Dinosaur Gallery

Teacher’s Handbook
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Excavation dossier; Dinosaurs; Science Connection N°6 2005,
Federal Science Policy

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To ensure you enjoy your visit…

The new Dinosaur Gallery is bigger and more comprehensive than its predecessor and now occupies all of the ground floor (and part of the basement) of the museum’s Janlet Wing. The building has been completely renovated and the parts to which the public has access have been restored to their original condition as much as possible. The objective of the Royal Belgian Institute of Natural Sciences was to both restore the building and to use it as a contemporary museum, which is understandable, interactive and pleasant.

The Dinosaur Gallery is the largest gallery in Europe devoted to dinosaurs. The golden thread linking the exhibits is questioning the data gathered by observing the exhibits, both the skeletons and the casts (but no animatronics or robots).

The exhibits are arranged along three main axes:

• Under Our Feet: how and where do archaeological excavations take place, and what do they reveal to us about the world of dinosaurs?
• Living Animals: how did they move around, how did they eat and how did they defend themselves?
• Still With Us? How did most of them become extinct while some evolved into birds?

The permanent exhibition aims to be a benchmark in the popular understanding of dinosaur biology and ethnology and thus is as educational as possible. This is why it uses a wide range of interpretive materials: films, models, activities for all ages, multimedia panels, clear and concise texts, all based on the collections of the Royal Belgian Institute of Natural Sciences.

The Dinosaur Gallery has been designed to be enjoyed as much by children (who may or may not be able to read) as by adults. Each visitor can visit an archaeological dig, unearth a fossil, touch life-size replicas of dinosaur bones, watch interviews with famous palaeontologists, measure themselves against a virtual Pachycephalosaurus, learn how to read a cladogram and, of course, enjoy looking at many dinosaur skeletons.

An extension to the original gallery is devoted to a unique and innovative teaching aid, the “palaeoLAB”, which is based on the principal of learning by real experiences and which allows children to follow in the footsteps of palaeontologists.

The palaeoLAB offers around 40 different activities that can be done individually or in groups, led by one of the museum’s education officers: unearthing real fossils, studying them and making plaster casts of them, matching dinosaur teeth to dinosaur jawbones, putting together a life-sized skeleton of a Stegosaurus, drawing a geological map of Belgium showing its fossil-bearing rocks, starting a mini-sandstorm and seeing its erosive effects, looking at books in the library and surfing the internet to find the answer to a riddle.

This very concrete approach to science, even if it involves an element of fun, teaches pupils about erosion, the dating of fossils, why we look “here” and not “there” and how we interpret and handle them. The Education Officer is there to assist and complete the participants’ personal discoveries with his/her explanations.
Accompaniment

Guided tours

These last 1 hour 15 minutes and are aimed at children from 3rd year primary upwards and aim to stimulate the children's personal observations as much as to explain the exhibition.

Tell Us A Story

This lasts 1 hour and is aimed at the youngest schoolchildren from 3rd year kindergarten to 2nd year primary: from a story to reality, an amusing way of discovering the riches of the Dinosaur Gallery.

Activities

These last 2 hours and are aimed at children aged 6 and above. They include a theoretical part and a more creative, fun or experimental part.

PalaeoLAB

This is aimed at children from 3rd year primary to 2nd year secondary, either as 1 hour 15 minutes of handling objects, or a 1-hour tour of the Gallery followed by 1 hour of handling objects in the palaeoLAB.

Website

This teacher’s pack, practical information and much more information on the Museum’s permanent exhibitions can be found on our website at www.sciencesnaturelles.be

Group Prices

Adult: €6
Child: €3

Guided tours

Children (maximum group size 15) €35
Adults (maximum group size 15) €62 on weekdays, €75 at weekends

Activities

Children: €3 each

PalaeoLAB

Children: €3 each

Prior reservations required for all groups

by telephone to +32 (0)2 627 42 52
24-hour recorded information line +32 (0)2 627 42 38

B-excursion train tickets

Groups can purchase B-excursion tickets which include a return train journey and entry to the Evolution Gallery at the Museum. (Quote reference n° 273, available at all staffed railway stations or by telephone +32 (0) 65 582 362 or by email to groups.national@b-rail.be). Note! To benefit from this special offer, you must reserve places at the Museum by telephone (+32 (0) 2 627 42 52) first, then contact Belgian Railways (SNCB).
Trail

From the main entrance to the Dinosaur Gallery, you emerge onto the mezzanine with a magnificent view of the gallery. You are welcomed by birds in flight which invite you to go over to the iguanodons' cage on your right. The lifts and staircases down to the ground floor and the basement are on the first level of the mezzanine next to the cage. Let your tour begin!

Zone 1. Under Our Feet

This zone is spread over three levels. In the basement you can learn how the iguanodons were discovered at Bernissart. On the ground floor, you will learn about fossilisation and what our palaeontologists were able to deduce from the excavations at Bernissart in Belgium, at Bayan Mandahu in China and at Kundur in Russia. On the wall of the mezzanine around the cage are some anecdotes about the iguanodons.

1. Major dates in the study of dinosaurs

1822: discovery of the lower jawbone of a Megalosaurus, the first dinosaur to be given a name (engraving)
1825: discovery of teeth of an Iguanodon, the second dinosaur to be given a name (engraving)
1841: Richard Owen coins the word “dinosaur” (meaning “terrible lizard”) (photo)
1854: first dinosaur statues exhibited at Crystal Palace Park in London (photo)
1858: first reconstruction of a complete dinosaur skeleton (Hadrosaurus)
1878: discovery of the iguanodons at Bernissart (photo of fossils + text)
1880: G. Lavalette publishes drawings of the iguanodons and a crocodile in the positions in which they were unearthed.

The Bernissart iguanodons cage

A completely glazed, more spacious new cage now houses nine iguanodons in their historical position, standing like kangaroos. The position of each skeleton was chosen based on the most notable anatomical details observed: the best-preserved skull, the most complete spine and the most detailed thorax.

Lavalette’s drawings

In the windows running alongside the cage are displayed reproductions of drawings by Gustave Lavalotte (among others) from the 1880s. They represent, in detail, several iguanodons and a crocodile, in the positions in which they were lying when they were discovered at Bernissart.

Drawing by G Lavalotte (1883): Iguanodon bernissartensis in the position in which it was found in the Sainte-Barbe mine
Four anecdotes about the iguanodons and their cage

1. This gallery has housed the iguanodons since 1902, and until 1932 they were not in their glass cage, so they were exposed to all the changes in temperature and humidity experienced in the gallery, which, slowly but surely, was making them disintegrate. This is why, between 1933 and 1937, all the skeletons were disassembled and soaked in a protective mixture of lacquer and alcohol. It is this that turned the bones black, not the fact that they were discovered in a coalmine.

2. In 1940, the iguanodon skeletons were once again disassembled and packed into cases because it was feared they would be damaged or destroyed in air raids. The cases were stored in the museum’s cellars, whose doorways were blocked with sandbags. However, the cellars were so damp that it was decided to return the dinosaurs to the gallery before the end of the war in 1945.

3. The first specimen to be assembled was an Iguanodon bernissartensis. From 1883 onwards, it was on display in the courtyard of the old Hôtel de Nassau in a glass display case that was supposed to protect it from the weather. Soon afterwards, the skeleton was joined by an Iguanodon atherfieldensis and various other fossils discovered in the mine at Bernissart.

4. The eight specimens of Iguanodon bernissartensis displayed in the glass cage are of greatly differing sizes, from 629cm to 730cm in length and from 390cm to 506cm in height. The single specimen of Iguanodon atherfieldensis is considerably smaller: it is 391cm long and 362cm tall.

The Iguanodon atherfieldensis case
The scientists do not agree!
This specimen is considerably smaller than the others. Could it be an Iguanodon mantelli among the Iguanodon bernissartensis as claimed by Boulanger and Dollo in the 1880s? Or perhaps a male in a group of females as suggested by Nopsca in 1929? Or a young dinosaur in a group of adults? In fact, Norman, who classified it as an Iguanodon atherfieldensis in 1986 took a more nuanced approach, and said that these hypotheses could neither be proved nor disproved definitively merely from observing the skeletons.

So what can we say about this dinosaur?
Its skeleton is slightly different to that of an Iguanodon bernissartensis. To be certain that it belonged to another species it must not have been able to mate with the Iguanodon bernissartensis. If it could mate with them and produce offspring that were not sterile then it would be the same species. Obviously, we will never know as the dinosaurs died millions of years ago. So it remains an unsolved mystery!
Specimens

- *Iguanodon bernissartensis*: 125 to 128 million years old, Bernissart, Belgium. Despite being assembled and disassembled several times, the iguanodons are still displayed as bipeds (like a kangaroo) as they were originally displayed.
- *Iguanodon atherfieldensis*: 125 to 128 million years old, Bernissart, Belgium
- Birds shown in flying positions

Also to see

- Engraving of half a lower jawbone of a Megalosaurus
- Engraving of the teeth of an iguanodon
- Photos by Richard Owen, Louis Dollo and Albert Boulanger
- Photos of the iguanodon statues at Crystal Palace Park, London.
- Photo of the first Hadrosaurus skeleton assembled in its probable living position
- Drawings by G. Lavalette of fossils discovered in the Sainte-Barbe coalmine in 1883.
- Drawings of *Iguanodon bernissartensis* and *Iguanodon atherfieldensis* showing their main anatomical differences.

2. The discovery of the iguanodons

A fortuitous discovery

Our story begins at the end of March 1878 at the Sainte-Barbe coalmine at the Bernissart colliery. Miners working 322m below the ground were digging a gallery when they found a pocket of clay. Instead of digging around it, they decided to dig through it and came across tree trunks filled with gold! In fact, it was an iguanodon bone incrusted with iron pyrites, which reflects light like gold. On 12 April 1878, the Royal Belgian Museum of Natural History was informed of the discovery by telegram.

