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Teachers Notes (Middle Years)
by Dr John Long

The Big Picture Book

by Dr John Long,
illustrated by Brian Choo

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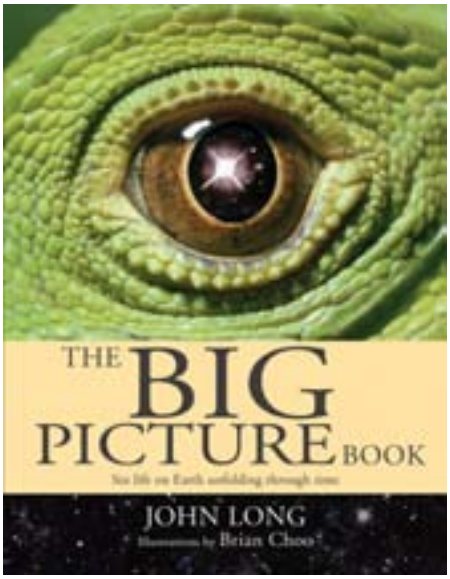

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INTRODUCTION

This book was written to introduce to upper primary and lower secondary level children an outline of the three main themes that contribute towards our understanding of evolution: time, physical processes, and biological change. The book can be used to augment studies in general science (astronomy, geology, biology), but also to contribute to an understanding of the birth of human culture and to promote discussion of environmental issues confronting the world today. The writing is a simple, almost lyrical style to facilitate an easy level of reading, with pronunciation guide and glossary at the back of the book to help children say and understand the meaning of most of the technical words used in the text.

SCIENCE STUDIES

The Big Picture Book features the very latest information on the timing of major evolutionary events compiled by palaeontologist John Long. John worked in consultation with many experts from around the world to check that all facts are correct, or as near as possible to date specified, at the time this book went to press. This means that some of the dates presented here for major events will be in direct conflict with many existing popular books on evolution because these books are already outdated. For example, the evolution of the first modern humans (*Homo sapiens sapiens),* is here placed at 160,000 years because of a recent paper published in the science journal *Nature* in 2002, so such information pushes back the previously oldest dates (100-120,000 years) by another 40,000 years.

The four main scientific themes explored in the book are Time, Astronomy, Geology and Biology.

TIME

A long human life can reach 100 years. Ten such lives back to back make a thousand years. A million (1,000,000) is a 1000 times 1000. The standard unit of measuring geological time is in millions of years. A billion is 1000 times one million (1000,000,000).

How do we know the age of the universe, the age of earth and the ages of fossils shown in the book?

To answer this question we must first look at ways scientists have to date rocks and meteorites. Radiometric dating relies on the known decay rates of radioactive varieties of each element (called isotopes). For example the decay of Uranium into Lead takes hundreds of million of years. Scientists can measure accurately rates of decay of all radioactive isotopes and then calculate from the amounts left in the mineral structures of rocks, exactly how old that rock is.

- Radioactive dates on meteorites from space show that the solar system must have formed around 4,500 million years ago.
- Meteorites are the same material that forms the cores of planets so they are thought to be the left over material after the planets had formed. Thus the timing of their formation dates the formation of our solar system.

The age of the Universe is calculated from looking at rates at which galaxies are moving away from each other. Scientists first calculated this using the known speed of light and the shift in colour change from galaxies as they move away from each other, giving an estimated speed of universe expansion (away from the Big Bang). The scientists then extrapolated back to the estimated time of the Big Bang and came up with an estimate that ranged from 12 to 15 billion years ago. We know that at least by 12 billion years ago the known Universe had formed.

ASTRONOMY

The Big Picture Book mentions the concepts of how the universe may have formed, called the Big Bang Theory. It shows images of galaxies, stars, solar systems, planets and their moons.

- The universe consists of many galaxies each speeding away from each other at incredibly fast speeds.
- Galaxies contain many million of stars, some of which have planets orbiting around them.
- Each star with a set of planets orbiting it is called a 'solar system'. Planets may have smaller bodies orbiting them, these are called moons.
- Earth is one such planet within a solar system; it has one moon.

Meteorites are rocks from space (called 'meteors' when in space 'meteorites' when they hit Earth). They are made of the same material that planets are made of. Most are made of iron and nickel (which forms the core of Earth); others are stony (like the outer layers, or mantle, of a planet).

Asteroids are larger versions of meteors that may have a more complex composition, and often carry large amounts of ice with them. If they have a long trailing tail of gas and ice, they are called comets.

GEOLOGY

The Earth is a dynamic system with processes that have been operating for billions of years. The study of how the surface crustal plates of the Earth move is called 'plate tectonics'.

The movement of continents has been shown to be a continuous process that is still happening today. Australia is drifting north at around 6cm/year, the same speed at which human hair grows. So, if we extrapolate back in time, we can see how Australia was once further south. Similar fossils found in Australia and Antarctica confirm the idea that they were once part of the same landmass.

Evidence for the movement of Earth's continents comes from:

- Unique forms of fossils found only in certain continents at a certain time when they were once a giant landmass (e.g. the reptile *Lystrosaurus*);
- Ancient magnetism trapped in the rocks that shows the ancient North-South directions (as magnetic grains in sand aligned themselves);
- Modern measurement of crustal movement e.g. Australia's drift north.

The movement of continents over time explains many things we see in the world today. When plates of Earth's crust grind against each other the following events can occur:

- Earthquakes caused when pressure building up is suddenly released
- Tsunamis, or tidal waves, caused by underwater earthquakes
- Volcanic eruptions when molten lava rises to the top through cracks caused by plate tectonic movements
- Mountain ranges formed as continental plates push one another upwards.

