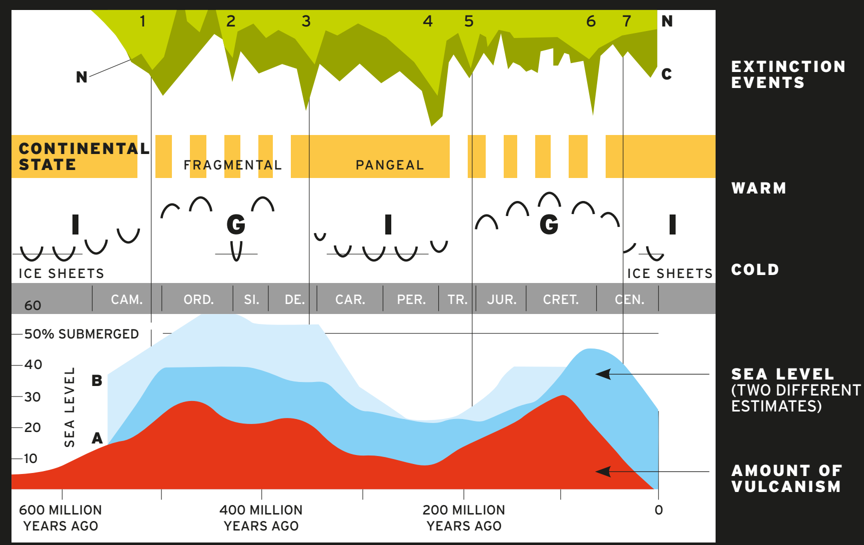
LEFT:
ARCHAEOPTERYX, ON THE BORDERLINE BETWEEN BIRDS AND THEROPODS. THE LINK BETWEEN THEROPOD DINOSAURS AND BIRDS IS STRONGLY SUPPORTED, AND DISCOVERIES IN MANY PARTS OF THE WORLD, ESPECIALLY NORTH-EAST CHINA, HAVE PROVIDED MUCH EVIDENCE IN SUPPORT OF THIS IDEA. *CONFUCIORNIS*, DISPLAYED IN THIS EXHIBITION, IS ONE OF THE EARLY BIRDS THAT TOOK TO THE AIR NEAR THE END OF THE REIGN OF DINOSAURS. *(STEVE MORTON)*

THE SAURISCHIANS
MORE THEROPODS, SOME WITH A DIFFERENCE

WHEN MOST PEOPLE THINK OF THEROPODS, THEY THINK OF *T. rex*, the super-predator; but there were some species that took a very different path in this ferocious family tree. This was exploitation of resources to the greatest.

Gallimimus, the ostrich mimic, was one of the family's innovators. Although a relative of *T. rex*, it had lost all of its teeth! Most likely its main diet consisted of small animals, possibly including insects and even plants and fruits. It had long, manipulable arms and three-toed hind feet. Its body was clearly built for speed.

Unlike *Gallimimus*, *Velociraptor*, a close relative of *T. rex*, kept to the path of meat-eating. Although not so large, it would have been highly dangerous. It may have even hunted in packs, as was shown in Steven Spielberg's *Jurassic Park* (perhaps not the most accurate title, considering *Velociraptor* was from the Late Cretaceous). With its large eyes and likely three-dimensional vision, in addition to a large, scythe-shaped claw on each hind foot, it would have used its flattened, serrated teeth to slice up meat. Luckily for us, this agile predator did not survive the extinctions of the Late Cretaceous – but its lineage did give rise to birds.



N = NUMBER OF SPECIES
I = ICEHOUSE CONDITIONS
G = GREENHOUSE CONDITIONS

ABOVE:
THE RELATIONSHIP BETWEEN TIMES OF MAJOR EXTINCTION IN THE PAST (NUMBERED 1 TO 7) USING TWO DIFFERENT CALCULATIONS OF THE NUMBER OF SPECIES (N, C). THE EXTINCTION EVENTS REPRESENTED ARE AT THE END OF THE PERMIAN, 252 MILLION YEARS AGO (MYA), AND END OF THE CRETACEOUS (66 MYA). AT THE END OF THE PERMIAN, MANY OF BOTH ANCIENT REPTILES AND THE MAMMAL-LIKE REPTILES DIED OUT, ALONG WITH A GOOD NUMBER OF OTHER COMPLEX LIFE FORMS – AND AT THE END OF THE CRETACEOUS, MOST DINOSAURS DIED OUT – EXCEPT FOR THE BIRDS. THOSE WERE TIMES WHEN CONTINENTAL MASSES WERE FRAGMENTING. CLIMATE WAS ALSO CERTAINLY CHANGING IN CONCERT WITH THESE GEOGRAPHIC CHANGES. THE COMBINATION WAS FATAL – BUT ALSO GAVE NEW OPPORTUNITIES TO OTHER ORGANISMS. *(FROM THE GREAT RUSSIAN DINOSAUR CATALOGUE, VICKERS-RICH AND RICH, 1993)*

THE ORNITHISCHIANS FRILLS, HORNS AND TAILS WITH CLUBS

THE DIVERSITY OF THE BIRD-HIPPED ORNITHISCHIAN dinosaurs in the Cretaceous was absolutely mind-boggling. Some of the most outstanding fossils from this group have been recovered from locales around the world – Asia was one of the hot-spots. Major groups to show up during this time were the frilled and horned dinosaurs (ceratopsians such as *Protoceratops* and *Serendipaceratops*), the bone-headed dinosaurs (pachycephalosaurs), and members of the genus *Stegosaurus*. Others that had appeared in the later Jurassic persisted or diversified, such as the armored tank-like dinosaurs (ankylosaurs, such as *Talarurus*) and a variety of ornithopods, such as *Leaellynasaura, Qantassaurus* and *Hypsilophodon*.

The radiation of dinosaurs in the late Mesozoic came as vegetation patterns changed and megacontinents separated. This led to a fragmented landscape, the development of isolated areas and new feeding opportunites. These changes were profound, and were the drivers of the development of new types of animals and plants, a process we know as evolution by natural selection. Flowering plants probably arose in the Jurassic and began to expand in the Cretaceous; in contrast, many species of long-lived foliage, such as the club mosses (lycopods), scouring rushes (sphenopsids) and maidenhair trees (ginkgos) were less biodiverse, while the ferns continued unabated and the seed ferns lost out early in the Cretaceous. The result would have been noticeable to anyone around back then: the air took on a new fragrance.

ABOVE:
LEAELLYN RICH HOLDS THE SKULL OF HER FAVORITE ORNITHOPOD DINOSAUR, *LEAELLYNASAURA*. THE IMPRESSION OF THE TOP OF THE BRAIN, FORMED BY CLAY FILLING THE BRAINCASE AFTER THE DINOSAUR DIED, SHOWS THAT THE OPTIC LOBES – THE PART OF THE BRAIN THAT PROCESSES NERVE IMPULSES FROM THE EYES – WERE GREATLY ENLARGED, SO IT COULD LIKELY SEE IN THE DARK. HERE, SHE IS PICTURED IN THE TUNNEL AT DINOSAUR COVE IN SOUTHEASTERN AUSTRALIA WHERE HER DINOSAUR WAS DISCOVERED. *(STEVE MORTON)*

Talarurus was an ankylosaur, a group that responded well to the enhanced conditions of the Cretaceous, though the group's origins lay in the Late Jurassic. In general, ankylosaurs were heavy, armored animals, with bodies and heads covered with thick bony plates that made it difficult for any of the large carnivorous dinosaurs to threaten them. The bony club on their tails would also have been quite a deterrent to a lurking predator! *Talarurus* was the Mesozoic equivalent of the living armadillo – only much, much bigger.

Protoceratops is one of the best known dinosaurs on Earth – hundreds of skeletons, both young and old, have been collected in Central Asia – and is a Late Cretaceous innovation. Scraps of its relatives have been found in Australia (*Serendipaceratops*) and possibly Africa, suggesting that this group may have had its origins on the southern megacontinent of Gondwana. From embryos in eggs, to hatchlings, teenagers as well as male and female adults – we know an astounding amount about these sheep-sized dinosaurs. Due to the concentrations of *Protoceratops* skeletons, it seems the dinosaurs may have lived in groups that nested in colonies close to rivers and lakes in an otherwise arid landscape. The frill on the back of the head may have been for temperature control. It could also have been for social dominance, and to help animals of one species recognise each other, similar to the function of horns in present-day antelope.