Three years of hazardous excavations

On 15 May 1878, De Pauw’s team began excavating 322m below the ground. In August, an earthquake cut them off for two hours. On 22 October, they were forced to return to the surface by a flood, leaving their tools and fossils behind. After a six-month safety break, excavations began again on 12 May 1879. The excavations ended in 1881, shortly after the discovery of more iguanodons 356m below the ground.

Iguanodons in blocks

Due to their being filled with iron pyrites, the bones crumbled on contact with air. De Pauw thus had to find a way of protecting them until the iron pyrites could be removed in a laboratory: they were covered in damp paper which was then covered in plaster of Paris. But as the bones could not be plastered and transported whole, they were cut into blocks of 50cm to 200cm. Each specimen was given a reference letter and each block a reference number, so its exact position could be recorded on an overall plan.

The Iguanodons’ Fold

This is the name that was given to the pocket of clay in which the iguanodons were discovered. Several galleries were dug into it 322m below the surface. At the entrance to the main gallery, two iguanodons were found buried vertically, upside down. The other skeletons were found closer to the centre of the pocket, lying almost horizontally. Little by little as they were dug out of the clay, they were cut into blocks, around 600 in all. They were then covered in plaster of Paris and pulled up to the surface in horse-drawn coal wagons.
In the museum’s laboratories

It took 37 carts to bring the 130 tonnes of fossils, plaster and iron reinforcing rods (used on the larger blocks) to Brussels. In the museum’s laboratories, the iguanodons underwent some pretty serious cleaning. The laboratory staff removed them from the sediment surrounding them and removed the iron pyrites from inside them. They were then plunged into tanks of boiling glue to solidify them, then they were covered with tin foil to protect them from humidity.

The first assembly of an iguanodon

In 1882, under the direction of Louis Dollo, De Pauw began to assemble the most complete skeletons in their “probable living position”. Given their large size, a room with a high ceiling was required, and St George’s Chapel was chosen (now the chapel is part of the Royal Library). Scaffolding was built with ropes hanging from it: by adjusting their length, the bones of the skeletons could be moved into their most natural positions. Once the skeletons had been fully assembled, they were reinforced with iron rods.

Specimens

- Several authentic and more-or-less complete specimens of Iguanodon bernissartensis in the positions in which they were discovered in the mine.

Also to see

- Four two-dimensional dioramas illustrating the different stages of the process from the discovery to the first assembly
- Copy of the telegram of 12 April 1878
- Model of the underground galleries 322m below the surface
- Early twentieth-century miners’ tools
- Louis De Pauw at the first assembly of an iguanodon (two-dimensional animation based on a photo taken in St George’s Chapel in 1882).

To experience

- Discovery of the iguanodons (sound effects in the corridor)
3. The excavation sites

3.1 Bernissart

In the era of the iguanodons

There were not only dinosaurs at Bernissart: thousands of fossils of animals and plants have also been found there. They are all clues as to the types of climate and environment the iguanodons lived in. But what types were they? To work this out, look at the specimens in the display cases entitled “Other Treasures of Bernissart”

Specimens

Other treasures of Bernissart (original fossils)

- Bernissartia fagesii (crocodile)
- Goniopholis simus (crocodile)
- Toe of a theropod
- Coccolepis macropterus (fish)
- Lepidotes bernissartensis (fish)
- Macromesodon bernissartensis (fish)
- Callopterus insignis (fish)
- Armiapollis dolloi (fish)
- Aethalionopsis robustus (fish)
- Pattersonella formosa (fish)
- Chiticephalus dumonii (freshwater turtle)
- Peltochelys duchasteli (freshwater turtle)
- Hylaeobatrachus croyii (salamander)
- Hylaeoneura lignei (cricket)
- Weichselia reticulata (fern)
- Pityostrobus bernissartensis (pine cone)
- Pinooxylon (fragment of coniferous tree)

Also to see

- Drawing of Weichselia reticulata
- Drawing of Bernissart fish
- Drawing of Hylaeoneura lignei

To do

- Bernissart at the time of the iguanodons (choose the correct landscape from those shown on the rolls)

Open case

How can we explain why so many iguanodons were found in the same place? Since the end of the nineteenth century, scientists have come up with all sorts of catastrophic scenarios to answer this question. Today we know that the iguanodons did not all die at the same time: some of the skeletons were discovered in layers of clay that were deposited at different times.

Also to see

- Death of an iguanodon (low-relief sculpture) several catastrophic scenarios which attempt to explain why so many iguanodons were found in the same place.

To do

- Sound-effects book illustrating the different iguanodon death scenarios and explaining the formation of the clay pocket.
Might there still be more iguanodons at Bernissart?
The place where the iguanodon skeletons were found can no longer be accessed. It is more than 300m underground and the mineshaft leading down to it was closed off and sealed years ago. However, in 2002 and 2003, teachers and students from the Mine Engineering Faculty of the Mons Polytechnic University sunk test bores around the Iguanodon Fold to see if the earth there contained any other iguanodons. For the results, see the three-dimensional model of the sites and the revealing contents of the test bores.

Also to see
- Two test bores of sediment from the Iguanodon Fold.
  They show that there are probably more iguanodons there, but we do not know in what condition.

To discover
- Three-dimensional model of the Iguanodon Fold

Technology to help palaeontology
A CT scan allows us to examine the skull of an Iguanodon bernissartensis from every angle, even from inside! Optical and electronic microscopes allow us to study the pollen grains and spores in the Bernissart clay. When compared with pollen grains found in the UK, we were able to narrow down the probable date when the clay layer was formed.

Also to see
- Macro-photos of fossilised fern spores and pollen grains

To discover
- Three-dimensional model of the skull of an Iguanodon bernissartensis

3.2 Bayan Mandahu, Inner Mongolia, China

Dinosaur stories
1. Died while fighting! That’s what happened to these two dinosaurs: Velociraptor the carnivore had sunk its long claw on its back foot into the stomach of Protoceratops the herbivore, which had seized the front foot of its aggressor in its powerful beak.

2. Is Oviraptor mis-named? For many years it was believed that this carnivore attacked new-born Protoceratops so it was named Oviraptor philoceratops which means “the egg-stealer which likes ceratopsians”. But in 1990, some palaeontologists discovered one crouching over a nest: it had probably died while sitting on its own eggs.

3. There were already mammals on the Earth at the time of the dinosaurs but they were small (less than 50cm long). From their teeth, we think that the two specimens displayed on the side of the display case ate hard plants.

Specimens
- Skull of a Velociraptor mongoliensis, 70-75 million years old, Shabarakh Usu, Mongolia (cast)
- Skull of a Protoceratops helenikerhinius, 70-75 million years old, Bayan Mandahu (cast)
- Oviraptor philoceratops, juvenile, 70-75 million years old, Bayan Mandahu (cast).
· 2 skulls of Multituberculata ind.: mammal
· Kryptobaatar mandahuensis: mammal, 70-75 million years old, Bayan Mandahu (cast)

Buried by the sand
Many complete skeletons have been unearthed at Bayan Mandahu in China. The sediment in which they were discovered is a very fine-grained sandstone which indicates that, when the dinosaurs died, the area was almost a desert. Pinacosaurus, Oviraptor and Zangerlia were probably trapped in one of the sandstorms which frequently swept across this area in the Late Cretaceous Period, or they may have been surprised by the collapse of an unstable sand dune.

Victims of sand!
1. Zangerlia the terrestrial tortoise, was probably buried by a sand dune: it was covered with sand so quickly that it didn't have time to retract its head and paws inside its shell!

2. The ankylosaur Pinacosaurus has bony plates covering its head and back, forming strong armour against predators, but which offered no protection against the sandstorm that buried it!

Specimens
· Zangerlia neimongolensis: turtle, 70-75 million years old, Bayan Mandahu (cast)
· Pinacosaurus mephistocephalus: ankylosaur, 70-75 million years old, Bayan Mandahu (cast)

Also to see
· Death of Pinacosaurus (low relief sculpture)

To do
· Sandstorms cover or uncover corpses at random (interactive)

3.3 Kundur  Russia

Carried away by a mudslide
During the monsoon, mudslides run down from the surrounding mountains and frequently devastate the region of Kundur in Russia. The dinosaurs these mudslides dragged with them did not survive. Wherever the flow was slower or there was an obstacle, their corpses would pile up, then decompose and their bones would mix together in giant “bone beds”.

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4. Fossilisation

What is a fossil?
A fossil is any remains or imprint of an organism (animal, vegetable, etc) generally preserved in sedimentary rock such as sandstone or limestone. Most frequently, fossils are bones, teeth or shells, but also eggs, droppings, plants, insects and footprints.

Specimens
- Fragment of wood: 65-85 million years old, Montzen, Belgium (original)
- Dryophyllum dewalque: imprint of leaf, 58-61 million years old, Overbroek, Belgium (original)
- Insects in amber: less than 2 million years old, Madagascar (original)
- Smerdis macrurus: fish, 30-35 million years old, Provence, France (original)
- Probactrosaurus: dinosaur's caudal vertebra, 120-130 million years old, Dashuiguo, Inner Mongolia, China (original)
- Dinosaur eggs, 70-75 million years old, Bayan Mandahu (original)
- Chiroptera ind.: bat, less than 47 million years old, Messel, Germany (original)
- Gasteropods: 180-183 million years old, Dudelange, Luxembourg (originals)

To discover
- Thumb of an Iguanodon bernissartensis with ball of iron pyrites (commentary)
- Interview of Armand de Ricqlès on fossilisation (film)

To do
- From dinosaur to treasure (information panel, game)
5. Where can dinosaurs be found?

Chance discoveries of new sites
Often, new dinosaur sites are discovered by chance! At Bernissart, the miners were digging a gallery to extract coal when they found the iguanodons. At Kundur, bulldozers being used to widen a road uncovered the first fossilised Olorotitan bones. At Aix-en-Provence, dinosaur nests are regularly uncovered during ground-levelling work.