The continuous movement of the ancient continents has had a profound effect, changing the climate of the world through a number of mechanisms:

- New ocean currents are created when newly formed supercontinents block old current pathways or close old oceans
- Ice ages develop as unpredicted wobbles in the Earth's orbit cause variable seasons, and supercontinents stop warm currents from warming the southern and northern polar areas
- Volcanic eruptions and degassing from the Earth's mantle into the oceans increases greenhouse gases in the atmosphere, warming the Earth

BIOLOGY

There is a great diversity of life-forms on the earth today, and all have evolved from ancestral species over time.

What is a species?

A species is the scientific term we give to similar kinds of living things that have a unique genetic make-up enabling them to breed with their own kind. To avoid confusion caused by language differences, scientists in every country call all living things by their 'scientific', or Linnean, names. Every living thing is given a two-part name made up of a genus and species name. For example, an African lion has the genus name *Panthera*, and the species name *leo*, hence it is *Panthera leo*. The tiger is a different species of the same genus, *Panthera tigris*. Our human scientific name is *Homo sapiens,* meaning 'man the wise'.

What is evolution?

The process of a species gradually changing over long periods of time into a new species is called evolution. Although evolution was once referred to as a theory (as it was in Charles Darwin's day - back in 1859), it is now an accepted scientific fact proven by:

- Accurate geological dating of fossils using modern techniques;
- Complete series of fossils showing all the major links between different kinds of living creatures (e.g. the links between birds and reptiles are shown by fossils of feathered dinosaurs with long arms (almost wings) just before they evolved into the first birds –see p.33);
- The fossil record today which is known from over a hundred million specimens in hundreds of major museums around the world (e.g. Museum Victoria in Melbourne has about 3 million fossil specimens alone).
- Measurement of the degrees of change from one species to another in all modern organisms using the analysis of their DNA (deoxyribonucleic acid, a molecule which is in all genes of all living creatures and plants);
- Observation of how the complexity of life has increased steadily through time, from simple organisms billions of years old, to more complex forms in younger geological time;
- The observation that all medical, genetic and biological research in the world today relies on the predictability of evolution as the only explanation for how organisms mutate and form new varieties and eventually new species.

The Big Picture Book shows the major steps in the evolution of life, starting with the origins of life from organic molecules, through to single cells with a nucleus (eukaryotes), to multi-cellular animals

and plants (metazoans), through to the great radiation of invertebrate and vertebrate species. The major steps in evolution are arbitrary events, accorded differing rank by different scientists. Here I have chosen what I consider to be the biggest events in evolution and earth history.

In the big scheme of things, the evolution of humans is a relatively small event. It is the spread of our species throughout the world over the period of some 160,000 years that dramatically changed the face of the planet.

SCIENCE AND THE FUTURE

The book ends with a predication about what the Earth will look like in 50 million years time. What can we learn from the trends seen in the rest of the book?

- Processes of plate tectonics and evolution will certainly continue to operate, as they have done for billions of years, and thus will certainly change the Earth's overall appearance and alter its biological composition (its fauna and flora).
- If we look back in time 40 million years we see that many creatures were alive then that are alive today, but in slightly different form (e.g. whales, sharks, penguins). What could we expect in 50 million years from today?

Will climates be warmer or colder in future, or will we keep the cycle between hotter greenhouse times and colder ice ages?

CULTURAL STUDIES

The latter part of the book presents a simple view of human evolution. It shows how people first evolved in Africa and later spread to all corners of the globe. Once settled in new lands, they developed new cultures.

How have humans changed the way the Earth looks?

- Hunting animals, farming crops and clearing forests
- Building dams, changing waterways and draining swamps
- Making roads to open up travel between different lands
- Building machines that connect countries through technology

How does a culture develop?

- Like biological evolution, human cultures evolved over time from people adapting to their local climates and the food resources available.
- Cultures are dependant upon what resources they have in their areas – for example, if near the sea, fishing is important; if in the mountains, then hunting is often more important.
- People first use their time to find food (gathering plant foods or hunting animals), but as more free time develops once food is under control, people develop more art and religious ideas.

Today (pp42-43), the physical processes highlighted throughout the book are still operating as are the biological processes of evolution. The people of the earth are now the dominant large species on the planet and we have made many amazing technological discoveries. We have spacecraft, medicines, and can build huge skyscrapers, but our need for more space is causing devastation to many other species.

LANGUAGE

The book is written in an easy to read style but contains a lot of scientific and technical terms.

Most of the names of prehistoric animals in the book are taken from Greek or Latin bases. Sometimes, though, local words or place names are used (e.g. Aboriginal words or site names). A lot can be learned about language from connecting words in the book.

E.g. The word palaeontology comes from the Greek meaning “study of ancient life” (Greek ‘palaeontos –ancient life, ‘logos’-word or study of).

MEANINGS OF SOME OF THE NAMES FEATURED IN THE BOOK:

Stromatolite — *stromata*, Greek meaning ‘layer’ and *lite* - from Greek *lithos* meaning ‘stone’.

Trilobite — Greek meaning ‘three-lobed thing’.

Aranadaspis — Aboriginal Aranda tribe of central Australia, plus Greek *aspis* meaning shield.

Dinosaur — from the Greek meaning ‘terrible lizard’ (*deinos*, *sauros*).

Ichthyosaur — from the Greek meaning ‘fish lizard’.

Pterosaur — the Greek meaning ‘wing lizard’.