ANKYLOSAURS, THE ARMORED TANKS OF DINOSAURS, HAVE NEARLY A GLOBAL RECORD, EVEN IN THE COLD POLAR LANDS OF EARLY CRETACEOUS AUSTRALIA. *MINMI* (*PICTURED RIGHT*) IS AN ANKYLOSAUR FROM THE CRETACEOUS OF AUSTRALIA, BEST KNOWN FROM SEVERAL COMPLETE SKELETONS FOUND IN QUEENSLAND. *TALARURUS*, ON DISPLAY IN *DINOSAURS: DAWN TO EXTINCTION*, IS A RELATIVE OF *MINMI*. *TALARURUS* HAD A SQUAT POSTURE AND WAS PROBABLY RATHER SLOW. IT HAD A BROAD, HIPPOPOTAMUS-LIKE CHEST, AND ITS BODY WAS COVERED WITH PROTECTIVE, BONY NODULES. ITS HEAVY HEAD AND BODY ARMOR WOULD HAVE MADE IT DIFFICULT PREY FOR ANY OF THE CARNIVOROUS DINOSAURS, AND THE BONY CLUB ON THE END OF ITS TAIL WOULD HAVE BEEN QUITE DANGEROUS TO ANY PREDATOR THAT TRIED! *(PETER TRUSLER, COURTESY OF THE AUSTRALIA POST)*

ILLUSTRATION: PETER TRUSLER

THE MOST INTREPID OF THE DINOSAURS POLAR INHABITANTS!

MOST DINOSAUR RECONSTRUCTIONS PLACE THEM IN temperate or tropic environments, but some lived in chillier circumstances, near the North and South Poles of the time. The southern coasts of Australia have yielded the most diverse of these collections from Early Cretaceous times, whereas the North Polar slopes of Alaska host many Late Cretaceous remains.

Polar dinosaurs didn't have an easy life. The region was starved of sunlight for at least three months of the year and the only light would have been the colourful curtains of aurora (a natural light display) or moonlight. During these times, temperatures would have dropped below freezing. The ground froze and there would have been snow and ice, though the world at this time was in a global greenhouse phase, so there were no polar ice caps – unlike today. Forests grew at high latitudes in the snow; some trees were evergreen while others, like the gingkos, experienced annual leaf fall.

RIGHT: *LEAELLYNASAURA* AND *QANTASSAURUS* STARE AT THE AURORA AUSTRALIS IN THE WINTER SKY OF SOUTHERN AUSTRALIA DURING THE EARLY CRETACEOUS, MORE THAN 110 MILLION YEARS AGO. AN ORNITHOMIMOSAUR *(PICTURED BOTTOM LEFT)* HIBERNATES UNDER A FALLEN CONIFER LOG IN THE FOREST THAT COVERED THIS LAND – WHICH LAY AT 70 DEGREES SOUTH, NOT FAR FROM THE SOUTH POLE OF THE DAY. HOWEVER, THERE WERE NO ICE CAPS THEN, AS THE WORLD WAS STILL IN A GREENHOUSE CLIMATE.

ILLUSTRATION: PETER TRUSLER

SKULL WITH BRAIN IMPRESSION (SHOWING JUST HOW LARGE THE OPTIC LOBES WERE) AND PARTIAL SKELETON OF *LEAELLYNASAURA* – INCLUDING HIND LEG, TAIL AND FOOT. THIS PARTICULAR DINOSAUR LIKELY DIED OF A PROLONGED BONE INFECTION THAT MAY HAVE BEEN IMPARTED BY A BITE FROM A CARNIVORE (FOSSIL SPECIMEN OF DISEASED LEG BONE NOT SHOWN HERE). THESE FOSSILS ARE FROM THE EARLY CRETACEOUS OF SOUTHERN AUSTRALIA WHICH LAY NEAR THE SOUTH POLE WHEN *LEAELLYNASAURA* WAS ALIVE. *(STEVE MORTON AND FRANK COFFA)*

ONE OF PETER TRUSLER'S FIRST RECONSTRUCTION PAINTINGS OF AN EXTINCT ANIMAL IN THE ENVIRONMENT WHERE IT LIVED AND DIED. TRUSLER DECIDED TO RECONSTRUCT THE DEATH SCENE, AND SO THE PLANTS, THE SEDIMENTS ON THE RIVER BANK, AND EVEN THE ANGLE OF LIGHT TOWARD THE END OF THE DAY AND THE ANGLE OF THE LIGHT AT 70 DEGREES SOUTH LATITUDE OF THE TIMES HAS BEEN TAKEN INTO ACCOUNT. TRUSLER GUESSED THE DINOSAUR'S SKIN COLOR BASED ON HIS KNOWLEDGE OF THE SKIN COLORS OF ANIMALS THAT LIVE IN LIGHT-DAPPLED FOREST FLOORS.

ILLUSTRATION: PETER TRUSLER

DIVERSITY IN THE JURASSIC AND CRETACEOUS

THE JURASSIC AND CRETACEOUS WERE TIMES WHEN DINOSAURS THRIVED, BUT THEY WERE NOT THE ONLY SPECIES IN EXISTENCE. MAMMALS, DINOSAURS, INSECTS, AND BIRDS ALL LIVED TOGETHER. RESEARCH HAS UNEARTHED AN AMAZING VARIETY OF FEEDING STYLES AND BODY SHAPES FROM THESE PERIODS, AS THE NEAR-EXTINCTION OF MANY OF THE PRIMITIVE REPTILIAN GROUPS AT THE END OF THE TRIASSIC RESULTED IN MANY ECOLOGICAL OPENINGS FOR THE DINOSAURS TO MOVE INTO.

CAN YOU SPOT THE SMALL MAMMAL?

The mouse-sized *Bishops* stares questioningly at the group of polar dinosaurs moving along the shores of partially frozen lake in the springtime of south-eastern Australia some 115 million years ago.

ANKYLOSAURS

Ankylosaurs were large, armored dinosaurs. Many ankylosaurs had a club tail like the cast that you see here. Their armored bodies meant that they could not move very fast. Here are some different theories - past and present - by scientists about the function of the ankylosaur's club tail.

AS A BONE-BREAKING WEAPON OF DEFENSE. THE TAIL WAS HEAVY, MADE UP OF THICK BONES AND OSSIFIED TENDONS, AND WAS NOT FLEXIBLE. IT WAS LIKELY VERY STRONG

TO FIND A MATE. THE CLUB TAIL WAS IMPRESSIVE IN SIZE AND STRENGTH, AND COULD HAVE BEEN USED TO ATTRACT A FEMALE OR COMPETE WITH OTHER MALES

TO CONFUSE PREDATORS. THE CLUB TAIL COULD HAVE FUNCTIONED AS A 'DUMMY HEAD' THAT DIVERTED PREDATORS FROM THE 'REAL' HEAD, SO THE DINO COULD STRIKE FIRST

ILLUSTRATION: PETER TRUSLER (BISHOPS); **IMAGE:** STEVE MORTON (PROTOCERATOPS SKULL)

PROTOCERATOPS

Protoceratops was an herbivorous, horned dinosaur, about the size of a sheep. It moved in herds, and had a distinctive neck frill. Here are some different theories by scientists - past and present - about the *Protoceratops's* neck frill and what it was used for.

CONTROLLING BODY TEMPERATURE. THE NECK FRILL COULD HAVE ACTED AS A SOLAR PANEL OR A RADIATOR, TRANSFERRING HEAT AS NECESSARY

TO SCARE OFF OTHER ANIMALS. SCIENTISTS KNOW THE NECK FRILL WAS LARGE AND TENDED TO GROW EVEN BIGGER AS THE DINOSAUR AGED

TO PROTECT THE NECK FROM ATTACKS BY PREDATORS. THE FRILLS THINNED AND DEVELOPED HOLES WITH AGE, AND SOME HAVE BEEN FOUND WITH BITE MARKS

ILLUSTRATION: PETER TRUSLER

SIX
END OF THE DINOSAURS – ALMOST

NEAR THE END OF THE CRETACEOUS, METEORITE IMPACTS, MASSIVE VOLCANIC ERUPTIONS AND CONTINENTAL FRAGMENTATION DRAMATICALLY CHANGED CONDITIONS ON PLANET EARTH. DIVERSITY OF LIFE WAS HEAVILY IMPACTED, AND THE EFFECTS OF ALL THESE ARE STILL BEING FELT TODAY. WE ARE TRYING TO MAKE SENSE OF THIS ERA AND THERE'S A VERY GOOD REASON WHY: WE'RE STILL LIVING IN IT.