Also to see
- Map of principal dinosaur zones

To discover
- Where do fossils hide themselves? Fossil-hunter’s chessboard: to spot fossils in the ground you need good eyes, and some intuition (interactive)

To do
- Where to find dinosaurs (interactive panel)

Zone 2. Living animals

From a study of fossilised dinosaur bones, several things can be deduced about how these large animals lived.

1. Posture

1.1 What the fossils reveal to us

Diplodocus carnegii
Even if the specimen on display is rather small (it is "only" 17m long), Diplodocus was one of the largest dinosaurs: it could grow up to 27m in length (of which half was its tail). As with all sauropods, the vertebrae in its neck and back had large cavities – called pleuroceles - in them, which made the bones lighter without losing their strength.
How do we estimate the weight of dinosaurs?

Scientists have noted that the mass of the vertebrae of terrestrial vertebrates (e.g. mouse, human, horse) is in proportion to the circumference of the bones of their legs, in particular the femur for bipeds and the femur and humerus of quadrupeds. They have taken many measurements from the skeletons of living species and have devised equations from them, which are used today to estimate the weight of extinct animals such as dinosaurs.

**Bipeds or quadrupeds?**

The position of the fourth trochanter gives us clues about dinosaurs’ posture. This protuberance on the femur is the anchor point for a muscle which pulls the leg backwards. In lighter bipeds, such as *Struthiomimus* it is high up the bone, so that a small contraction can result in plenty of movement, whereas in the heavier quadrupeds such as Diplodocus it is lower down the bone, so the muscle can move a heavier leg but in a smaller field of movement.

**Struthiomimus altus**

*Struthiomimus* was an omniverous theropod with a toothless beak which ate small animals, insects and vegetation. It had a slender body with long, well-muscled hind legs, a long neck, a small head and large eyes: it looked very like modern-day ratites (e.g. emu, ostrich) and like them it could run fast, easily reaching 60Km/h!

**They could have been heavier!**

We know that the circumference of the legs of a terrestrial animal depends on its weight. To put it another way, an elephant has proportionally larger legs than a mouse. Scientists have estimated that for an animal weighing 140 tons, its legs would have been so large they would have touched, thus preventing it from moving! Even the largest sauropods known did not weigh more than 100 tonnes, so there remained a little room for manoeuvre.

**Specimens**

- young Diplodocus carnegii (dinosaur, quadruped, cast)
- back vertebrae of a giant sauropod (dinosaur, cast)
- *Struthiomimus altus* (biped dinosaur, cast)
- Ostrich in natural posture (next to the *Struthiomimus* which means “which mimics an ostrich”)
- Right-hand front leg of a giant sauropod (cast/sculpture)
To do

- Build a “diplo-bridge” (shows the suspension-bridge structure of a Diplodocus)
- Who is the heaviest? (use a tape measure and a conversion table to estimate the weight of three bipeds based on their femurs).
- A question of position (this allows you to compare the effect of the fourth tronchater on the movement of the hind legs).
- Height gauge (to compare the height of different dinosaurs)
- Small, large or giant? (electro for younger children)

1.2 Posture and appearance of Iguanodon bernissartensis

Iguanodon bernissartensis: mixed postures

In contrast to the first reconstructions which positioned them as bipeds resting on their tails like kangaroos, Iguanodon bernissartensis probably walked on four legs and ran on two legs. The specimens extracted from the mine at Bernissart are particularly well-preserved and form the largest group of iguanodons in the world!

In 1882, the iguanodon was positioned as a biped

Louis Dallo, who supervised the first positioning, was convinced that Iguanodon bernissartensis was a biped. On what did he base this opinion?
- the front and hind legs were more different than those of quadrupeds
- the spinal column was that of a biped
- the hips, the hind legs and the proportions of the head and thorax resemble those of running birds (e.g. ostrich, cassoway, etc)
- a fossilised iguanodon skeleton found in the UK suggests that it moved around on its hind legs.

In 1980, the posture of the iguanodons was reviewed

Almost a century after Louis Dollo, the palaeontologist David B. Norman did a new study of Iguanodon bernissartensis and arrived at a different conclusion: the spinal column was kept more or less horizontal when the dinosaur was walking or running. In other words, the “kangaroo” biped posture was no longer correct. However, the skeletons remained in their original postures remained untouched because they were too fragile to be re-positioned.

What did the iguanodons look like?

Around 1835, Gideon Mantell imagined that an iguanodon looked like a giant iguana with a horn on its nose. In 1854, Benjamin Waterhouse Hawkins suggested that it resembled the rhinoceros at Crystal Palace Park in London. In 1882, the Bernissart iguanodons were positioned as bipeds like kangaroos with the thumb in place. In 1980, David Norman suggested that iguanodons were quadrupeds.

The skin of an iguanodon

Thanks to imprints found at Bernissart, we know the shape of an iguanodon’s skin. However we do not know its colour, nor that of other dinosaurs, because fossilisation has changed the original colours of the rare pieces of skin unearthed.

Specimens

- hand of Iguanodon bernissartensis: dinosaur (original)
- Iguanodon bernissartensis: mixed-posture dinosaur, here shown as a quadruped (cast)
- skeleton of a cassoway

Also to see

- 4 different drawings of iguanodon feet
2. Movements and migrations

2.1 What fossilised tracks tell us

How to calculate the speed of a dinosaur
There is a formula for estimating the speed at which animals move, and it can also be used for dinosaurs. What data is required?
- the height of the hip or the length of the foot (one can be calculated from the other)
- the distance between two successive footprints made by the same foot (this can be measured on a fossilised trail)

We also know that Struthiomimus walked in steps, we are thus a long way from the peaks of 60km/h that we know this sprinter could achieve.

Dinosaurs step by step
To attribute a fossilised footprint to a specific dinosaur is not easy, unless a skeleton is found at the end of the track! By contrast, tracks can be linked to groups or families of dinosaurs. If they are rather circular and large (up to 1m in diameter) they were made by sauropods: if they are tridactyl (threetoed) they were made by an orthopod (if the toes are short and rounded) or a theropod (if the toes are long with pointed claws on the ends).

Specimens
- fossilised track with footprints of several dinosaurs and birds (plaster cast)
- fossilised track with footsteps of Struthiomimus (plaster cast)

Also to see
- miniature tracks made by different dinosaurs

To discover
- What fossilised tracks tell us (audio commentary and synchronised lights of a big track)

2.2 North Pole and South Pole

Cryolophosaurus ellioti
Literally this name means “crested frozen lizard”. This theropod was discovered in Antarctica, near the South Pole. It was surrounded by the remains of other animals, including a plebeosaurus (primitive dinosaur) and a tritylodont (distant ancestor of mammals), which had already been discovered in Jurassic Period sites, which enabled them to be dated.

Dinosaurs at the North Pole
At the end of the Cretaceous Period, dinosaurs lived above the Arctic Circle. They included the theropod Troodon, the hadrosaurus Edmontosaurus and the ceratopsian Pachyrhinosaurus. Many Pachyrhinosaurus bones and skulls have been unearthed in Alaska (USA) and Alberta and the Yukon Territory (Canada).
These fossils indicate that these herbivores lived in herds and migrated to the North in the summer, then migrated South again as winter began.

**Specimens**
- Crylophosaurus elloti (dinosaur, cast)
- Skull of Pachyrhinosaurus canadensis (dinosaur, cast)
- Naturalised penguin (polar bird)

**Also to see**
- Map “On the trail of Pachyrhinosaurus”

**To discover**
- Filmed interview of Phil Currie on polar dinosaurs

3. Communication: Skulls just for showing off? Not really….

**Parasaurolophus crest**
It is hollow but closed at the tip: it therefore was not used for breathing underwater as was thought for many years. It amplified calls, so that, even over long distances, Parasaurolophus could warn each other of danger and be recognised by each other, or could challenge rivals or attract mates. Visually, the longer the crest the more impressive it was and the more it amplified calls!

**Centrosaurus collar**
In addition to a solid horn on its nose, Centrosaurus had a collar around its skull, with two points facing downwards and two holes which made it lighter without reducing its efficiency at protecting the neck. Just like the dorsal plates on a Stegosaurus it was covered with skin, which could possibly have been reddened by an influx of blood to attract mates, frighten off rivals and scare away predators.

**Pachycephalosaurus helmet**
Literally, this name means “thick-headed lizard” and this is a good description of this dinosaur, for the top of its skull was between 20 and 25cm thick! Palaeontologists think that it used its bony helmet like a ram, especially during fights between rival males in the mating season. But it could also have used it to bash the sides of predators that attacked it.

**Specimens**
- skull of Parasaurolophus walkeri: dinosaur (cast)
- skull of Centrosaurus apertus: dinosaur (cast)
- skull of Pachycephalosaurus wyomingensis: dinosaur (cast)

**To discover**
- Like a trombone! From the throat to the nostrils, sound passed through a series of connected tubes rather like a trombone which served as resonators, amplifying it a lot. The pitch of the sound depended on the length of the Parasaurolophus’s crest (audio)

**To do**
- Face to face with Pachycephalosaurus. This dinosaur used its head like a ram (measure it compared to a virtual Pachycephalosaurus.)
4. Reproduction

Their very own names

Today we have discovered more than 40 types of dinosaur eggs. But which dinosaur laid which egg? To answer this question, the ideal would be to find bones in the eggs which could be compared to those of adult dinosaurs which died while sitting on the eggs! However, this is very rare. So we have to classify the eggs by size, overall shape and the structure of the shell. This is why these eggs have their own names which are not those of dinosaurs.

**Maiasaura peeblesorum**

In Ancient Greek, maia means a mother or nurse, and we think that this dinosaur looked after its young. In any case, they nested in huge colonies on the same sites, generation after generation. It is also one of the rare dinosaurs of which we know the stages of growth from embryo to adult.

A baby Maiasaura grown to adulthood

Just like in a tree trunk, dinosaur bones contain growth rings which enable us to estimate their age and the speed at which they grew. Thus we know that Maiasaura was 30cm long when it hatched and grew to almost 4m tall in just one or two years! It reached its adult height of around 9m after 6 to 8 years. Such fast growth protected it from predators, enabling it to soon be able to defend itself by its size.