The scientific name for humans, *Homo* comes from the Greek word meaning ‘man’. The family Hominidae is made from this root, and the word ‘hominid’ is an informal derivative of this term.

ABOUT THE WRITER AND ILLUSTRATOR

DR JOHN LONG

John Long was born in Melbourne, Australia, and began collecting fossils at the age of 7. He graduated from Monash University with a PhD in 1984 and has since held research positions in the Geology Departments at the Australian National University, University of Western Australia, and the University of Tasmania. In 1989 he was appointed as Curator of Vertebrate Palaeontology at the Western Australian Museum in Perth and at the end of 2004 he returned to Melbourne to take up the position of Head of Sciences at Museum Victoria.

John’s research work has focussed on the early evolution of fishes in Australia and other parts of Gondwana. He has collected fossils throughout Australia, Thailand, Vietnam, South Africa, and has been on two expeditions to Antarctica. He has become well-known for his discoveries of well-preserved Devonian age fish fossils from Gogo, in the Kimberley (including his discovery of *Mcnamaraspis,* the State Fossil Emblem of Western Australia), and of dinosaurs and marine reptile fossils in Western Australia. He has published over 110 scientific papers and more than 70 popular science articles.

In 2001 he was the winner of the prestigious Eureka Prize for the Promotion of Science, and in 2003 won the Riversleigh Medal for contributions to Palaeontology.

John has written: “I decided to write this book because my friend Susan Marie of Subiaco Library once told me during Children’s Book Week that we desperately need an accurate, simple book about prehistoric life for kids. After having looked around at what was available, I decided to write this book with sparse text to state the simple, clear facts about the origin of our Universe, of the Earth and its many changes, and the most important points of the evolution of all life.”

BRIAN CHOO

Brian Choo is an artist who has been studying and reconstructing fossil animals for several years. Brian was born in Singapore but moved to Perth, Western Australia, when he was 3. He gained his BSc in Biology at Murdoch University and did his Hon. in Geology at UWA, eventually deciding that art rather than academia was his true path in life.

He has been obsessed with dinosaurs since he was a kid and has been drawing them ever since. As a freelance natural history artist and science writer he has contributed to a wide range of popular

science periodicals (including *Dinonews, Scientriffic* and *Nature Australia*) as well as museum displays and TV documentaries. In addition to painting, he enjoys electronic gaming, bushwalking, scuba diving and maintaining marine aquaria.

He is also a member of the Friends of the Western Swamp Tortoise society and takes an active role in helping Australia's most endangered reptile.

About his work for *The Big Picture Book*, Brian says: “This has been the largest project I've ever worked on – nearly 20 major paintings in a year – but it was worth every minute! Natural history illustration has always been a major driving passion of mine and this book gave me the opportunity to depict scenes and creatures that no other artist has ever bothered to tackle before. I took great pains to make sure that the artistic subjects conformed as closely to current scientific understanding as possible (more time was spent researching in university libraries and harassing palaeontologists than actually painting).”

APPENDIX:
A BIG PICTURE 'BESTIARY' BY BRIAN CHOO

The following document provides brief details on all the major animals and plants presented in my series of illustrations in *The Big Picture Book* (Allen & Unwin, 2005). The listed references consist of the actual sources that I used in researching the contents of each painting. Some of these are highly specialised academic publications that may be hard to find outside of major university or museum libraries.

PAGE 11 (3,500,000,000 YEARS AGO)

Stromatolites

The fossil stromatolites of the Warrawoona Group of rocks in the arid Pilbara region of Western Australia represent some of the oldest evidence for life on Earth. This scene depicts what the domical fossil stromatolites at a remote site called "North Pole" (about two and a half hours drive from Port Hedland) may have looked 3.49 billion years ago. Inspiration from photographs of living stromatolitic colonies at Shark Bay, Western Australia, helped to provide the overall look and eerie feel of the scene.

References

Grey, K., Hickman, A. H., Van Kranendonk, M. J., and Freeman, M. J. (2002), 3.45 billion year-old stromatolites in the Pilbara region of Western Australia: proposals for site protection and public access. Department of Mineral and Petroleum Resources Record 2002/17.

McNamara. K. J. (1997), Stromatolites: Perth, Western Australian Museum.

PAGE 13 (2,100,000,000 YEAR AGO)

Grypania spiralis

Grypania was an ancient organism that lived on the seafloor, for all the world resembling a piece of coiled spaghetti up to half-a-metre in length. It appears to have been an early form of photosynthetic alga. The oldest *Grypania* fossils are 2.1 billion year old specimens from Michigan. Younger specimens (~1.3 billion years old) are known from Montana, China and India.

References

Han, T.M., and Runnegar, B. (1992), Megascopic eukaryotic algae from the 2.1-billion-year-old Negaunee iron-formation, Michigan. *Science* 257:232-235.

PAGE 14-15 (1,000,000)

An imaginary scene depicting stromatolites and primitive seaweeds growing near the shore.

PAGE 17. (560,000,000)

The famous fossil site at Ediacara, South Australia as it may have appeared over 550 million years ago. The creatures here lived on a sandy shallow seabed and represent one of the earliest known assemblages of large, multicellular organisms.

There has been considerable debate as to the nature of these creatures, some researchers claiming that they represent the ancestors of modern animals, others viewing the whole assemblage as an early evolutionary experiment that produced no living descendents.

Dickinsonia tenuis

(striated bluish flat things)

Curious looking segmented organisms, up to a metre long, that are abundant at Ediacara. There are several interpretations as to what these creatures were; here they are restored as large, flattened worms that crawled along the sea floor.