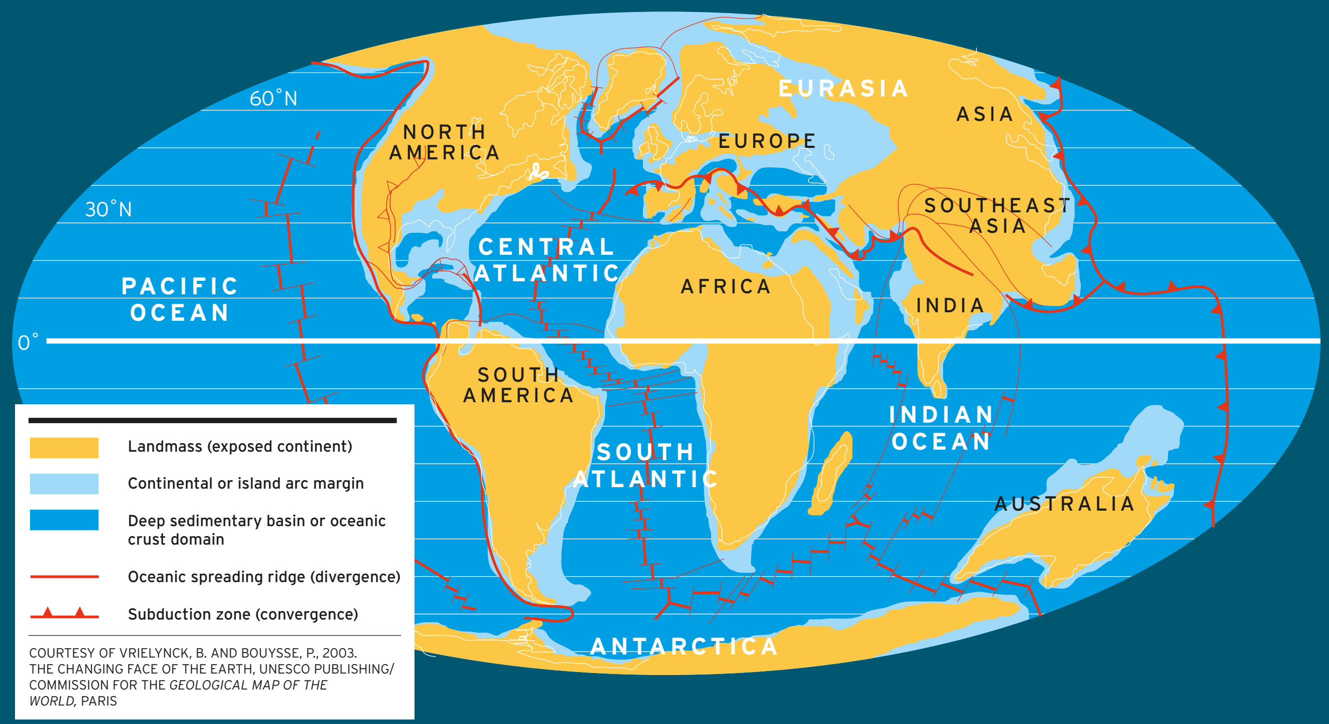
PG.

92 **Times of change**
Find out why the Lutetian era was responsible for giving birth to the wildly different species we see today, from the quirky koalas of Australia to African giraffes.

94 **Surprise!**
Following the break-up of the megacontinents into the world we know today, fauna and flora in the various geographical areas began to develop in very different ways.

LUTETIAN 48–41 MILLION YEARS AGO

EARTH'S CONTINENTS CONTINUED TO FRAGMENT, HAVING BEGUN TO SPLIT APART IN THE MESOZOIC. IN THE PALEOGENE, AUSTRALIA FINALLY BROKE OFF FROM ANTARCTICA AND SOUTH AMERICA LOST ITS CONNECTIONS WITH THAT CONTINENT AS WELL. THE ANIMALS AND PLANTS ON THESE TERRESTRIAL SPLINTERS ENDURED EVEN GREATER ISOLATION AND CONTINUED ON THEIR INDEPENDENT EVOLUTIONARY PATHS.



COURTESY OF VRIELYNCK, B. AND BOUYSSE, P., 2003. THE CHANGING FACE OF THE EARTH, UNESCO PUBLISHING/ COMMISSION FOR THE *GEOLOGICAL MAP OF THE WORLD*, PARIS

30%

DURING THIS PERIOD, WHEN GLACIERS WERE AT THEIR THICKEST AND SEA LEVELS AT THEIR LOWEST, ICE COVERED 30% OF EARTH'S LAND SURFACE.

THE END OF THE CRETACEOUS WAS ANOTHER STRESSFUL TIME IN THE HISTORY OF LIFE. PLANET EARTH HAD BEEN IN THE GRIP OF A GREENHOUSE CLIMATE FOR MUCH OF THE MESOZOIC, BUT THINGS BEGAN TO COOL AS THE CRETACEOUS PROGRESSED.

Towards the end of this long and prosperous period of time for the dinosaurs, the climate inexorably changed – and not in a good way for many animals of the time. The survivors of this cooling seem to have been those of small size and with good body temperature control. Luckily, mammals and birds had these attributes in spades. The extinction of the dinosaurs and other life at the end of the Cretaceous – the famous K-T (Cretaceous – Tertiary) boundary – has been blamed on a meteorite, or even a series of them, around this time. However, meteorites appear to have struck quite some time before the extinction. It was probably a contributing factor, but probably more dangerous to life at this time were the massive volcanic outpourings in western India, evidenced by the Deccan Traps. Their emissions into the atmosphere would have brought about major climatic change, just as Siberian volcanic activity did at the end of the Permian. The K-T event was not as devastating as the late Permian happening, but nonetheless, most dinosaurs and many other groups suffered a huge loss of numbers.

Just as the dinosaurs were able to take advantage of the end of the Permian extinctions, and move into niches vacated by mammal-like reptiles and many other terrestrial inhabitants, so too the mammals and birds moved into vacant eco-space. And so, in the time called the Cenozoic (recent life) from Paleocene times onwards, mammals and birds developed into a diverse array of new species. This ranged from platypuses to horses, from pandas to giraffes. The biodiversity truly is stunning, and we take it for granted. But there's a reason for that. The Cenozoic looks familiar to us because we are still right in the midst of this exciting geologic era.

BELOW: *PROTOPLOTUS*, A FOSSIL BIRD FROM THE EOCENE OF SUMATRA – ONE OF THE PRIMITIVE BIRDS THAT IS INTERMEDIATE BETWEEN LIVING ANHINGAS (SNAKE-BIRDS) AND CORMORANTS. THE ANCESTORS OF OUR LIVING BIRDS SHOW UP IN THE EARLY CENOZOIC AND SPECIES GRADUALLY MODERNIZE THROUGH THE 66 MILLION YEARS OF THIS ERA. *(PETER TRUSLER)*

THE LAST OF THE BIG ONES - THE AUSTRALIAN MEGAFAUNA THAT INHABITED THIS CONTINENT UP UNTIL A FEW TENS OF THOUSANDS OF YEARS AGO. BACK ROW FROM LEFT TO RIGHT: *GENYORNIS* (A DROMORNITHID), *DIPROTODON* AND *PROCOPTODON* (BOTH GIANT MARSUPIALS). FRONT ROW FROM LEFT TO RIGHT *MEGALANIA* (A VARANID LIZARD), *THYLACOLEO* AND *THYLACINUS* (THE TASMANIAN TIGER) - BOTH MARSUPIALS, THE FIRST RELATED TO THE POSSUMS AND THE OTHER A MARSUPICARNIVORE. *(PETER TRUSLER COURTESY OF AUSTRALIA POST)*

ILLUSTRATION: PETER TRUSLER

FOSSILS IN MOTION

WELCOME TO THE PRESENT DAY! YOU HAVE JOURNEYED BACK TO THE PRECAMBRIAN OCEANS, EXPERIENCED THE STARK LANDSCAPE OF THE TRIASSIC, THE BEAUTIFUL AURORA OF THE CRETACEOUS, LEARNT ABOUT THE EXCITING WORLD OF PALEONTOLOGY AND MET A BUNCH OF DIFFERENT DINOSAURS, MAMMALS, AND CROC-LIKE REPTILES ALONG THE WAY. NOW IT'S TIME TO TAKE A LOOK AT WHO WE ARE. LOOKING AT DIFFERENT FEATURES OF THESE ANCIENT ANIMALS AND COMPARING THEM TO OURSELVES, WE BEGIN TO UNDERSTAND A BIT MORE ABOUT US, OUR HISTORY, AND PERHAPS EVEN OUR FUTURE.