Yes, but…

Maiasaura was perhaps not so much of a good mother as all that, because we have never discovered fossilised mothers and babies together. It is therefore possible that young hadrosaurs lived in groups before joining the adults when they were 1 or 2 years old and big enough to follow the herd of adults as it moved around.

How can you tell a male from a female?

Male and female Proceratops became more and more different as they grew up. Palaeontologists think that those with the most well-developed nasal horns and the widest collars were probably adult males. During the mating season, they would use their horns and collars to intimidate their rivals and attract females.

**Specimens**

- Megaloolithus fossilised eggs, perhaps laid by a titanosaur (casts)
- Unrecognised dinosaur eggs from Mongolia (originals)
- Elongatoolithus fossilised eggs, possibly laid by an Oviraptor (originals)
- Eggs laid by two unrecognised dinosaurs from China (originals)
- Maiasaura peeblesorum adult and juvenile, two babies and eggs (dinosaurs, casts)

**Also to see**

- Series of 4 femurs of Maiasaura peeblesorum showing growth (dinosaur, casts)
- 4 skulls of Protoceratops helenikorhinus (dinosaurs, 3 originals and 1 cast)
- Maiasaura nest with babies and eggs

**To discover**

- Filmed interview of Jack Horner on the discovery of the Maiasaura babies.

**To do**

- Who laid what? (electro for younger children)
- Dinosaur eggs to be observed through a magnifying glass
5. Attack and defence

Arms and armour of Ankylosaurus
Tipped with a heavy bony lump, the tail of Ankylosaurus could easily break the back of over-eager predators. Its back was covered from head to tail in armour made up of nodules, spines and bony plates, firmly anchored in its skin. This range of armour made it one of the best-protected dinosaurs and compensated for its relative slowness and lack of agility.

Stegosaurus stenops
Fine blood vessels ran all over the skin covering its bony plates

When the plates went red
Its bony spikes made the tail of a Stegosaurus an efficient defensive weapon. By contrast, its dorsal plates were more a deterrent. Well-supplied with blood (some bear the imprints of many blood vessels) they were probably only covered in a thin layer of skin and thus could be reddened by increasing the blood supply, which would have frightened off predators and could also have been used to intimidate rivals, attract mates and to recognise each other!

Allosaurus THE Jurassic predator
At almost 12m long, Allosaurus was one of the greatest predators at the end of the Jurassic Period in North America. At the end of each of the three fingers of each hand was a 15cm-long razor-sharp claw. It powerful jaw was equipped with more than 70 backward-pointing teeth with serrations like a steak knife. It preyed on herbivores like Diplodocus which it probably attacked in a pack, or on Stegosaurus which was closer to its own size.

Diplodocus's whip
Diplodocus had a long slender tail which was particular flexible in its last few metres. When waved, the end of its tail could reach supersonic speeds, making a cracking sound like a whip. It was too weak to injure predators but the noise it made would probably scare some predators away. When in a herd, the tail-cracks could also be used to recognise each other and to sound the alarm.

The well-named “terrible claw”
In North America, Deinonychus (from the Ancient Greek deinos meaning “terrible” and onuchos meaning “claw”) terrorised the other dinosaurs during the Early Cretaceous Period. It was armed with huge 12cm-long claws on the second toe of each of its feet which were sharp and curved backwards like a sickle and which were raised when it moved, but could be dropped very fast when seizing prey.

Specimens
- Tail and skull of Ankylosaurus magniventris: herbivorous dinosaur (cast and sculpture)
- Stegosaurus stenops: herbivorous dinosaur (cast)
- Skull of Allosaurus fragilis: carnivorous dinosaur (cast)
Also to see
- Anatomical drawing of a Stegosaurus dorsal plate
- Model of Deinonychus claw showing movement of claw

6 Feeding

When dinosaurs had teeth!
As soon as they fell out, they were replaced. When dinosaurs’ teeth were worn out or fell out, they were quickly replaced with new ones. In general, they only had one type of tooth, of varying sizes. The teeth of Tyrannosaurus rex were pointed and curved backwards, which means they would hold prey in its mouth and then cut it to pieces, whereas those of Diplodocus were long and arranged like the teeth of a comb and were used to strip leaves from branches, and those of Chasmosaurus were small and sharp, to grind up the vegetation cut down with its beak.

Specimens
- Skull of Iguanodon bernissartensis: herbivorous dinosaur (cast)
- Skull of Chasmosaurus belli: herbivorous dinosaur (cast)
- Skull of Diplodocus carnegii: herbivorous dinosaur (cast)
- Skull of Camarasaurus lentus: herbivorous dinosaur (cast)
- Skull of Tyrannosaurus rex: carnivorous dinosaur (cast)

To discover
- Who ate what? (electro for younger children)
- When dinosaurs had teeth! Sections of jawbones of 5 skulls that can be handled and observed closely (in drawers)

A giraffe-like neck?
Not at all! When at rest, most sauropods kept their necks horizontal. How? Either the neck was supported by curved, lengthy, ribs (in which case it was long but not very flexible) or it was covered in large ligaments and powerful muscles (in which case it was shorter but more flexible). It was perhaps this diversity of shape that allowed Diplodocus, Camarasaurus and Apatosaurus to live together without having to fight for food: each ate the food available at its height!

Stones in the stomach?
Some animals swallow stones, known as “gastroliths” which are used to help digestion by grinding up food in the stomach. Palaeontologists think they have found evidence of them in sauropods. The problem is that these gastroliths look just like any other stones, and, as soft tissue (such as the stomach) very rarely fossilises, it is difficult to prove that stones found near dinosaurs were in fact gastroliths rather than just simple pebbles!

Dinosaur droppings
Coproliths are fossilised droppings (from the Greek kopros (meaning excrement) and lithos (meaning stone)). They are irregularly shaped and can be very difficult to identify, as they are so rare, because they usually broke down before they could be fossilised. They sometimes contain fragments of partially-digested plants and bones, which allows us to say they came from herbivores or carnivores, but without being certain that they came from a dinosaur.
To do
- Who has the most flexible neck? Shape of vertebrae, length of ribs, placement of muscles and ligaments: the necks of Camarasaurus and Apatosaurus were very different (this installation allows you to test the flexibility of sauropod necks)
- How to use gastroliths: as the stomach churned, the swallowed stones ground up the food and thus helped digestion. Thanks to the pebbles I swallow, I can more easily digest insects, earthworms and seeds. What am I? (this installation helps us to understand how these stones grind up food). To understand, turn the handle and watch.
- Which animal made this dropping? (electro for younger children)

Stegosaurus stenops
Stegosaurus ate vegetation such as ferns and young shoots. Its name is derived from the bony plates fixed in its skin along its spinal column (literally “roof lizard”). They were too fragile to be used in self-defence, unlike the four spikes on its tail.

An army of bacteria in the stomach
Stegosaurus was herbivorous. Its small beak with a notch at the front and its small, simple teeth could cut vegetation but could not grind it up. It thus needed an army of bacteria in its stomach to break it down by decomposition. Some palaeontologists think that the excess heat generated by this process was evacuated through the blood stream, which transported it to the dorsal plates where it could be cooled by the surrounding air before returning to circulation.

Specimens
- Pinus heeri: fossilised pine cones (originals)
- Pinus andraei: fossilised pine cones (originals)
- Matonidium goepperti var. minor: fragments of fossilised ferns (originals)
- Lacopteris dunkeri: fragments of fossilised ferns (originals)
- Fossilised angiosperm leaf fragments (originals)
- Scaphognathus crassirostris: pterosaur skull (cast)
- Vinctifer comptoni: fossilised fish (original)
- Hanggginia chowi: half-jawbone of fossilised mammal (original)
- Young Diplodocus carnegii: herbivorous dinosaur (cast)
- Gastroliths
- Chicken in natural pose (it also swallows small stones)
- Stegosaurus stenops: herbivorous dinosaur (cast)
- Copraliths probably from carnivores discovered at Bernissart (originals)

Also to see
- Map of the Western USA (Montana, Wyoming, Utah, Colorado and Oklahoma): five states at the foot of the Rocky Mountains crossed by the Morrison formation.

To discover
- How can the excess heat generated by digestion be evacuated? Stegosaurus found a solution. Put your hand near its dorsal spines and see what you feel! A cooling system (this installation examines the possible thermoregulatory role of the Stegosaurus's dorsal spines).
This third zone presents the evolution of dinosaurs from their first appearance at the end of the Triassic Period to the present day.

1. The first dinosaurs

A veritable evolutionary explosion
The first dinosaurs appeared in the Late Triassic Period, 230 million years ago. Very quickly the ornithischians or “bird-hipped” dinosaurs and the saurischians or “lizard-hipped” dinosaurs could be distinguished. They diversified so rapidly that the main groups (theropods, prosauropods and thyreophors) were already evident at the start of the Jurassic Period, but they were still fairly primitive dinosaurs.

Two of the oldest saurischians
The first, Eoraptor (“gold thief”) lived almost 230 million years ago. The second, Coelophysis was more evolved and already a theropod. Both were small and agile and carnivorous. It was even suspected that Coelophysis engaged in cannibalism, because the remains of young Coelophysis were found in the stomachs of two adults. However, it was later shown that, in one case, these bones were those of a primitive crocodile, and in the other, the younger dinosaur had been underneath the adult and not inside it.

Two very different herbivores
Lesothosaurus, one of the oldest ornithischians, was a biped and less than 1m tall. It had a long tail, two wide-spread hind legs and quite short front legs, a horned beak and small teeth laid out in the shape of a nettle leaf. The saurischian Plateosaurus was a quadruped (although it could occasionally rear up on its powerful back legs) and, at 7m long, it was one of the largest dinosaurs of the Triassic Period. Most significantly, it was also one of the first “long-necks”.