Tribrachidium heraldicum

(yellow disc shaped creature in lower left corner)

An enigmatic radially shaped creature, fossils of *Tribrachidium* resemble jellyfish but differ in that the body is divided into three curved lobes as opposed to the four lobes of modern jellyfish. It is unclear whether this animal floated in midwater or crawled on the sea floor as depicted here.

Charniodiscus arborea

(red frond like creatures)

Large, frond-like organisms that were rooted to the seafloor. In life, they probably resembled modern sea-pens, animals related to corals that filter edible particles from the water. Whether these Ediacaran forms are related to sea-pens or not is a topic of debate.

The jellyfish floating in the background are hypothetical. Some Ediacaran organisms have been restored as jellyfish-like forms but these interpretations are open to question.

References

Ediacaran Biota at Palaeos:
http://www.palaeos.com/Ecology/Biota/Ediacara.html

Learning about the Vendian Animals at Berkeley:
http://www.ucmp.berkeley.edu/vendian/critters.html

Ediacara at the fossil Lagerstatten website:
http://palaeo.gly.bris.ac.uk/Palaeofiles/Lagerstatten/Ediacara/title.htm

Glaessner, M. F., and Wade, M. (1966), The Late Precambrian fossils from Ediacara, South Australia. *Palaeontology* 9: 599-628

PAGE 19. (530,000,000 YEARS AGO)

This incredible array of creatures represents a tiny sample of the wondrous fossils recovered from the Maotianshan Shale of Chengjiang County in Yunnan, China. The creatures lived and died on or over a muddy seafloor more than 520 million years ago, the fine sediments preserving their bodies perfectly, including many details of their soft tissue. This site, and a younger site in Canada called the Burgess Shale, provides snapshots of the titanic diversification of life at the dawn of the Palaeozoic Era, the so-called "Cambrian Explosion".

***Opabina* sp.**

(blue creature about to become lunch)

Opabinia was a five-eyed segmented creature with pincers mounted on the end of a long hose. Its relationships are unclear but it may have been an arthropod related to *Anomalocaris*.

Anomalocaris saron

(big predator with red pincers)

Anomalocaris and its kin were the world's first superpredators, killer animals much bigger and meaner than anything else in their world. They belonged to a diverse but short-lived group of arthropods called the Dinocarida, which appeared and died out during the Cambrian Period. Dinocarids were armed with two big pincers and a weird, circular mouth that looked like a slice of pineapple (it’s under the head so you can’t see it in the picture). The Chinese *Anomalocaris saron* is notable for the two long filaments that stick out of its telson (tail), absent in its close North American cousins.

Canadaspis laevigata

(yellow shrimps swimming in midwater)

One of the earliest malacostracans, the group of crustaceans that includes modern crabs, lobsters and prawns. Except for the ends of its tail and antennae, the body was covered by a taco-like carapace. Each of its legs possessed a little membranous-fin that allowed it to swim through the

water. You can guess by its name that *Canadaspis* is also present in the Canadian Burgess Shale, as the larger *C. perfecta*.

Eodredlichia intermedia

(red bugs rooting around on the seafloor)

Eoredlichia was a fairly typical early trilobite. Trilobites were ovoid, flattened animals that had a pair of furrows running down the length of the body, dividing the body when seen from above into three lobes. Most were probably scavenging bottom-dwellers. While phenomenally successful for a time, the trilobites went into a gradual decline, the last few species disappearing about 248 million years ago at the end of the Permian Period.

Haikouichthys ercaicunensis

(little leech-like fish)

This and the similar forms from Chengjiang represent the earliest evidence we have for the Chordata - some would go as far as to call it a true vertebrate. Even at this early stage, *Haikouichthys* already had well-developed eyes, a nostril and a dorsal fin supported by fin-rays. Jaws and teeth were many millions of years away, however. *Haikouichthys* was described in 1999 on the basis of a single, incomplete specimen. More than 500 specimens of this animal were subsequently discovered in a single fossil locality making this the best known early chordate.

Note that *Haikouichthys* is much older and considerably more advanced than the Burgess Shale *Pikaia* which has become entrenched in popular literature as "the world's oldest chordate".

Leptomitis teretiusculus

(tubular sponges growing in the background)

Yuknessia simplex

(seaweed)

A type of green algae that produced clumps of hair-like fronds.

References

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Rigby, J.K. and Hou, X-G, 1995. Lower Cambrian Demosponges and Hexactinellid Sponges from Yunnan, China. *Journal of Paleontology*, 69, 1009-1019.

Shu, D-G., Conway Morris, S., Han, J., Zhang, Z-F., Yasul, K., Janvier, P., Chen, L., Zhang X-L., Liu, J-N., Li, Y., and Liu, H-Q. (2003). Head and backbone of the Early Cambrian vertebrate *Haikouichthys. Nature* 421: 526-529.

PAGE 20-21 (440,000,000 YEARS AGO)

Kalbarri, Western Australia over 420 million years ago played host to some of the first animals to walk on the land. The trackways of these ancient pioneers are today preserved in the Tumblagooda Sandstone, deposits laid down by a great river system flowed into a shallow sea.

eurypterid

(yellow scorpion-like creatures)

Eurypterids were a diverse group of aquatic chelicerate arthropods that lived from the Ordovician to the Permian. They ranged in size from 20cm to 2 metres in length. Commonly called "sea-scorpions", only early members of this group lived in the sea, the majority seem to have favoured shallow, brackish-water environments. Most eurypterids were probably predators, and very fearsome ones at that!