STRIDE AND FOOTPRINTS

THE STRIDE OF AN ANIMAL – THE DISTANCE BETWEEN SUCCESSIVE FOOTPRINTS – HELPS PALEONTOLOGISTS UNDERSTAND ITS SIZE AND LOCOMOTION. ANIMALS WITH VERY LONG STRIDES WERE OFTEN LARGE IN SIZE AND MOVED SLOWLY, BUT SOME RUNNERS MIGHT ALSO HAVE HAD VERY LONG STRIDES.

ARTIST NOTE:
AUSTRALIA POST ENGAGED ME TO CRAFT A SET OF STAMPS THAT HIGHLIGHTED THE NOW EXTINCT MEGAFAUNA OF AUSTRALIA – AND I BEGAN WITH BONES AND SKELETONS. BUT THERE WAS A UNIQUE OPPORTUNITY TO UNDERSTAND JUST HOW ONE OF THESE MEGAFAUNAL CHARACTERS ACTUALLY WALKED – AN ANCIENT TRACKWAY IN THE WESTERN PART OF THE STATE OF VICTORIA, AUSTRALIA – TRACKS LEFT LONG AGO BY ONE OF THE LARGEST OF THE MEGAFAUNA, THE GIANT MARSUPIAL *DIPROTODON*. BY MAPPING THESE TRACKS IN DETAIL, IT WAS QUITE STRAIGHTFORWARD TO SKETCH OUT THE ANIMAL'S GAIT. ONCE THE COMPLETELY ARTICULATED FOOT BONES OF *DIPROTODON* WERE AVAILABLE, IT BECAME POSSIBLE TO MAKE A REASONABLY ACCURATE RECONSTRUCTION OF THE FEET OF THIS GIGANTIC MARSUPIAL, PART OF THE AUSTRALIAN MEGAFAUNA THAT ARE NO LONGER WITH US. THEIR OFFSPRING EITHER DOWNSIZED OR WENT EXTINCT. *(PETER TRUSLER)*

HUMAN

THE WALKING STRIDE LENGTH OF A HUMAN VARIES SIGNIFICANTLY ACCORDING TO THE HEIGHT OF A PERSON.

THEROPODS

THEROPODS WERE A LARGE GROUP OF PREDATORY DINOSAURS THAT LIVED DURING THE JURASSIC AND CRETACEOUS. *T. REX* IS A FAMOUS EXAMPLE OF A THEROPOD. THESE WERE HABITUAL BIPEDS, WITH NARROW TRACKWAYS IN WHICH THE PRINTS OF THE HINDFEET OFTEN ARE ARRANGED IN A SINGLE LINE WITH A SLIGHT INWARD FOOT ROTATION.

ORNITHOPODS

SMALL, BIPEDAL RUNNING GRAZERS, THESE WERE A SUCCESSFUL GROUP OF HERBIVORES IN THE CRETACEOUS. ORNITHOPODS, WHICH INCLUDED *LEAELLYNASAURA*, WERE BIPEDAL WITH FAIRLY NARROW TRACKWAYS AND FOOTPRINTS THAT OFTEN SHOW AN INWARD ROTATION.

ORNITHOMIMIDS

A GROUP OF THEROPOD DINOSAURS THAT WERE FAST-MOVING, OMNIVOROUS OR HERBIVOROUS, AND LIVED DURING THE CRETACEOUS. THESE DINOSAURS, OF WHICH *GALLIMIMUS* WAS ONE SPECIES, WERE EXCLUSIVELY BIPEDAL AND THEIR FOOTPRINTS WERE ARRANGED IN A STRAIGHT LINE.

MOVE IT!

DINOSAURS, CROCODILE-LIKE REPTILES, AND MAMMAL-LIKE REPTILES ALL HAD DIFFERENT POSTURES, DEPENDING ON HOW THEIR LIMBS WERE POSITIONED IN RELATION TO THEIR BODY. HUMANS ARE BIPEDAL, WHICH MEANS WE STAND UPRIGHT ON OUR 'HIND' LEGS.

HERRERASAURUS
3 METERS (10 FEET) IN LENGTH

EXAERETODON
2.4 METERS (8 FEET) IN LENGTH

EXAERETODON

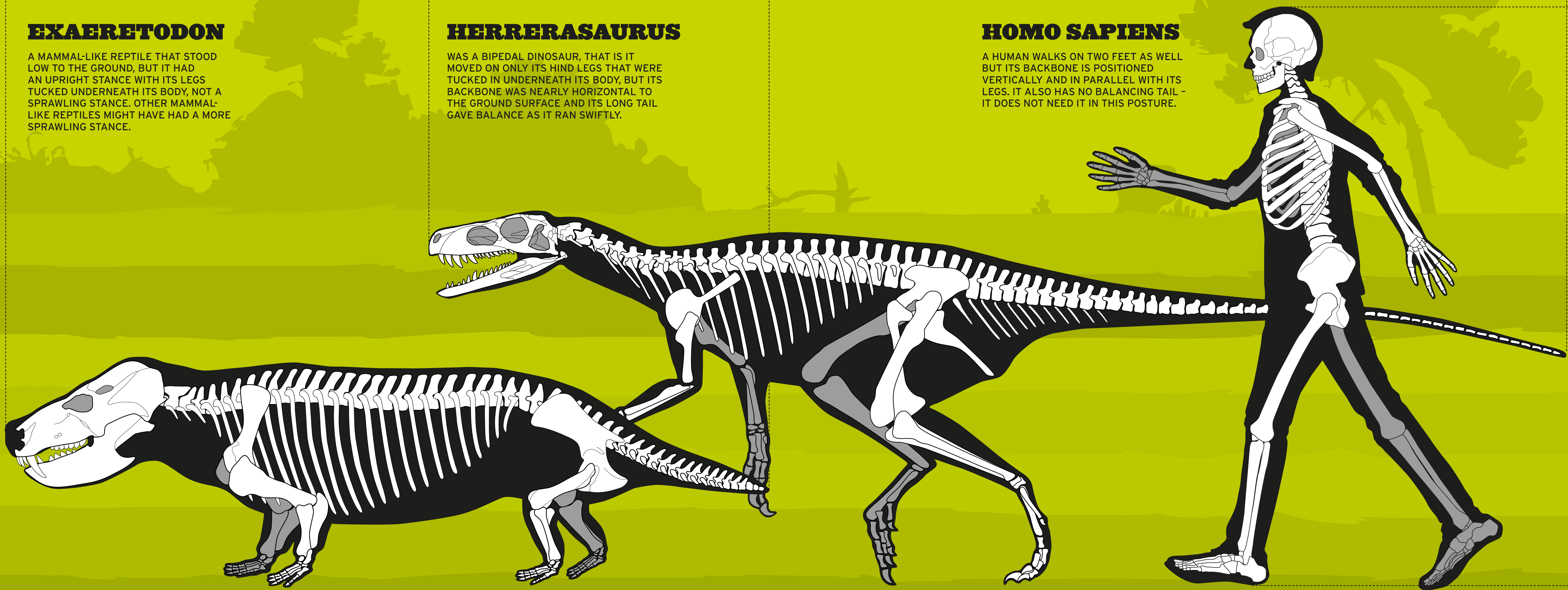
A MAMMAL-LIKE REPTILE THAT STOOD LOW TO THE GROUND, BUT IT HAD AN UPRIGHT STANCE WITH ITS LEGS TUCKED UNDERNEATH ITS BODY, NOT A SPRAWLING STANCE. OTHER MAMMAL-LIKE REPTILES MIGHT HAVE HAD A MORE SPRAWLING STANCE.