20 leaflets on the most important branches of the cladogram

1. Ornithischia
2. Thyreophora
3. Ankylosauria
4. Stegosauria
5. Ornithopoda
6. Marginocephalia
7. Pachycephalosauria
8. Ceratopsia
9. Saurischia
10. Sauropodomorpha
11. Sauropoda
12. Prosauropoda
13. Theropoda
14. Carnosauria
15. Coelurosauria
16. Tyrannosauridae
17. Ornithomimosauria
18. Eumaniraptora
19. Dromaeosauridae
20. Aves
Specimens
- Eoraptor lunensis 220-225 million years old, Ischigualasto Provincial Park, Argentina (cast)
- Coelophysis bauri 204-220 million years old, Ghost Ranch, New Mexico, USA (cast)
- Skull of Lesothosaurus diagnosticus 196-200 million years old, Mastise, Lesthoto (cast)
- Skull of Plateosaurus engelhardti 203-210 million years old, Trossingen, Germany (cast)

Also to see
- Cladogram of dinosaurs and its main branches (metal structure)

To discover
- Cla-dis-tic! (panel explaining cladistics, on the left-hand side of the zone)
- Cla-do-grams (panel explaining how to read a cladogram, on the right-hand side of the zone)

2. Evolution and flight

2.1 With or without feathers?

The first dinosaur with feathers
Birds are descended from theropods. One piece of evidence of this is the presence of more-or-less well-developed feathers on the bodies of these dinosaurs. Since 1996, the excavations at Sihetun in China have been yielding such high-quality fossils that traces of feathers can still be seen on them. The Sinosauropteryx is the most primitive, with a sort of down made up of simple hollow filaments. The down did not enable the dinosaur to fly but helped it conserve its body heat.

Did Tyrannosaurus rex have feathers or not?
Did Tyrannosaurus rex, the terrifying predator that lived at the end of the Cretaceous Period, look like a big chicken? It may have done! The body of Dilong a small, primitive Tyrannosaurus found at Sihetun, was covered with barely ramified feathers, but Tyrannosaurus rex, which was more evolved than Dilong could have lost its feathers during its evolution, or due to its growth: perhaps its large size meant it was able to maintain its body temperature unaided.

The magnificent Caudipteryx
A primitive representative of the oviraptosaurs, Caudipteryx is one of the best-known feathered theropods discovered at Sihetun. It was about the same size as a turkey, with long hind legs which were perfect for running and a beak containing a few teeth at the front (it must have used gastroliths for most of its digestion). Long, symmetrical feathers decorated its short front legs and formed its fan-shaped tail, which was used in its mating rituals but not for flying!

Velociraptor almost a bird?
The dromeosaur Velociraptor was anatomically very close to a bird: its hips pointed backwards, it had long, hollow bones, its clavicles were fused, it had a long, narrow omoplate, it had an extended forearm and a thumb allowing it to fold its hand along its forearm, it had three long fingers on each hand and four toes on each foot, of which one pointed backwards. But did it have feathers? No Velociraptor fossil yet found shows any traces of feathers, but Microraptor a similar small dromeosaur whose fossils were found at Sihetun, was covered in feathers.

Archeopteryx the first bird
Living during the Late Jurassic Period, Archeopteryx is the oldest known bird. Like the dromeosaurs, it had pointed teeth, three clawed fingers and a long, rigid tail. Like modern-day birds, its body was completely covered in feathers and its wing feathers were asymmetric (and thus perfectly adapted to active flying). In addition, it could also perch on branches using its backward-facing first toe.
Where did flight come from?
One day, did a theropod that was running along flapping its feathered arms take off and start flying? It's not certain. The feathers of Microraptor, a small dromeosaur discovered at Sihetun, were similar to those of modern-day birds, but they covered its four legs and its tail. The feathers on its hind legs were too long to allow it to run and thus to take off. More likely is that it climbed trees, using its clawed feet and hands, and then glided from one tree to another.

Specimens
- Sinosauropteryx prima: 125-130 million years old, Sihetun, Liaoning, China (cast)
- Caudipteryx zoui: 125-130 million years old, Sihetun, Liaoning, China (model)
- Velociraptor mongoliensis: 70-75 million years old, Bayn Dzak, Mongolia (cast made using several specimens)
- Archaeopteryx lithographica: 150-155 million years old, Solnhofen, Germany (cast made using several specimens)

Also to see
- From theropods to birds (drawing)

2.2 What were these feathers used for?
The feathers were used for flying, keeping warm, in mating rituals and to frighten predators. The main types of feathers were flying feathers, contour feathers which covered the body and down, which was used to keep warm. They were made in the skin from keratine, just like scales, hair and nails. They had a central rachis (spine) with a hollow at the base (calamus) and two vexillae (rows of barbs with smooth, hooked barbules).

The evolution of feathers

Stage 1
According to scientists, the feathers of modern-day birds go through the same growth stages as all feathers since they first evolved in theropods (such as Sinosauropteryx). They surmise that each new stage was an innovation. In the first stage, under the epidermis, a dermic papilla is born and lengthens onto a simple hollow tube: the seed.

Stage 2
In the second stage, a ring of cells forms at the base of the tube and digs deeper and deeper: this is the follicle. Inside the follicle, simple feathers are produced, whereas outside it becomes a calamus, from which the feathers emerge. At this stage, the feathers are a sort of primitive down which helps to preserve body heat, thus keeping the animal warm.

Stage 3
At the beginning of the third stage, the feathers either begin to make barbules (if they are to become down) or they create a rachis from which flying feathers with simple barbs grow. At the end of the third stage, the feathers are flat with ramified barbs and smooth barbules.

Stages 4 & 5
In the fourth stage, hooked barbules develop which attach themselves to the smooth barbules on neighbouring barbs. This tightly links them together, making the vexillae waterproof and the feathers aerodynamic. But it is not until the fifth stage, when the wing feathers and tail feathers become asymmetric, that flight becomes possible.
Specimens
- Tyrannosaurus rex
- Velociraptor mongoliensis
- Microraptor gui
- Trichoglossus haematodus

Also to see
- Stages of development of feathers (drawings)

To do
- What were feathers used for? (electro for younger children)

2.3 Tyrannosaurus rex:
a strange type of bird

Tyrannosaurus rex (literally “tyrant king lizard”) was one of the largest carnivores that has ever lived! It could grow to 15m long and had ridiculously small arms but an extremely powerful jawbone, filled with teeth as sharp as steak knives. This one, nicknamed Stan, was installed here in 1992 and is just over 12m long.

Male or Female?
When analysing slices of bone from a Tyrannosaurus rex unearthed in Montana, scientists found a structure similar to that found in female birds: the “medullary bone”, a thin layer of bone with a very rich blood supply present in the long bones, but only between ovulation and laying an egg: it provided the calcium for the egg shells. So the fossilised bone was not from a Tyrannosaurus rex (male) but rather a Tyrannosaurus regina (female) which was about to lay an egg.

Stan the survivor
The skeleton of Stan the Tyrannosaurus rex bears marks made by many wounds, including broken ribs, fused vertebrae and vertebrae immobilised by an excess of bone. On the rear of his skull is a hole the exact shape of a Tyrannosaurus rex tooth! So most of these injuries could have been caused buy other Tyrannosaurus rex. Perhaps they lived in groups? Or perhaps they fought over prey? But Stan’s wounds had all healed or were in the process of healing: he was a survivor.

Yes, but…
Whether he was a scavenger or a predator, Tyrannosaurus rex was carnivorous. We can prove this because we know he suffered from gout! This disease (that also affects humans) is often caused by a diet too rich in red meat. It causes inflammation of the joints and sometimes bony lesions, as on Tyrannosaurus rex skeletons!

It is possible that the largest dinosaurs, such as the sauropods and adult Tyrannosaurus rex, were able to maintain an almost constant internal body temperature, thanks to their large size, because the larger the animal, the slower it cools down: this is known as gigantothermics.

Specimens
- Sinosauropteryx prima: feathered dinosaur (cast)
- Tyrannosaurus rex: possibly feathered dinosaur (cast)
- Caudipteryx zoui: feathered dinosaur (sculpture)
- Velociraptor mongoliensis feathered dinosaur (cast)
- Archaeopteryx lithographica primitive bird (cast made from several specimens)
- naturalised crow (occasional scavenger to be compared with Tyrannosaurus rex)

Also to see
- Series of drawings showing evolution of feathers
- From theropods to birds: drawing showing evolution of theropods into birds

To discover
- What were feathers used for? (electro for younger children)
- Filmed interview of Armand de Ricqlès on the growth of Tyrannosaurus rex surmised from the structure of its bones
- Filmed interview of Jack Horner on the predatory behaviour of Tyrannosaurus rex: hunter or scavenger?
3. Evolution and Spreading out

3.1 Ornithopods

These dinosaurs were members of one of the most diversified branches of the ornithischians: more than 100 different species have been discovered, dating from the Mid-Jurassic Period to the Late Cretaceous Period. All were herbivorous and had no armour. Their lower head pointed down and the lower jawbone's joint with the skull was below the level of the teeth in the upper jawbone.

Lengthening of the front of the hip bone

The Euornithopods shared evolved characteristics in their hips, such as the lengthened front of the hip bone. They lived from the Mid-Jurassic Period to the Late Cretaceous Period. Hypsilophodon, a primitive Euornithopod, would have certainly lived with iguanodonts: like them, its fossilised remains have been discovered in the UK and Spain in layers dating from the Early Cretaceous Period. Its speed and agility were doubtless its best means of escaping predators.

Horned beak on upper jawbone

The iguanodonts did not have teeth at the front of their upper jawbones, but rather a sort of horned beak. Zalmoxes a primitive iguanodon, was only 3m long but was very strong. It appears to have lived on an island in what is now Transylvania, in the Late Cretaceous Period. This could explain its small size, better adapted to a small territory where food was scarce.