Some eurypterids became amphibious, venturing out of the water for at least part of their life cycle and become some of the earliest animals to walk on the land. Numerous trackways made by eurypterids and other arthropods are preserved in the Tumblagooda Sandstone and can be viewed at Murchison River gorge in Kalbarri National Park. Some of these tracks are almost 20 cm wide and must have been made by quite substantial-sized animals. While body fossils of eurypterids are known from elsewhere in Australia, none are preserved in the Tumblagooda Sandstone. The eurypterids in the picture are based on complete specimens of *Mixopterus kiaeri* from Ringerike, Norway.

Kalbarria brimmellae

(small bug in right foreground)

Kalbarria is the only known Tumblagooda animal known from a decent body fossil. It was a euthycarcinoid, a group of ancient aquatic arthropods with eleven pairs of legs which may have included the ancestors of modern insects. Like the eurypterids, some euthycarcinoids like *Kalbarria*, ventured out onto the shore and left their trackways preserved in the sand.

Note about the plants in the background

No plant fossils are known from the Tumblagooda Sandstone, but we know from other sites around the world that simple plants had colonised the shore. The plants in the picture are loosely based on *Baragwanathia longifolia* from similarly aged deposits in Victoria, Australia.

References

Eurypterida at Palaeos:

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PAGE 23 (400,000,000 YEARS AGO)

All these creatures are from the Xitun Formation of Yunnan Province, China. These Early Devonian deposits were produced on a sandy, shallow seafloor and have produced many exquisitely preserved fossil fish.

Polybranchiaspis liaojiaoshanensis (try to say that fast five times!)

(the quintet of weird flat fish)

Polybranchiaspis was one of the Galeaspida, a weird group of jawless fish that possessed a massive, flattened bony shield whose shape varied between different genera. The opening in front of the eyes that looks like a mouth is in fact a water intake, leading to the internal nostrils and the gills. The real mouth is positioned under the body and is visible on the fish showing us its ventral surface.

Youngolepis praecursor

(really big fish)

Youngolepis was a primitive predatory lobe-finned fish that may be near the base of the lineage that gave rise to modern lungfish. Most *Youngolepis* material represents animals less than 30 cm long, however undescribed material from China suggests that it may have grown up to a metre long, providing the basis for the menacing creature in the painting.

Psarolepis romeri

(spike-toothed fish in left foreground)

A small predatory fish with large spines and a whorl of large teeth on the tip of the lower jaw. It appears to have been an early member of a very primitive group of bony fish called the Onychodontiformes. The well preserved fossils of *Psarolepis* have provided valuable information about the early evolution of bony fish.

Phymolepis cuifenshanensis

(pair of armoured fish in the middle distance)

These odd fish belong to a large group of placoderms called the antiarchs. These were fish with box-like armour and long jointed "arms" instead of pectoral fins. They probably rooted around in the sediment for food, like a modern catfish.

***Nostolepis* sp.**

(pair of small blue fish in the background)

Nostolepis was a small acanthodian fish whose fossil spines have been found around the world. Acanthodians were the first vertebrates to evolve jaws; they had distinctive fins composed of a triangular sheet of skin supported by a single large spine.

***Lingula* sp.**

(seashells in the foreground)

Lingula was/is a brachiopod marine animal whose body is enclosed in a bivalve shell. These are NOT molluscs but rather belong to their own phylum - the shells of a bivalve mollusc like a clam consist of lateral valves while those of a brachiopod are composed of dorsal and ventral valves. There were once thousands of species of brachiopods in the oceans, but many forms died out at the end of the Permian Period and today there are only about 300 living species.

Lingula is still alive today and is harvested for food in the Indo-Pacific. With a fossil record going back over 400 million years, it is the longest lasting of all animal genera. This form of brachiopod lives in a vertical muddy tube in the sediment where it filters edible particles from the water.

Uncatoella verticillata

(seaweed)

A form of branching algae with stems up to 6 cm high that produced bunches of grape-like fruiting bodies.

References

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Long, J. A. (2001), On the relationships of *Psarolepis* and the onychodontiform fishes. *Journal of Vertebrate Paleontology* 21: 815-820.

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PAGE 25. (370,000,000 YEARS AGO)

Life on a Late Devonian riverbed in what will become eastern Greenland. The site is famous for producing the early tetrapods, *Acanthostega* and *Ichthyostega*.

Acanthostega gunneri

(four-legged animal in foreground)

This critter is one of an increasing number of early tetrapod (four-legged vertebrates) discoveries that are rewriting our understanding of how terrestrial life evolved. The first specimen of *Acanthostega* was an incomplete skull found in 1933, but the importance of this creature was revealed when several exquisitely preserved specimens were discovered in 1987.

Before then, textbooks depicted the evolution of terrestrial vertebrates as having involved some fish with fins stranded in a drying pool which began dragging themselves to the nearest body of water, the action providing the impetus for fins to develop into legs and feet. Thus, despite the lack of supporting fossil evidence, it was assumed that the evolution of legs was driven by the colonization of the land.

Yet *Acanthostega* was a fish-like animal that had legs and feet but was clearly an aquatic creature that rarely, if ever, came up onto the dry land. It had well-defined digits (no less that eight per foot!) but no wrists or ankles. The hips were weakly attached to the spine and would not have been able to support much weight out of the water. It also retained internal gills, a fish-like tail and a fish's sensory lateral line.