HERRERASAURUS

WAS A BIPEDAL DINOSAUR, THAT IS IT MOVED ON ONLY ITS HIND LEGS THAT WERE TUCKED IN UNDERNEATH ITS BODY, BUT ITS BACKBONE WAS NEARLY HORIZONTAL TO THE GROUND SURFACE AND ITS LONG TAIL GAVE BALANCE AS IT RAN SWIFTLY.

HOMO SAPIENS

A HUMAN WALKS ON TWO FEET AS WELL BUT ITS BACKBONE IS POSITIONED VERTICALLY AND IN PARALLEL WITH ITS LEGS. IT ALSO HAS NO BALANCING TAIL – IT DOES NOT NEED IT IN THIS POSTURE.



AVERAGE HOMO SAPIEN
1.6-1.7 METERS (5.2-5.6 FEET) IIN HEIGHT

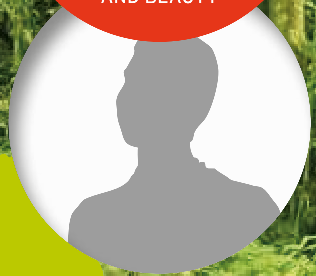
CREATURE CALLS

WE DO NOT KNOW WHAT NOISES ANCIENT ANIMALS MADE BECAUSE THE ORGANS NEEDED TO MAKE SOUNDS OFTEN DO NOT FOSSILIZE. WHAT WE DO KNOW IS MODERN BIRDS, LIZARDS AND CROCODILES ARE DESCENDED FROM ANCIENT ANIMALS. STUDYING MODERN ANIMALS CAN HELP US GUESS WHAT SOUNDS THEIR EXTINCT ANCESTORS MAY HAVE MADE.

LOOKING AT DIFFERENT SKULL STRUCTURES, SCIENTISTS THINK THERE WAS A RANGE OF SOUNDS PRODUCED BY DIFFERENT DINOSAUR SPECIES, INCLUDING BELLOWS, HONKS, SQUEAKS, ROARS, SNARLS, SNORTS, GRUNTS, HISSES, RUMBLES AND HOOTS!

ALLIGATOR
ADULT ALLIGATORS ARE ALERTED BY SOUNDS PRODUCED BY BABY ALLIGATORS WHEN THEY HATCH. DURING COURTSHIP, MALE CHINESE ALLIGATORS BELLOW TO ATTRACT FEMALE ALLIGATORS

HUMAN
THE HUMAN VOICE IS HIGHLY COMPLEX. BY HEARING A PERSON'S VOICE, IT IS POSSIBLE TO GUESS WITH SOME ACCURACY THEIR AGE, GENDER AND MOOD. THE HUMAN VOICE CAN ALSO SING WITH PRECISION AND BEAUTY



MAGPIE GOOSE
THE MAGPIE GOOSE USUALLY USES HONKING AND TRUMPETING SOUNDS FOR GREETING AND DISTANCE CALLING

KOMODO DRAGON
KOMODO DRAGONS ARE THE LARGEST MONITOR LIZARDS IN THE WORLD. HISSING SOUNDS ARE USUALLY PRODUCED DURING FEEDING, ATTACKS AND MATING

MEGALANIA AND GENYORNIS

MEGALANIA WAS THE LARGEST CARNIVORE IN THE MEGAFAUNA OF AUSTRALIA – A CLOSE RELATIVE OF THE KOMODO DRAGON OF INDONESIA. IT QUITE LIKELY WAS AN AMBUSH PREDATOR AS ITS LEGS SPLAYED TO THE SIDE AND IT WOULD NOT HAVE BEEN AN AGILE, FAST-MOVING FORM. STILL, SOME INDIVIDUALS REACHED UP TO PERHAPS 7 METERS IN LENGTH AND THEY HAD AN IMPRESSIVE SET OF TEETH. TRUSLER SAYS, "IN RECONSTRUCTING THIS SCENE IN THE PLEISTOCENE OF AUSTRALIA, I HAVE TRIED TO GET THIS IDEA ACROSS, AND ALSO LEAVE THE VIEWER WONDERING IF THE BIG LIZARD WAS REALLY AFTER THE DROMORNITHID BIRD, *GENYORNIS*, OR JUST OUT FOR SCRAMBLED EGGS!"

MEGALANIA

PRONOUNCED
meg-eh-LANE-ee-eh

NAME MEANING
Ancient great roamer

CLASSIFICATION
Reptilia, Diapsida, Squamata, Lacertilia

ERA
Pleistocene and Holocene, surviving until 30,000 to 40,000 years ago

DIET
Meat, a carnivore, including carrion

SCALE
4 to7 meters (13 to 23 feet) in length

COUNTRY
Australia

GENYORNIS

PRONOUNCED
jenny-ORE-niss

NAME MEANING
Jawed bird

CLASSIFICATION
Aves, Dromornithidae

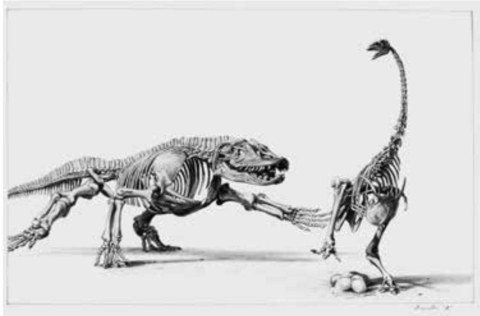
ERA
Pleistocene to Holocene, surviving until 30,000 to 40,000 years ago

DIET
Plants, an herbivore

SCALE
1.5 meters (5 feet) height

COUNTRY
Australia

ILLUSTRATION: PETER TRUSLER



ABOVE:
IN RECONSTRUCTING THE FINAL IMAGE OF *MEGALANIA* ATTACKING *GENYORNIS*, TRUSLER NOTES THAT AS PER HIS USUAL PROCESS, THERE WERE A SERIES OF ARTWORKS THAT PRECEDED THE FINAL. HE SAYS, "I BEGAN WITH THE SKELETON, THEN ADDED MUSCLE, THEN PRELIMINARY SKIN AND FEATHERS – AND FROM THAT THE FINAL PAINTING EMERGED. EVEN BEFORE CRAFTING THE SKELETON, I HAD TO SKETCH IN MY MIND JUST HOW THE BONES FIT TOGETHER TO BE SURE THAT I HAD THE RIGHT MOTION IMAGINED. FOR *GENYORNIS* THIS WAS STRAIGHTFORWARD – THERE WERE SKELETONS OF THIS BIRD KNOWN. FOR *MEGALANIA*, HOWEVER, ONLY FRAGMENTS WERE AVAILABLE AND I HAD TO FILL IN THE MISSING BITS USING THE SKELETON OF ITS NEAR RELATIVE, WHICH LIVED NEARBY ON THE ISLAND OF KOMODO."

THE *PRESENT* IS THE KEY TO THE *PAST*, AND THAT VERY PAST IS LIKELY OUR KEY TO THE *FUTURE*

CONCLUSION

Not so long ago, massive ice sheets moved back and forth across the surface of the Earth. This happened several times during the end of the Pleistocene epoch, from around two and a half million to just a few thousand years ago. The time that humans spread across the face of the Earth was one of significant climate change. And it's not over. We are still really in this icehouse climate, but human activity over the last 150 years has brought about the melting of those sheets of ice. Over the last 70 years, one human lifetime, the population of the Earth has more than tripled. We live in sobering times, but unlike any species before us, we have the ability to make decisions that could well insure that we do not face the same tragedy as the dinosaurs did some 66 million years ago. In contrast to any other species that has ever lived, we also have the power to bring about our own destruction. Just how humans deal with the next 50 years on this planet will affect Earth's fate. What can we learn from the dinosaurs?