Evolution of a spurred thumb on the hand

The Ankylopollexia had particularly enlarged skulls in front of the eye sockets. Their hands had evolved a spurred thumb (like the iguanodon). Lurdusaurus was a relatively primitive ankylopollexian which lived in present-day Niger during the Early Cretaceous Period. It must have appeared clumsy with its heavy, bulky body, its rather long neck, its powerful front legs and its short hind legs.

Toes ending in a small hoof

Iguanodonts and their descendants, the Hadrosauriforms were all very tall ornithopods. Each of their toes ended in a small hoof instead of a claw. They had a diastem – a toothed area – between their beak and their first row of teeth, which were simpler and narrower on the upper jawbone than on the lower jawbone.

Simplified structure of teeth on lower jawbone

Living in China in the Early Cretaceous Period, Probactrosaurus is one of the earliest ancestors of the hadrosaurs. It still had a spurred thumb like the iguanodonts. But the teeth on its lower jawbone were more simply structured and had begun to be arranged in rows like the more evolved hadrosaurs: when clenched together, the rows of teeth locked into each other. The bones of the forearms and the hands also became more slender.

Bactrosaurus

The hadrosaurs were particularly numerous and diversified in Asia from the Mid-Cretaceous Period onwards. Discovered in China in layers dating from the Late Cretaceous Period, Bactrosaurus is one of the best-known and most primitive hadrosaurs. It differs from Probactrosaurus in anatomical details which place it closer to the more-evolved hadrosaurs: its rows of teeth are more compact, the bones of its hands are much lighter and its thumbs appear to have disappeared.

Anatotitan

The hadrosaurs (literally “duck-billed dinosaurs”) derive their name from their long, flat beaks, and are divided into two groups: lambeosaurs like Armurosaurus and hadrosaurs like Anatotitan, which either had a solid crest or no crest at all. Their large nostrils were probably surrounded by a membrane which amplified their cries by inflating like the windbag in bagpipes. The most remarkable feature of Anatotitan was that it had almost 1,000 teeth!
Armurosaurus & Olorotitan
The lambeosaurs were hadrosaurs with hollow crests. The crest’s shape varied from one species to another and was used as an excellent visual and acoustic sign of recognition. The crest of Armurosaurus was semi-circular, while that of Olorotitan pointed sharply backwards. Widespread in North-Eastern Asia at the end of the Cretaceous Period, the lambeosaurs probably lived in herds, close to where the vegetation was at its most abundant.

Olorotitan arharensis
This was one of the last dinosaurs to have lived in Asia before the great extinction in the Late Cretaceous Period. Its fossilised remains were discovered in 2001, not far from the River Amur which flows along the border between Russia and China. Like Parasaurolophus, Olorotitan was a lambeosaur, a hadrosaur whose hollow crest amplified its cries.

Yes, but…
Sometimes fossilised teeth and fragments of bone from dinosaurs (other than birds) are found in Tertiary Era layers of earth: does this mean some survived the extinction at the end of the Cretaceous Period? No, because these fossils dated from before the extinction and had only moved into the Tertiary Era layer because of erosion!

Crests with multiple uses
Whether they were hollow (as in the lambeosaurs) or solid (as in the hadrosaurs) the shape of the crests varied enormously from one species to another. They could thus be used to distinguish relatives, to attract mates or to frighten away rivals. In addition, the hollow crests were used as resonators for the animal’s cries, allowing them to communicate with each other over long distances.

Did iguanodons migrate?
Iguanodonts were widespread in Europe in the Early Cretaceous Period, when the continents of the Northern hemisphere had not yet separated completely. Herds of iguanodons could thus have migrated across Laurasia, because their remains have been found in North America and Mongolia! Those which lived in Asia experienced a major diversification at the end of the Early Cretaceous Period, which is when the first hadrosaurs appeared.

Specimens
- Hypsilophodon foxii: 120-130 million years old. Isle of Wight, UK (cast made from several specimens)
- Zalmoxes shqiperorum: 68-70 million years old. Nalat Vad, Transylvania, Romania (cast)
- Lurdusaurus arenatus: 112-120 million years old. Gadoufaoua, Niger (cast)
- Iguanodon bernissartensis: foot. 125-128 million years old. Bernissart, Belgium (cast)
- Probactrosaurus gobiensis: 120-130 million years old. Dashuigo, Inner Mongolia, China (cast)
- Bactrosaurus johnsoni: 68-70 million years old. Erenhot, Inner Mongolia, China (cast)
- Anatotitan copei: 65-68 million years old. Hell Creek Formation, USA (cast)
- Amurosaurus riabinini: 65-68 million years old, Blagoveschensk, Russia (cast)
- Olorotitan arharensis: 65-68 million years old. Kundur, Russia (cast)

Also to see
- Evolution of ornithopods (drawings)
- Interview with Pascal Godefroit on Asian dinosaurs (video)

To do
- To Each His Crest! Find the right crest, using the descriptive leaflets to help you.
3.2 Major extinction at the end of the Cretaceous Period

Around 65 million years ago, at the end of the Cretaceous Period and the start of the Tertiary Era, almost two thirds of all the animal and plant species on Earth became extinct. Among these victims were dinosaurs (except for birds), pterosaurs, mosasaurs, ammonites and over three-quarters of plankton. This massive extinction could have been caused by the impact of a meteorite near Mexico.

Triceratops horridus
Triceratops means “three-horned face”. It is one of the few ceratopsians whose large collar at the back of its skull, was not lightened by openings. The length of the horns and the shape of the collar vary so much from one individual to another that some fossilised skulls have been wrongly attributed to other species.

The Mont-Dieu meteorite
The pieces of this meteorite were discovered in the North of France, near the Mont-Dieu forest. The largest piece weighed 435kg, but the entire meteorite would have weighed around 800kg. This is far smaller than the Chicxulub meteorite which was between 10km and 12km in diameter, but the Mont-Dieu meteorite is still one of the largest found in Europe. It is made of iron and nickel, plus some sulphur and silica. It is probably the heart of an asteroid that came from between Mars and Jupiter.

Other theories
At the same time, India experienced intense volcanic activity: the Deccan plateau was covered in a 2km thick layer of lava, covering over 500,000 square kilometres (about the same area as France). The gas, ash and sulphuric acid spewed out by the volcanos had a disastrous effect on vegetation and the animals that ate it.

Evidence using iridium
In places all over the Earth, geologists have found strong concentrations of iridium in the think layer of sediment laid down between the end of the Cretaceous Period and the start of the Tertiary Era. Although rare on Earth, iridium is common in meteorites, and it was probably released into the atmosphere when a huge meteorite crashed into Mexico around 65 million years ago. Blown by the wind over long distances, it was deposited all over the Earth’s surface.

The Chicxulub crater
This crater is located on the Yucatan peninsula in Mexico, and it was formed by the landing of a giant meteorite at the end of the Cretaceous Period. The impact of the meteor deformed many rocks and minerals. The inside of the crater is largely made of suevite, a mixture of solid and melted original rocks. Outside the crater we find rocks vitrified by the heat and “shocked” quartz with striations caused by the shock wave and the enormous pressure.

The survivors
It appears that the animals which survived did not eat plants or plankton - which had temporarily become very rare types of food - but rather decomposing material, including insects, freshwater vertebrates (fish, amphibians, turtles, crocodiles, etc), small terrestrial reptiles (lizards, snakes, etc) and small insectivorous or herbivorous mammals which rapidly took the place of the dinosaurs.
Specimens
- Triceratops horridus: cast made from several specimens, Hell Creek Foundation, Montana, USA
- Armura ind.: amphibian, around 47 million years old, Messel, Germany (original)
- Erquelinnesia gosseleti: turtle, 57 million years old, Erquelinnes, Belgium (original)
- Snake resembling a boa constrictor, 47 million years old, Messel, Germany (original)
- Leptictidium: mammal, 47 million years old, Messel, Germany (original)
- Fragment of the Mont-Dieu meteorite
- Mosasaur skull (original)

Also to see
- Macro-photos of fossilised pollen grains and spores from the end of the Cretaceous Period
- Graph showing variations in iridium levels between the end of the Cretaceous Period and the beginning of the Tertiary Era
- Macro-photos of suevite, vitrified rocks and shocked quartz
- Interview of Philippe Claeys on the meteorite which fell to Earth at the end of the Cretaceous Period. (video)

4. Dinosaur or not?

4.1 Dinosaur

The ancestry of dinosaurs
Like us, dinosaurs were amniotic tetrapods (terrestrial vertebrates whose embryos develop in a sac filled with amniotic fluid). Other amniotic animals include synapsids (mammalian reptiles and mammals) and diapsids, which are distinguished by the number and position of the openings in their temporal craniums. Diapsids include lepidodsauromorphs (snakes and lizards) and archosaurs (pterosaurs, crocodiles and dinosaurs).

Characteristics of dinosaurs
Like all archosaurs, they have a cranial opening in front of each eye socket and teeth which are not fused to the jawbones but rather fixed in cavities. By contrast, dinosaurs have vertical legs under their bodies (more lateral in other archosaurs). This erect posture helped their movement a lot, but, above all, it permitted the development of bipeds, such as Velociraptor, and very large dinosaurs, such as Diplodocus.

Seven features of dinosaurs
Here are some characteristics of a dinosaur (to be distinguished on any dinosaur taken at random). Shrunken or absent 4th and 5th fingers. Shoulders articulated towards the rear. More than 3 vertebrae fused in the sacrum. Opening at the centre of the pelvis. Crest on the front part of the tibia. Talus bone extended towards the third metatarsal bone.

Specimens
- Sculpture of a dinosaur (Megalosaurus)

To see also
- Archosaur cladogram

4.2 Not dinosaurs

These are not dinosaurs
1. Pterosaurs such as Pteradon longiceps, which lived at the same time as dinosaurs and were closely related to them: they were also archosaurs. But they display several differences with dinosaurs, notably in their pelvis and their heels.

2. Crocodiles, which were also close relatives of dinosaurs, such as this Crocodylus depressifrons from Leval, which were also archosaurs. But their posture was erect when they ran and semi-erect when they walked (their legs bent outwards).