In short, here was a primitive aquatic tetrapod with legs that probably couldn't use them on land to any great degree. So these legs didn't evolve for the purpose of moving about out of water. Some modern fish have leg-like fins for clambering about on submerged rocks and weeds, like the sargassum fish (*Histrio histrio*). Perhaps *Acanthostega* used its primitive legs in a similar fashion on the riverbeds of ancient Greenland? Regardless, when the first vertebrates did clamber out of the water shortly after *Acanthostega*, they already possessed fully formed legs.

***Remigolepis* sp.**

(school of blue fish)

This is a school of juvenile antiarch placoderms called *Remigolepis*. These strange fish were heavily armoured and had stubby little pectoral fins/arms that probably made them rather awkward swimmers. There were many different species of *Remigolepis* in the Late Devonian Period, ranging

from small forms less than a foot long to big bruisers well over a metre in length. Their fossils have turned up in Greenland, China, Russia and Australia.

***Holoptychius* sp.**

(large fish in background)

Holoptychias was a large predatory fish that lived across the globe in the Late Devonian. Some specimens suggest a size of close to 2 metres, about the same as a good-sized barramundi. It belonged to a group of extinct lobe-finned fish called the Porolepiformes, which had large rounded scales and long pectoral fins with extensive fleshy-lobes.

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PAGE 26-27 (330,000,000 YEARS AGO)

A reconstruction of what the Joggins Fossil Cliffs of Nova Scotia, Canada, may have looked like during the Carboniferous Period. The site, located near the head of the stormy Bay of Fundy, has produced a stunning assemblage of life from an ancient lycopod forest, including some of the world's first reptiles.

Hylonomus lyelli

The earliest undisputed reptile, distinguished from its amphibian ancestors by fairly subtle features of the skeleton, for example the presence of a distinctive ankle-bone called the astragalus (present in modern reptiles, birds & mammals) which was formed from the fusion of three separate bones in the primitive amphibian foot.

In life, *Hylonomus* probably resembled a modern lizard, a little over 20 cm long. It probably fed on insects, piercing them with rows of small sharp teeth.

Dendrerpeton acadianum

(large red amphibian)

Dendrerpeton is the most common fossil vertebrate from Joggins and is known from hundreds of partial or isolated specimens and one nearly complete articulated skeleton. It was a carnivorous amphibian that grew to about 60 cm in length. *Dendrerpeton* was one of the earliest members of a major amphibian group called the temnospondyls that became extremely common in the Permian and Triassic Periods, surviving in Australia until the Cretaceous.

Asaphestera intermedia

(small blue amphibian)

One of a group of extinct amphibians called microsaurs, *Asaphestera* was a small terrestrial form with powerful limbs and a strong skull with short teeth adapted for crushing arthropods.

Arthropleura armata

(giant millipede-like creature)

Arthropleura was a huge flattened millipede-like arthropod that could grow to 2 metres in length. It is known from both body fossils and preserved trackways found in Europe and North America. Despite its fearsome appearance, it was probably an inoffensive scavenger and detritivore that posed little threat to other animals. Trackways produced by *Arthropleura* have been found at Joggins; they resemble the tracks made by caterpillar tractors.

It is unclear as to whether *Arthropleura* and its relatives were related to modern millipedes or not.

megasecopteran

(flying insect)

The Megasecoptera were one of the earliest groups of flying insects which, although now extinct, enjoyed great success during the Carboniferous. They looked a bit like the predatory dragonflies (which were also around in the Carboniferous) but were plant feeders, using sucking mouthparts to extract spores and pollen. The megasecopteran in the picture is based on a Joggins specimen with a 13 cm wingspan.

Sigillaria scutellata

(trees)

Sigillaria was a giant lycopod or club moss that could grow to well over 30 metres tall. It possessed a tall, columnar trunk with straight, fluted furrows along the midsection. The grass-like leaves grew on the upper part of the undivided or once- divided trunk.

Many of the small fossil vertebrates of Joggins were found in the hollowed out stumps of *Sigillaria* trees. Perhaps the animals fell into the hollows and became trapped, or perhaps they lived in the hollows and died when a fire swept through the area.

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PAGE 28-29 (260,000,000 YEARS AGO)

These creatures are mammal-like reptiles or therapsids whose fossils were discovered near the village of Ocher in the Perm Region of Russia. These animals lived near rivers flowing off the young Ural Mountains, and were sometimes buried in mudflows after heavy rains; the mud preserved their skeletons perfectly.

Biarmosuchus tener

(red animal draped on rock)

Biarmosuchus was about the size of a large dog. One of the most primitive of mammal-like reptiles, its long slender limbs suggest it was an agile predator.

Eotitanosuchus olsoni

(striped animal in foreground)

One of the largest predators of its time, *Eotitanosuchus* could grow to a length of over 5 metres. Huge sabre-like teeth allowed it to pierce the thick hides of its prey.

Estemmenosuchus mirabilis

(pair of horned animal)

Two species of the incredibly weird *Estemmenosuchus* have been found at the Ocher site. These were bulky herbivores with large bony horns projecting from their skulls. What they used these horns for is unclear; perhaps they were display structures used to intimidate rivals.

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PAGE 31 - 220,000,000 YEARS AGO

Life in a Late Triassic forest. Today the fossil remains of these animals are preserved in the Ischigualasto Formation of north-western Argentina, providing a valuable window into this important time in Earth's history.

Eoraptor lunensis

Eoraptor is one of the earliest known dinosaurs and the most primitive form of true dinosaur yet discovered. It was a metre long predator that lacked the specialised features present in later dinosaurs. *Herrerasaurus*, whose skull is pictured on the opposite page, was a larger contemporary of *Eoraptor*.