In comparing ourselves to dinosaurs, we are able to learn about ourselves. Looking at our skin, our strides, how we move, and how we sound, we are learning about our own history and where we came from. It has been said, "The present is the key to the past, and that very past is likely our key to the future." How we use that key will determine not only our fate, but that of all life itself.

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APPENDIX

A

ADEOPAPPOSAURUS

PRONOUNCED
ah-day-oh-pap-poh-SAWR-us

NAME MEANING
Far-eating lizard

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Saurischia, Sauropodmorpha

ERA
Early Jurassic, 190 million years ago

DIET
Plants, an herbivore

SCALE
1.8 meters (6 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province

AETOSAUROIDES

PRONOUNCED
a-EAT-oh-SORE-oid-ees

NAME MEANING
Eagle lizard

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Thecodontia, Aetosauria (crocodile-like reptile)

ERA
Late Triassic, 228 million years ago

DIET
Meat and plants, an omnivore

SCALE
2 to 3 meters (7 to 10 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

B

BANDED IRON FORMATION (BIF)

PRONOUNCED
ban-did-IRON-four-MAY-shun

NAME MEANING
An iron rock with red and black bands

CLASSIFICATION
Rock formation precipitated by bacteria, and controlled by the presence or absence of oxygen in the environment

ERA
Precambrian, about 2 billion years ago

DIET
sunlight and/or minerals needed for the bacteria

SCALE
About 1 meter (39 inches) wide

COUNTRY
Western Australia

BORHYAENID

PRONOUNCED
bore-high-EE-nid

NAME MEANING
Strong hyaena

CLASSIFICATION
Mammalia, Metatheria (marsupial), Borhyaenidae (Mammalia, Placentalia, for Dire Wolf, Canis dirus)

ERA
Miocene (Pleistocene for Dire Wolf), approximately 15 million years ago

DIET
Lots of meat

SCALE
About 1 to 1.5 meters (39 inches to 5 feet) in length

COUNTRY
Argentina (USA – Dire Wolf)

BULLOCKORNIS

PRONOUNCED
bullok-ORE-niss

NAME MEANING
Bullock (bull) bird

CLASSIFICATION
Aves, Dromornithidae

ERA
Late Miocene, 5 to 11 million years ago

DIET
Plants, an herbivore

SCALE
1.5 meters (5 feet) in height

COUNTRY
Australia

CAMBRIAN-ORDOVICIAN-SILURIAN FAUNAS

PRONOUNCED
CAME-bree-un; ore-doe-VISH-ee-an; sigh-LURE-ee-an

NAME MEANING
Time periods named after ancient human tribes and regions in Europe

CLASSIFICATION
Geological Time Periods

ERA
541 to 419 million years ago

SCALE
A wide range of sizes from very small to animals more than a meter in length

COUNTRY
Global

CRYOLOPHOSAURUS

PRONOUNCED
cry-oh-loph-oh-SAWR-us

NAME MEANING
Cold crested lizard

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Saurischia,Theropoda

ERA
Early Jurassic, 190 million years ago

DIET
Meat, a carnivore

SCALE
6 to 7 meters (20 to 23 feet) in length

COUNTRY
Antarctica

ECTENINION

PRONOUNCED
ek-teh-NIN-ee-on

CLASSIFICATION
Reptilia, Synapsida, Therapsida, Cynodontia

ERA
Late Triassic, 228 million years ago

DIET
Carnivore, likely dining on insects

SCALE
0.5 meters (20 inches) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

CHALAMINIA

PRONOUNCED
chal-ah-MEN-ee-ah

CLASSIFICATION
Reptilia, Synapsida, Cynodontia

ERA
Latest Triassic, 210 million years ago

DIET
Insects and other small prey, insectivore

SCALE
0.3 meters (12 inches) in length

COUNTRY
Northwestern Argentina, La Rioja Province, Talampaya Park

DEVONIAN FAUNA AND FLORA

PRONOUNCED
duh-VONE-ee-un

NAME MEANING
A time period based on rocks in Devon England

CLASSIFICATION
A geologic time period

ERA
419.2 to 358.9 million years ago

COUNTRY
Global

THE EDIACARANS

PRONOUNCED
ee-dee-AK-a-rans

NAME MEANING
Animalia from Ediacara (the Ediacara Hills in South Australia)

CLASSIFICATION
Vendobionts (a group of animals that left no "offspring" today and others that led to molluscs, arthropods and other groups)

ERA
From around 600 to 541 million years ago

DIET
Varied, but to a large extent the microbial mats that covered most of the sea floor of the time

SCALE
From a few millimeters to over 1 meter

COUNTRY
Global

CHINIQUODON

PRONOUNCED
chin-EE-kwo-don

NAME MEANING
Primitive mammal from Chinqua, Brazil

CLASSIFICATION
Reptilia, Synapsida, Therapsida, Dynodontia

ERA
Late Triassic, 228 million years ago

DIET
Meat, a carnivore

SCALE
Up to 1 meter (39 inches) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

DICYNODON

PRONOUNCED
die-SIGN-oh-don

NAME MEANING
Double dog-tooth

CLASSIFICATION
Reptilia, Therapsida, Dicynodontia

ERA
Late Permian, 254 million years ago

DIET
Plants, an herbivore

SCALE
About 1 meter (39 inches) in length

COUNTRY
Northern Russia, near Archangelsk

EODROMAEUS

PRONOUNCED
ee-oh-DRO-mee-us

NAME MEANING
Ancient runner

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Saurischia, Theropoda

ERA
Late Triassic, 230 million years ago

DIET
Meat, a carnivore

SCALE
About 0.7 meters (28 inches) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

EORAPTOR

PRONOUNCED
EE-oh-rap-tor

NAME MEANING
Dawn hunter

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Sauropodmorpha

ERA
Late Triassic, 228 million years ago

DIET
Omnivorous – both plants and meat

SCALE
1 to 1.4 meters (3 to 5 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

GALLIMIMUS

PRONOUNCED
gal-ih-MIME-us

NAME MEANING
Ostrich-mimic, chicken-mimic

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Saurischia, Theropoda

ERA
Late Cretaceous, 70 million years ago

DIET
Plants and animals, an omnivore

SCALE
4 meters (13 feet) in length

COUNTRY
Southeastern Mongolia, Gobi Desert

KAMBARA

PRONOUNCED
kam-BAR-ah

NAME MEANING
An Aboriginal word meaning crocodile

CLASSIFICATION
Reptilia, Crocodylomorpha, Crodylidae, Mekosuchinae

ERA
Early Eocene, 55 million years ago

DIET
Fish and other aquatic material

SCALE
Size range similar to the living saltwater crocodile, 1 to 5 meters (3 to 16 feet) in length

COUNTRY
Australia

EXAERETODON

PRONOUNCED
x-air-ET-oh-don

CLASSIFICATION
Reptilia, Synapsida, Therapsida, Cynodontia

ERA
Late Triassic, 228 million years ago

DIET
Plants and animals, an omnivore

SCALE
Adults up to 2.4 meters (8 feet) in length, juveniles as small as 0.4 meters (16 inches) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

HERRERASAURUS

PRONOUNCED
he-rare-ah-SAWR-us

NAME MEANING
Herrera's lizard, named after the *gaucho* (cowboy) who led paleontologists to Ischgualasto

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Saurischia, Theropoda

ERA
Late Triassic, 228 million years ago

DIET
Meat, a carnivore

SCALE
About 3 meters (10 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

KOOLASUCHUS

PRONOUNCED
cool-eh-SOOK-us

NAME MEANING
Cool "crocodile", named after Lesley Kool and the fact that it lived in very cool conditions

CLASSIFICATION
Amphibia, Labyrinthodontia, Temnospondyli

ERA
Early Cretaceous, 120 million years ago

DIET
Meat from a mainly aquatic environment

SCALE
2 to 4 meters (6 to 13 feet), approaching the size of the living saltwater crocodiles

COUNTRY
Australia

FASOLOSUCHUS

PRONOUNCED
fas-sole-oh-SOOK-us

NAME MEANING
Fasola's ancient crocodile, named after Juan Fasola, a preparatory and fossil hunter from Tucuman