3. Dimetrodon a “mammalian reptile” which had only one pair of temporal openings, unlike dinosaurs which had two. It is thus a synapsid. In addition, it lived around 300 million years ago, long before dinosaurs.
4. Mosasaurs, such as Plioplatecarpus houzeaui, discovered at Spiennes, lived at about the same time as dinosaurs, in the Late Cretaceous Period, but they were not archosaurs. In fact, these marine lizards are lepidosauromorphs, close relatives of monitor lizards.

5. Champsosaurs, such as Champsosaurus lemoinei, discovered at Erquelinnes, are difficult to classify but are definitely not archosaurs. They lived alongside dinosaurs but survived to the Tertiary Era.

6. Also appearing in the Late Triassic Period, turtles such as Allopleuron hofmanni did not have any cranial temporal openings. Some classify them as primitive amniotics and others consider them as specialised diapsids.

Specimens
- Pteranodon longiceps: pterosaur (cast)
- Crocodylus depressifrons: fossilised crocodile (original)
- Dimetrodon: "mammalian reptile" (cast)
- Plioplatecarpus houzeaui: fossilised mosasaur (original)
- Champsosaurus lemoinei: fossilised champsosaur (original)
- Allopleuron hofmanni: fossilised turtle (original)

5. Time corridor: not all dinosaurs lived at the same time in the same place

Good fossils for dating
Ammonites lived at the same time as dinosaurs and were marine cephalopods like octopuses, but were protected by a shell which was often twisted into a spiral. Different species lived in huge territories and were rapidly replaced by new species. This is what makes them such good fossils for dating. For example, if two geographically-distant geological layers contain fossils of the same species of ammonite, they date from the same period.

Specimens
- Ammonites: dating fossils (originals)

To do
- Dating fossils (based on three correctly-placed ammonites, you must put each ammonite in the correct layer).

The Earth of the dinosaurs
Since dinosaurs made their appearance during the Triassic Period, the Earth underwent significant changes. Back then, the continents formed one bloc, known as Pangaea, set in a single ocean, the Panthalassic. At the start of the Jurassic Period, Pangaea split into two continents: Laurasia (which would become North America, Europe and Asia) to the North and Gondwana (which would become South America, Africa, Australia, India and Antarctica) to the South. Continental movement continued throughout the Cretaceous Period and has continued ever since.

Also to see
- 4 maps illustrating the tectonic plates from the Late Triassic Period to the Late Cretaceous Period
- 15 “small theatres” representing the principal sites where the dinosaurs in the gallery were discovered.
- Timeline of the Earth with illustrations of significant events (on mezzanine)

The Earth in the Triassic Period
When the first dinosaurs appeared in the middle of the Triassic Period, there was just one super-continent, Pangaea, which extended from the North Pole to the South Pole and was surrounded by a single ocean, the Panthalassic Ocean. Its climate was very arid, except in the polar regions which were swept by monsoons. Conifers were the most diversified and abundant trees in this period: they were better adapted to resist drought than other vegetation.
Vertebrae from the Late Triassic Period

The mammalian reptiles and primitive amphibians of the Early Triassic Period were gradually replaced by new groups of animals during the Late Triassic Period. Among there more modern vertebrates we find distant cousins of crocodiles in the rivers, pterosaurs in the air and small mammals and dinosaurs on the dry land. Rapid, agile and well-adapted to the arid climate, the dinosaurs rapidly became the dominant group on the continents from the end of the Triassic Period onwards.

Specimens

- Skull of Mastadonsaurus sp.: primitive amphibian from the Triassic Period (cast)
- Meuthodon gallicus: micro-fossil (original)
- Tricuspis sigogneanae: micro-fossil (original)
- Lepagia gaumensis: micro-fossil (original)
- Gaumia longiradicata: micro-fossil (original)
- Phytosauria: micro-fossil (original)
- Eudimorphodon: micro-fossil (original)
- Woutersia mirabilis: micro-fossil (original)
- Prosauropoda: micro-fossil (original)
- Sauropoda: micro-fossil (original)
- Ornithischia: micro-fossil (original)

To discover

- 2 Wentzscopes through which you can observe Late Triassic micro-fossils.

The Earth in the Jurassic Period

During the Jurassic Period, Pangaea began to split into several blocks and this had repercussions on the climate, which became more humid nearer the poles. Immense forests of conifers appeared which offered refuges for many small animals. On the dryer plains of the Late Jurassic Period, vegetation was much sparser and the herds of giant sauropods ate or crushed most of it as they passed.

Pterosaurs

The Pterosaurs were kings of the air in the Jurassic Period. They first appeared at the end of the Triassic Period and these cousins of dinosaurs diversified in the Early Jurassic Period. They were small with long tails and lived on the coastline and around lakes. The second wave of pterosaurs was known as the pterodactyloids, which had short tails, and developed from the Late Jurassic Period onwards. By the Cretaceous Period, the largest pterodactyloids were 12m long and could fly long distances to the interior of the continents.

Underwater Europe

In the Jurassic Period, most of Europe was covered by a deep, warm ocean, inhabited by corals, belemnites, ammonites and fish, meaning that the biggest predators of the Jurassic seas, crocodiles and plesiosaurs, were not short of prey! The ichthyosaurs’ rifled bodies, paddle-shaped feet and rudder-like tails made them the best adapted reptiles for life in the sea.

Specimens

- Compsognathus longipes: European dinosaur of the Late Jurassic Period (cast)
- Archaeopteryx lithographica: primitive European bird of the Late Jurassic Period (cast)
- Idiochelys fitzingeri: European turtle of the Late Jurassic Period (cast)
- Crocodileimus robustus: European crocodile of the Late Jurassic Period (cast)
- Alligatorellus beaumonti: European crocodile of the Late Jurassic Period (cast)
- Sapheosaurus thiollieri: European aquatic “lizard” of the Late Jurassic Period (cast)
- Homeosaurus pulchellus: European aquatic “lizard” of the Late Jurassic Period (cast)
- Scaphognaththus crassirostris: European pterosaur of the Late Jurassic Period (cast)
- Rhamphorhynchus munsteri: European pterosaur of the Late Jurassic Period (cast)
- Pterodactylus elegans: European pterosaur of the Late Jurassic Period (cast)
• Ammonites: cephalopods from the sea in the Jurassic Period (originals)
• Dapedium: sea fish of the Jurassic Period (original)
• Stenopterygius longifrons + Stenopterygius hauffianus: ichthyosaurs from the sea in the Jurassic Period (originals)

The Earth in the Early Cretaceous Period
The large continental blocks continued to move away from each other and plants and animals developed differently on each block. The climate became much more humid and new plants developed, including flowering plants (angiosperms) which first appeared in the Early Cretaceous Period. Their rapid growth and reproductive cycles made them the first plants to recolonise the zones devastated by herds of herbivorous dinosaurs.

And elsewhere in the world…
In the Early Cretaceous Period, small primitive ceratopsians, such as Psittacosaurus were abundant in Asia. The luxuriant forests of Liaoning, in the Sihetun region of China, were home to many different small, feathered theropods, including primitive birds. In Brazil, spinasaurid theropods feasted on pterosaurs and fish, as shown by the splendid fossils discovered in the Santana formation.

Specimens
• Tail and jawbone of an iguanodon: European dinosaur (originals)
• Skull of Hypsilophodon foxii: European dinosaur (original)
• Vertebra of theropod: European dinosaur (original)
• Coracid and tibia of sauropod: European dinosaur (original)
• Notelops brama: fossilised fish from Brazil (original)
• Ararilepidotes temnurus: fossilised fish from Brazil (original)
• Vinctifer comptoni: fossilised fish from Brazil (original)
• Cladocyclus gardneri: fossilised fish from Brazil (original)
• Lycoptera: fossilised fish from Brazil (original)
• Ephemeroptera: fossilised insect larva from China (original)
• Skull of Psittacosaurus lujiatunensis: dinosaur from China (original)

The Earth in the Late Cretaceous Period
A little before the great extinction at the end of the Cretaceous Period, the temperature began to fall and the dense forests of the Early Cretaceous Period began to give way to more sparsely forested landscapes. The sea levels fell and it became possible to move from Europe to Africa and from Asia to North America on dry land. The explosion of flowering plants encouraged the development of insects, birds and mammals. And while marine reptiles and pterosaurs were declining, dinosaurs had never been so diverse.

Europe in the Late Cretaceous Period
At the end of the Cretaceous Period, Europe was made up of a number of large islands, inhabited by many dinosaurs: small iguanodons, primitive hadrosaurs, ankylosaurs, sauropods, theropods and primitive birds. Due to their isolation, they appeared to be less well-developed than species in Asia and North America. In any case, the small size of dinosaurs found in Romania (such as Zalmoxes) shows that they had adapted to life on an island.

Specimens
• Hoplopteryx: fossilised fish from Belgium (original)
• Protosphyracna ferox: fossilised fish from Belgium (original)
• Saurocephalus intermedius: fossilised fish from Belgium (original)
• Femur, tibia and caudal vertebra of orthomerus dolloi: dinosaur from Belgium (originals)
• Femur of Megalosaurus briedai: Belgian dinosaur (cast)
• Claw of Megalosaurus lonzeensis: Belgian dinosaur (cast)
• Teeth of Craspedodon lonzeensis: Belgian dinosaur (originals)
• Telmatosaurus transsylvanicus: European dinosaur (cast)
• Struthiosaurus transsylvanicus: European dinosaur (cast)
• Magyarosaurus sp: European dinosaur (cast)
• Theropod: European dinosaur (cast)
• Rhabdodon priscus: European dinosaur (cast)
The Tertiary Era, era of dinosaurs?
At the end of the Cretaceous Period, modern birds (neorniths) were already well-represented by primitive forms of divers, cormorants, ducks, hens and perhaps even parrots! Form the start of the Tertiary Era, they experienced an evolutionary explosion similar to that experienced by mammals. Today, with more than 9,700 species of birds on Earth, birds are twice as diverse as mammals. So dinosaurs are far from extinct!