Exaeretodon frenguellii

Exaeretodon was a herbivorous traversodont that could grow up to 2 metres long. Traversodonts were advanced therapsids (mammal-like reptiles) that were probably closely related to the therapsids that gave rise to true mammals. Several different species of *Exaeretodon* lived in South America at the end of the Triassic Period and were among the most common herbivores.

Ischigualestia jenseni

This was one of the dicynodonts, a group of bulky herbivorous therapsids with two tusks in the upper jaw. They probably lived much like modern pigs or perhaps hippos, rooting around for roots and low-growing foliage. They were once the dominant terrestrial herbivores on the planet, but during the time depicted in the painting the group was in decline with only a few large species (like *Ischigualestia*) left. Dicynodonts are widely believed to have become extinct at the end of the Triassic although fragmentary and controversial evidence suggests they may have clung on for much longer in Australia.

(flying animals)

Pterosaur remains have not yet been found in the depicted region but are well known from contemporary deposits in other parts of the world. These pterosaurs are based on *Peteinosaurus zambelli*, known from two partial skeletons from Triassic Italy.

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PAGE 33 (150,000,000 YEARS AGO)

This is what Portugal may have looked like in the Late Jurassic Period. The remains of the large dinosaurs in the picture have been unearthed at Lourinhã, about 70 km north of Lisbon. The flying animals are based on fossils from elsewhere in Portugal and Germany.

Dacentrurus armatus

(spiny dinosaur in foreground)

Dacentrurus was the European counterpart to the famous North American *Stegosaurus*.

Known from incomplete remains from England, France and Portugal, its back was covered in a mix of low rounded plates (over the forequarters) and long spines (over the tail and hindquarters). Some specimens suggest that it could grow to a length of 10 metres.

There is no evidence that *Dacentrurus* had the shoulder spikes present in the illustration, their presence is based on similar structures on more completely known Chinese and Tanzanian stegosaurs.

Lourinhanosaurus antunesi

(bipedal dinosaur on the left)

Lourinhanosaurus was a medium-sized predatory dinosaur that was described in 1998. It is known from a single partial skeleton of an animal a little under 5 metres in length. Fossil dinosaur eggs and embryos from Portugal may have been laid by this species.

Lusotitan atalaiensis

(long-necked dinosaurs in background)

The biggest dinosaur of Jurassic Portugal was the huge *Lusotitan*, known from a single fairly complete skeleton of a 22 metre long animal. It was a very close relative of the slightly larger *Brachiosaurus* of *Jurassic Park* fame. Brachiosaurid sauropods like *Lusotitan* were the giraffes of the dinosaur world, using their long necks and chisel-like teeth to browse in the high branches.

Archaeopteryx lithographica

(bird in foreground)

Perhaps the most famous fossils of all time are the specimens of *Archaeopteryx* from southern Germany, the so-called first bird. When the first skeletons were discovered in the 19th century, scientists were astounded by the combination of reptilian and avian features. Unlike living birds, *Archaeopteryx* had the teeth, the flat sternum and the long bony tail of a reptile. However it clearly possessed feathers, a wishbone (furcula) and reduced fingers, all once considered to be unique bird features. Then as now, it provided dramatic physical proof that the familiar life of the present had evolved from less familiar life in the distant past.

In the late 20th and early 21st century it became increasingly clear that bird-like features, such as feathers and wishbones, were present in a wide range of non-avian theropod dinosaurs. So just as bats are nothing more than an odd group of mammals that evolved anatomical specialisations for flight, birds are also nothing more than an odd group of dinosaurs that also evolved anatomical specialisations for flight. *Archaeopteryx* is simply the earliest known bird-like dinosaur with the right combination of features for us humans to label it a true bird.

Isolated *Archaeopteryx* teeth have been recovered from Guimarota, Portugal.

pterosaurs

Only fragmentary Jurassic pterosaur remains are known from Portugal. The pterosaurs in the painting are based on *Rhamphorhynchus intermedius*, known from 100% complete skeletons with soft-tissue impressions from Germany.

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PAGE 35 (65,000,000 YEARS AGO)

A scene from Late Cretaceous North America that combines creatures from several fossil localities. Except for the pterosaur *Quetzalcoatlus* and the hypothetical butterfly, most of these animals are from the Hell Creek Formation, a series of ancient river deposits that mark the very end of the age of dinosaurs.

Undescribed oviraptorosaur

(large, yellow-crested, beaked animal)

This is a recently discovered dinosaur that has yet to be formally named, a teaser of some of the wonderful fossil creatures that are waiting to be scientifically described. The skeleton of this 5 metre long animal was discovered in South Dakota in 1998 and was collected and prepared by a commercial fossil company.

Oviraptorosaurs, of which this form was by far the largest, were strange bipedal dinosaurs with bird-like skulls and feathery bodies (based on finds from Liaoning, China) that brooded their eggs like their modern-day cousins, the birds.

Triceratops horridus

(horned animals in the background and the skull in the foreground)

Who doesn't know *Triceratops*? The largest and last of the herbivorous ceratopsian dinosaurs at up to 9 metres in length.

Quetzalcoatlus northropi

(pterosaur)

Named after an Aztec deity (Quetzalcoatl) and the manufacturer of the B-2 stealth bomber, this pterosaur was one of the largest and last of its kind. With a wingspan comparable to a WWII fighter plane and an enormous skull mounted on a long, slender neck, it was a truly bizarre looking animal. Its fossils were found in the Javelina Formation at Big Bend National Park, Texas.