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Rauisuchia

ERA
Latest Triassic, 210 million years ago

DIET
Meat, a carnivore

SCALE
9.2 meters (30 feet) in length

COUNTRY
Northwestern Argentina, La Rioja Province, Talampaya Park

ISCHIGUALASTIA

PRONOUNCED
is-chee-gua-LAS-tee-ah

NAME MEANING
Ancient reptile from Ischigualasto

CLASSIFICATION
Reptilia, Synapsida, Therapsida, Dicynodontia

ERA
Late Triassic, 228 million years ago

DIET
Plants, an herbivore

SCALE
About 0.7 to 1 meter (28 to 39 inches) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

LEAELLYNASAURA

PRONOUNCED
lee-el-in-eh-SAWR-eh

NAME MEANING
Leaellyn's lizard, named after a school girl, Leaellyn Rich, who helped in field work

CLASSIFICATION
Reptilia, Dinosauria, Ornithischia, Ornithopoda

ERA
Early Cretaceous, 106 million years ago

DIET
Plants, an herbivore

SCALE
Up to 1 meter (3 feet) in length

COUNTRY
Australia

LESSEMSAURUS

PRONOUNCED
less-im-SAWR-us

NAME MEANING
Lessem's lizard, named after Don Lessem, a American who has popularized dinosaurs in many different ways

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Saurischia, Sauropodomorpha

ERA
Latest Triassic, 210 million years ago

DIET
Plants, an herbivore

SCALE
19 meters (62 feet) in length

COUNTRY
Northwestern Argentina, La Rioja Province, Talampaya Park

LYSTROSAURUS

PRONOUNCED
Liss-trow-SAWR-us

NAME MEANING
Shovel reptile

CLASSIFICATION
Reptilia, Therapsida, Dicynodontia

ERA
Early Triassic, 250 million years ago

DIET
Plants, an herbivore

SCALE
Adults about 1 meter (3 feet) in length

COUNTRY
Russia

MARASUCHUS

PRONOUNCED
mar-ah-SOOK-us

NAME MEANING
Rodent-like lizard (named after the mara, which is a large rodent that lives in deserts of Argentina)

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Dinosauriformes – closely related to dinosaurs

ERA
Middle Triassic, 237 million years ago

DIET
Meat, a carnivore

SCALE
0.2 meters (8 inches) in length, mouse-sized

COUNTRY
Northwestern Argentina, La Rioja Province, Talampaya Park

MEGALANIA

PRONOUNCED
meg-eh-LANE-ee-eh

NAME MEANING
Ancient great roamer

CLASSIFICATION
Reptilia, Diapsida, Squamata, Lacertilia

ERA
Pleistocene and Holocene, surviving until 30,000 to 50,000 years ago

DIET
Meat, a carnivore, including carrion

SCALE
4 to7 meters (13 to 23 feet) in length

COUNTRY
Australia

MESOSAURUS

PRONOUNCED
mee-zo-SAWR-us

NAME MEANING
"Midde" lizard

CLASSIFICATION
Reptilia, Anapsida, Mesosaurida

ERA
Early Permian, 280 million years ago

DIET
Small swimming animals, such as crustaceans

SCALE
1 meter (3 feet) in length

COUNTRY
Eastern South America (Uruguay and Brazil) and southern Africa

PANPHAGIA

PRONOUNCED
pan-FAGH-ee-ah

NAME MEANING
"All eating" in reference to its broad, omnivorous diet

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Saurischia, Sauropodomorpha

ERA
Late Triassic, 228 million years ago

DIET
Omnivore, plants and animals

SCALE
1.2 meters (4 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

PERMIAN FLORA AND FAUNA

PRONOUNCED
PURR-me-an

NAME MEANING
A geologic period named after the rocks in the Perm region of Russia

CLASSIFICATION
A Geological Time Period

ERA
298.9 to 252.2 million years ago

COUNTRY
Global

PISANOSAURUS

PRONOUNCED
peh-san-oh-SAWR-us

NAME MEANING
Pisano's lizard, named after Juan Pisano, an Argentine paleontologist

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Ornithischia

ERA
Late Triassic, 228 million years ago

DIET
Plants, an herbivore

SCALE
1 meter (39 inches) in length

COUNTRY
Northwestern Argentina, La Rioja Province, Talampaya Park

PROBELESODON

PRONOUNCED
pro-bell-ESS-oh-don

CLASSIFICATION
Reptilia, Therapsida, Cynodontia

ERA
Late Triassic, 228 million years ago

DIET
Meat, a carnivore

SCALE
0.25 meters (10 inches) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

PROMASTODONSAURUS

PRONOUNCED
pro-mast-toe-don-SAWR-us

NAME MEANING
Mastodon-sized lizard (the mastodon is an ancient elephant)

CLASSIFICATION
Amphibia, Labyrinthodonta, Temnospondyli

ERA
Late Triassic, 228 million years ago

DIET
Fish and other animals, just about anything in the water!

SCALE
2.5 meters (8 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

PROTEROCHAMPSA

PRONOUNCED
pro-tehr-oh-CHAMP-suh

NAME MEANING
Early relative of crocodiles

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Thecodontia, Proterosuchia

ERA
Late Triassic, 228 million years ago

DIET
Meat, a carnivore

SCALE
2.5 meters (8 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

PROTOCERATOPS

PRONOUNCED
pro-toe-CER-a-tops

NAME MEANING
First horned face, referring to many of its relatives having horns

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Ornithischia, Ceratopsia

ERA
Late Cretaceous, 75 million years ago

DIET
Plants, an herbivore

SCALE
Embryos about 0.1 meter (4 inches) in length, adults up to 1.8 meters (6 feet)

COUNTRY
Southeastern Mongolia, Gobi Desert

PSEUDOHESPEROSUCHUS

PRONOUNCED
su-do-hes-purr-oh-SOOK-us

NAME MEANING
False hesperosuchus, western crocodile

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Crocodylia, Sphenosuchia

ERA
Latest Triassic, 210 million years ago

DIET
Meat, a carnivore

SCALE
1.3 meters (4 feet) in length

COUNTRY
Northwestern Argentina, La Rioja Province, Talampaya Park

SANJUANSAURUS

PRONOUNCED
san-wan-SAWR-us

NAME MEANING
San Juan's lizard

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Saurischia, Theropoda

ERA
Late Triassic, 228 million years ago

DIET
Meat, a carnivore

SCALE
1 to 3 meters (3 to 10 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

SAUROSUCHUS

PRONOUNCED
sawr-oh-SOOK-us

NAME MEANING
Lizard crocodile

CLASSIFICATION
Reptilia, Diapsida, Archosauria , Thecodontia, Rauisuchia (Pseudosuchia)

ERA
Late Triassic, 228 million years ago

DIET
Meat, a carnivore

SCALE
6 meters (20 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

SCAPHONYX

PRONOUNCED
ska-FON-ix

CLASSIFICATION
Reptilia, Diapsida, Archosauromorpha, Sauropterygia, Rhynchosauria

ERA
Late Triassic, 228 million years ago

DIET
Plants, an herbivore

SCALE
2 to 2.3 meters (7 to 7.5 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

SIDEROPS

PRONOUNCED
SIGH-deer-ops

NAME MEANING
iron face

CLASSIFICATION
Amphibia, Labyrinthodontia, Temnospondyli

ERA
Early Jurassic, 190 million years ago

DIET
Mainly aquatic vertebrates

SCALE
2.5 meters (8 feet) in length

COUNTRY
Queensland, Australia

SILLOSUCHUS

PRONOUNCED
sil-oh-SUE-cuss

NAME MEANING
Sill's crocodile, named after paleontologist William Sill who worked in Ischigualasto for many years

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Thecodontia, Rauisuchia

ERA
Late Triassic, 228 million years ago

DIET
Probably an herbivore

SCALE
5 meters (16 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

TALARURUS

PRONOUNCED
tal-ah-ROOR-us

NAME MEANING
Basket-tail, referring to the tail club used for defense

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Ornithischia, Ankylosauria

ERA
Late Cretaceous, 85 million years ago

DIET
Plants, an herbivore

SCALE
4 to 5 meters (13 to 16 feet) in length

COUNTRY
Southeastern Mongolia, Gobi Desert

TEHUELCHESAURUS

PRONOUNCED
Tu-hwelch-eh-SAWR-us

NAME MEANING
Tehuelche's lizard (named after the indigenous people of the region where this dinosaur was found)