Purgatorius ceratops

(mammal)

A small mammal based on fossil teeth. It seems to have been one of the earliest primatomorphs, the group of mammals that includes modern primates. A single tooth of *Purgatorius* has been found in the Hell Creek Formation, but more have been found in the younger overlying deposits, just after the great extinction event.

butterfly

No butterfly fossils are known from this period in Earth's history (although fossil moths are known from rocks over 140 million years old), with the earliest specimens at around 50 million years of age. However, the recent discovery of a 25 million year old butterfly (*Voltinia dramba*) from the Dominican Republic provides a hint (based on comparative biogeography with living relatives) that they existed well before the end of the Cretaceous Period.

Magnolia

(yellow flowers)

Among the over 170 species of flower plants have been discovered from the Hell Creek Formation are members of the family Magnoliaceae. Magnolias, popular decorative plants in the present day, are some of the most ancient and simple of living flowers.

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PAGE 37 (40,000,000 YEARS AGO)

The animals in this underwater scene are known from fossils discovered in New Zealand and Seymour Island, Antarctica. During this part of Earth's history (the late Eocene), Antarctica enjoyed a subtropical climate and many strange animals lived along its shores.

Zygorhiza sp.

(whales)

These primitive whales belong to an extinct group of predators called the Archaeoceti, which had a varied dentition (unlike the uniform pegs of modern toothed whales) and small but functional hind limbs. *Zygorhiza* grew to up to 6 metres in length and is mainly known from North American material, however fragmentary fossils from New Zealand suggest it lived in the southern hemisphere as well.

Carcharocles auriculatus

(giant shark)

One of the most fearsome predators of the Eocene seas was this 10-metre shark whose fossil teeth have been found around the world. Distantly related to the modern great white shark, some of its teeth grew to more than 10cm in length and today are highly prized by fossil collectors.

Anthropornis nordenskjoeldi

(penguins)

While they are dwarfed by the larger animals in the painting, these penguins when standing on the shore would have been as big as a full-grown man at over 1.5 metres tall.

Fossils of *Anthropornis* have been found at Seymour Island, Antarctica.

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PAGE 39 (4,000,000 YEARS AGO)

This scene reconstructs a few of the animals that lived along the shores of Lake Turkana, the northernmost lake within the Kenyan portion of the Great Rift Valley, Africa. The sediments of the Lake Turkana basin have produced fossil material from a span of time ranging from over 4 million years ago (in the Pliocene Epoch) to near the present day, including priceless specimens of our hominid ancestors.

Australopithecus anamensis

(apes in the foreground)

The genus *Australopithecus* includes the earliest members of our hominid ancestors to be known from fairly complete skeletal remains. Various species of *Australopithecus* lived throughout eastern and southern Africa from about 4.5 to 2 million years ago. Note that the oldest undoubted hominid fossil at the time of writing (2005) is the 7 million year old complete skull of *Sahelanthropus tchadensis* from Chad, described in July 2002.

Australopithecines were shorter than us with proportionally somewhat longer arms and shorter legs, but aside from that their skeletons were exceedingly similar to our own. They walked fully upright just like we do, with none of the "caveman waddling" you see in the old movies. The main differences were in the skull, which had a sloping forehead, heavy brow-ridges, a receding chin and a smaller brain.

Australopithecus anamensis is the oldest of the australopithecine species and lived around 4 million years ago in the Lake Turkana region. The remains include facial bones and bits of the limbs, not much to go on but enough to demonstrate that *anamensis* walked upright making it the earliest known bipedal hominid. The appearance of the apes in the painting is based on the slightly later

(but much more completely known) *Australopithecus afarensis* which lived in the same region from about 3-3.5 million years ago.

Sivatherium maurusium

(the thing that looks like a huge moose)

This was not a moose but rather a kind of extinct short-necked giraffe that could grow up to 2.2 metres tall at the shoulders. The "antlers" are not made of horn or hair but are bony structures called ossicones (like the knobs on a modern giraffe). Several species of these browsing herbivores once roamed across Africa and Asia - the first fossils were discovered in India and named after the Hindu deity Siva, or Shiva. *Sivatherium* was a common animal in savannah habitats from 5 to less than a million years ago with indirect evidence (based on Saharan rock paintings and a Sumerian bronze figurine) suggesting that it may have been alive as recently as 6000 years ago.

Aepyceros shungurae

(the antelopes)

Aepyceros shungurae was an earlier cousin of the modern impala antelope, *Aepyceros melampus*.

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PAGE 40 (160,000 YEARS AGO)

A scene from Pleistocene Germany.

Woolly mammoth (Mammuthus primigenius)

Without doubt the best known of all Ice Age animals. It was a large grazing elephant adapted to life in the cold steppe country of the Pleistocene with thick hair and large deposits of fat.

***Phalacrocorax* sp.**

(waterbird)

Cormorant - the same shags or cormorants you see on the seashore today.

Note on the ivory bird

This 4.7 cm long figurine, carved from mammoth ivory, is one of a series of 30,000 year old items recovered from Hohle Fels Cave in the Ach Valley, Germany. Carved objects from this and other German archaeological sites represents the earliest examples of human figurative art. The stunning level of detail at such an early date suggests that human artistic expression had a sudden, explosive origin.

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PAGE 45 (+50,000,000 YEARS AHEAD)

This is a completely imaginary scene of an alien world. None of these creatures actually exist...or do they?