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Saurischia, Sauropodomorpha

ERA
Early Jurassic, 190 million years ago

DIET
Plants, an herbivore

SCALE
15 meters (49 feet)

COUNTRY
Argentina

VENATICOSUCHUS

PRONOUNCED
veh-nat-teh-ko-SOOK-us

NAME MEANING
Hunting crocodile

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Thecodontia, Ornithosuchia

ERA
Late Triassic, 228 million years ago

DIET
Meat, a highly specialized carnivore

SCALE
1.4 meters (5 feet) in length

COUNTRY
Northwestern Argentina, San Juan Province, Ischigualasto

TARBOSAURUS

PRONOUNCED
tar-bow-SAWR-us

NAME MEANING
Alarming reptile

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Saurischia, Theropoda

ERA
Late Cretaceous, 70 million years ago

DIET
Meat, dead and alive (predator and carrion feeder)

SCALE
Adults up to 14 meters (46 feet) in length

COUNTRY
Southeastern Mongolia, Gobi Desert

VELOCIRAPTOR

PRONOUNCED
vel-ah-si-RAP-tore

NAME MEANING
Swift robber

CLASSIFICATION
Reptilia, Diapsida, Archosauria, Saurischia, Theropoda

ERA
Late Cretaceous, 75 million years ago

DIET
Meat, a carnivore

SCALE
A maximum of 3 meters (10 feet) in length

COUNTRY
Mongolia

REPTILIA CLASSIFICATION

CLASS: AMPHIBIA

SUBCLASS: LABYRINTHODONTA

- Order: Temnospondyli
  - *Koolasuchus* (Early Cretaceous, 120 mya)
  - *Siderops* (Early Jurassic, 190 mya)
  - *Promastodonsaurus* (Late Triassic, 228 mya)

CLASS: REPTILIA

SUBCLASS: ANAPSIDA

- Order: Captorhinida
  - Suborder: Captorhinomorpha
  - Suborder: Procolophonia
  - Suborder: Pareiasauroidea
- Order: Mesosaurida
  - *Mesosaurus* (Permian, 280 mya)

SUBCLASS: TESTUDINATA

- Order: Chelonia (turtles)
  - *Chelycarapookus* (Early Cretaceous, 106 mya)
  - *Chubutemys* (Early Cretaceous, 120 mya)

SUBCLASS: DIAPSIDA

INFRACLASS: LEPIDOSAUROMORPHA
- Superorder: Lepidosauria
  - Order: Sphenodonta
  - Order: Squamata
    - Suborder: Lacertilia (lizards)
      - *Megalania* (Pleistocene, 30,000-50,000 ya)
    - Suborder: Serpentes (snakes)
- Superorder: Sauropterygia
  - Order: Plesiosauria (plesiosaurs)

INFRACLASS: ARCHOSAUROMORPHA
- Superorder: Sauropterygia
  - Order: Rhynchosauria
    - *Scaphonyx* (Late Triassic, 228 mya)
- Superorder: Archosauria
  - Order: Thecodontia
    - Suborder: Proterosuchia
      - *Proterochampsa* (Late Triassic, 228 mya)
    - Suborder: Ornithosuchia
      - *Venaticosuchus* (Late Triassic, 228 mya)
    - Suborder: Rauisuchia
      - *Fasolasuchus* (Late Late Triassic, 210 mya)
      - *Sillosuchus* (Late Triassic, 228 mya)
      - *Saurosuchus* (Late Triassic, 228 mya)
    - Suborder: Aetosauria
      - *Aetosauroides* (Late Triassic, 228 mya)
    - Suborder: Phytosauria
  - Order: Crocodylia
    - Suborder: Sphenosuchia
      - *Pseudohesperosuchus* (Late Triassic, 210 mya)
    - Suborder: Protosuchia
    - Suborder: Eosuchia
      - Family: Crocodylidae
        - *Kambara* (Eocene, 55 mya)
  - Order: Pterosauria
  - Dinosauriformes:
    - *Marasuchus* (Middle Triassic, 235 mya)
  - Order: Saurischia
    - Suborder: Theropoda
      - *Herrerasaurus* (Late Triassic, 228 mya)
      - *Sanjuansaurus* (Late Triassic, 228 mya)
      - *Eodromaeus* (Late Triassic, 228 mya)
      - *Cryolophosaurus* (Early Jurassic, 190 mya)
      - *Megalosaurus* (Jurassic to Early. Cretaceous, 150-120 mya)
      - *Allosaurus* (Late Jurassic to Early Cretaceous, 150-120 mya)
      - *Timimus* (Early Cretaceous, 106 mya)
      - *Tarbosaurus* (Cretaceous, 85 mya)
      - *Velociraptor* (Late Cretaceous, 75 mya)
      - *Gallimimus* (Late Cretaceous, 70 mya)
    - Suborder: Sauropodomorpha
      - *Eoraptor* (Late Triassic, 228 mya)
      - *Panphagia* (Late Triassic, 228 mya)
      - *Lessemsaurus* (Late Triassic, 210 mya)
      - *Adelopapposauus* (Early Jurassic, 190 mya)
      - *Tehuelchesaurus* (Early Jurassic, 190 mya)
  - Order: Ornithischia
    - Suborder: Ornithopoda
      - *Pisanosaurus* (Late Triassic, 228 mya)
      - *Qantassaurus*(Early Cretaceous, 120 mya)
      - *Leaellynasaura* (Early Cretaceous, 106 mya)
      - *Atlascopcosaurus* (Early Cretaceous, 106 mya)
    - Suborder: Ceratopsia
      - *Serendipaceratops* (Early Cretaceous, 120 mya)
      - *Protoceratops* (Late Cretaceous, 75 mya)
    - Suborder: Ankylosauria
      - *Talarurus* (Late Cretaceous, 85 mya)

SUBCLASS: SYNAPSIDA

- Order: Therapsida
  - Suborder: Dicynodontia
    - *Lystrosaurus* (Early Triassic, 250 mya)
    - *Dicynodon* (Late Permian, 254 mya)
    - *Ischigualastia* (Late Triassic, 228 mya)
  - Suborder: Gorgonopsia
    - *Rubidgea* (Late Permian, 254 mya)
  - Suborder: Cynodontia
    - *Thrinaxodon* (Early Triassic, 250 mya)
    - *Chinquodon* (Middle to Late Triassic, 235-228 mya)
    - *Ecteninion* (Late Triassic, 228 mya)
    - *Exaeretodon* (Late Triassic, 228 mya)
    - *Probelesodon* (Middle Triassic, 228 mya)
    - *Chaliminia* (Late Triassic, 210 mya)

IMAGE: MARINA BAY SANDS PTE. LTD.

ABOUT ARTSCIENCE MUSEUM

ArtScience Museum™ at Marina Bay Sands is known as the museum that celebrates creativity, the processes at the heart of art and science, and their role in shaping society. The Museum seeks to understand what drives creative people, how they acquire and use their skills, and how the world around us is changed because of it. ArtScience Museum presents exhibitions and programmes to deliver these stories using a combination of beautiful design, intriguing content and intellectual discussion, in order to inspire the creativity in all of us.

Featuring 21 gallery spaces totaling 50,000 square feet, the boldly iconic lotus-inspired ArtScience Museum is also the premier venue for major international touring exhibitions from the most renowned collections in the world. Since it opened in 2011, ArtScience Museum has been home to some of the best-attended exhibitions in Singapore, including *"Titanic: The Artifact Exhibition", "Harry Potter: The Exhibition", "Andy Warhol: 15 Minutes Eternal", "Dali: Mind of a Genius", "The Art of the Brick"* and *"Mummy: Secrets of the Tomb". Recent exhibitions include "Essential Eames: A Herman Miller Exhibition"* and *"The Little Black Jacket".*

ArtScience Museum at Marina Bay Sands was awarded TripAdvisor's Certificate of Excellence in 2013. This recognition places the museum amid a select group of attractions that have been recognized by worldwide travelers for providing outstanding tourist experiences.


IMAGE: COURTESY OF DR. PATRICIA VICKERS-RICH