Specimens
- Messelornis cristata: fossilised birds (originals)
- Aves: fossilised birds (originals)
Even more…

1. Bernissart 1878: an historic discovery!

Found by chance at the end of March 1878, 322m underground in a coalmine near Mons in the Belgian Province of Hainaut, our famous Bernissart iguanodons are without doubt one of the most impressive dinosaur discoveries in the world.

An exceptional site

The Bernissart site is very unusual and remains unique to this day, a natural pocket of clay underground which allowed the perfect fossilisation of a whole swamp containing around 30 iguanodons which are about 125 million years old.

The large majority of known dinosaur sites, both past and present, are close to the surface and often only contain incomplete skeletons or bones from different skeletons. So the astonishing thing about Bernissart is its depth underground, almost as if the fossils had been sealed in a treasure chest made of clay.

It must also be stressed that the many accompanying fossils, including around 3,000 fish, crocodiles, turtles, a salamander, ferns and pinecones, enabled scientists to accurately recreate the environment in which the iguanodons lived.

An exemplary excavation

Between 1878 and 1881, thanks to the remarkable work of a team of miners, technicians and specialists from the then Natural History Museum, several complete iguanodon skeletons in good condition were slowly exhumed and brought to the surface.

Meticulous and innovative excavation methods allowed this priceless heritage to be saved: in particular thanks to Louis De Pauw, an experienced preparation specialist at the Museum who was the onsite director of operations. De Pauw had previously built his reputation on his restoration of the fossilised mammoth skeleton discovered at Lierre near Antwerp. It is generally thought that he invented the “plaster shell” technique where the fragile fossils were covered in plaster of Paris onsite so that they could be unearthed and then transported. This technique is still successfully used today, all over the world.

A world première

The first exhibition of a complete, authentic dinosaur skeleton in its life position took place in Brussels in 1883. A truly historic moment! This amazing reconstruction of our iguanodon was both realistic and scientifically accurate, was made by teams at the Museum, supervised by Louis Dollo, the renowned pioneer of vertebrate palaeontology. His in-depth research of the comparative anatomy of fossils and of living animals led him to found the science of palaeobiology.

An historic discovery

In 1841, Richard Owen, Director of the British Museum in London, coined the word “dinosaur” (from the Greek meaning “terrible lizard”) based on three fossilised dinosaur skeletons in his museum: Megalosaurus, Iguanodon and Hylaeosaurus. Not much was known about dinosaurs at that time and most of the fossilised skeletons were incomplete. Most of the fossilised dinosaurs that had been discovered had been discovered in Europe, particularly in the UK.

The discovery at Bernissart in 1878 was historic because, for the first time

- several specimens of the same dinosaur were found together
- their skeletons were complete and articulated in an “anatomical connection”
- their environment was clearly identified by accompanying fossils

A solid benchmark

From a general point of view, the iguanodons remain a benchmark par excellence in dinosaur research, despite the fact that, today, over 700 species of dinosaur have been described, because they were among the first to be discovered and their history is a perfect illustration of the progress of scientific investigations over the last 200 years.

A permanent success

Envied for many years by our French and German neighbours, the success of our iguanodons has not diminished over recent decades. Indeed, in 1985 and 1988, several of our fossilised dinosaur skeletons were exhibited in Japan to a very enthusiastic public. The iguanodons were also the star exhibits in a scientific exhibition in Barcelona from 2004 to 2006.
Valuable experience and knowledge
Finally, thanks to the experience gained by daily contact with our Bernissart iguanodons, as much in the field of scientific research as in that of museum preparation, the expertise and knowledge of our palaeontological researchers and technicians has been acknowledged for many years. This is why members of the Museum’s staff are regularly asked to take part in excavations in far-flung corners of the world organised by international projects (e.g. in China, Russia, Romania, etc.)

In conclusion
Although many other exciting discoveries of fossilised dinosaurs have been made around the world since 1878, the Bernissart iguanodons are still a spectacular collection of international renown, both for the richness of their discovery site and for their excellent conservation, but above all for the exceptional character of around 30 specimens of the same species.
2. Fossilisation and Fossils

The word “fossil” means “extracted from earth” and is used for all the remains, imprints and other traces of organisms (plants and animals) preserved in earth. However, quite arbitrarily, more recent remains preserved in earth are not considered to be fossils (those less than 10,000 years old, i.e. since the end of the last Ice Age). Most fossils are much older: millions or tens of millions or even billions of years old (fossilised bacteria found in rock at Gunflint, Canada, are two billion years old and stromaliths found in Australia are 3.5 billion years old). The preservation of a biological object for so long is quite rare, and is the result of complex processes generally known as “fossilisation”.

Living organisms are made up of organic matter (soft tissue) with or without a skeleton made of minerals (hard tissue). Even though there are some exceptions, the general rule is that soft tissue is very unlikely to fossilise, whereas hard tissue stands a good chance of fossilisation. This is why most fossils are bones, teeth, shells or carapaces.

In all cases, even for resistant tissue, the chance of fossilisation is unlikely. When an organism dies, the soft tissue is rapidly destroyed, broken down and “recycled” by scavengers, bacteria and saprophytic fungi. Oxidation, freezing and erosion destroy everything except the hardest hard tissue. By contrast, if the dead organism is rapidly covered or buried by sediment, fossilisation can begin. Overall, fossilisation consists of several processes.

- A skeleton or shell loses all or part of its organic matter and lands on a sedimentary bed. Before scavengers or the weather can break it down, it is covered by sand, mud, clay or alluvium which accumulates and buries it. Very slowly, all the hollow spaces in the original matter (e.g. the pores in bones) are filled with minerals. The transformation of the sediment into sedimentary rock (e.g. chalk, schist and sandstone) will eventually produce fossil-bearing rock, whose fossils’ mineralogical composition will be close to that or the original organism’s skeleton. The microstructure and macrostructure of the skeleton will be very well-preserved even if it is squashed flat by the weight of layers above it or deformed by folds in the rock.
- In some cases, the original material that becomes fossilised is replaced little by little, molecule by molecule, by minerals (carbonates, phosphates, silica) from the layers surrounding it or from water which percolates through the rock. There is also a process known as epigenisation or secondary mineralisation. This process produces spectacular fossils (such as the ammonites containing iron pyrites found at Cap Blanc-Nez in France) where only the macroscopic structure is preserved.
- The same phenomenon of replacement molecule by molecule can also occur between the organic material of an organism and its environment, as in the very rare fossilisation of organic soft tissues. The organic matter is replaced by phosphates or silica, as, for example, in the very rare fossils of molluscs and wood.
- Skeletons can also be partially or entirely dissolved by water circulating through the rock. This dissolution leaves a cavity in the rock which preserves an impression of the organism like a mould. Later, these cavities are often filled with other materials, such as calcite cement or very fine sediment. The fossil in these cases is thus a cast of the original skeleton.
- “Carbonisation” is an unusual form of preservation of organisms with no hard tissue. In these cases, the organic matter is buried particularly rapidly in sediment and oxidation is prevented. The volatile gases, such as hydrogen, ozone and oxygen are extracted and only the carbon remains and is preserved. The organism’s soft tissue is thus squashed under a film of carbon, preserving its tiniest details. Fossilised ferns or leaves are good examples. The extraordinary animals found in the Burgess Schist in the Yoho National Park in British Columbia in Canada are other examples.
- Finally, we also use “fossil” to describe organisms preserved in ice or frozen earth (such as the fossilised mammoths found in Siberia) or in amber (solidified vegetable resin in which insects are sometimes found) or in oil or bitumen (such as the fossilised bacteria found in crude oil).

And afterwards?

Following movements of the Earth’s crust, layers of very deep rock can be raised to the surface, bringing the fossils in them up to the surface too. The rock can then be eroded to reveal the fossils and this can lead to palaeontologists conducting an excavation.
"Living fossils"

This is a term more frequently used by journalists than scientists which brings together two supposed opposites and is used to designate non-extinct species that are very close to species which have been found in fossilised form. Sometimes these species are isolated survivors of extinct groups which were able to benefit from a very stable environment with very little pressure on selection and therefore evolution. An example is the well-known tree Gingko biloba which was present on Earth 270 million years ago, or the tuatara, a reptile found on a couple of islands off New Zealand that is the sole survivor of the Rhynchocephalia order whose characteristics have not changed since the Jurassic Period.

The journalistic effect is reinforced by species which were first discovered as fossils before being discovered as living animals or plants. One of the most famous of these is the coelocanth (Latimeria chalumnae) a fish which belongs to a group thought to have become extinct 65-70 million years ago, of which the first live specimen was caught in 1938. The same story is true for Metasequoia, a tree discovered in 1943 in an isolated valley in China, or Neopilina a mollusc found 4,000m below sea level in the Gulf of Panama in 1952 which is part of the Monoplacophoria, thought to have become extinct 350 million years ago.

Indicator fossils

Some types of fossils have the peculiarity of being typical of a particular geological period. If they are also quite common and widespread, they can be used as good stratigraphical indicators or “dating fossils”. For example, if two geological layers that are geographically distant from one another contain the same species of dating fossil, we know that they belong to the same Period. This is the case for ammonites whose various species lived over huge areas and replaced each other frequently. In the same way, scientists can use the shells of belemmites, another type of extinct cephalopod, to determine from their size, shape and their ridges and furrows the Period in which they lived.

In a similar way, facies fossils are types of fossils only found in certain types of sediments (or facies) and can thus give clues about the origins of the sediment. Their local distribution is closely linked to the physical, chemical and biological conditions of their environment. By comparing them with modern shapes, these fossils can provide us with information:

a) on the nature of the environment in which they lived (e.g. seawater or freshwater or brackish water)
b) on the depth at which they lived (e.g. coastal waters or mid-ocean)
c) on the climate at the time

On this last point, “pollen profiles” are widely used, for example by comparing fossilised pollen grains with modern pollen grains, to establish common points with modern climates. Pollen is very widespread, fossilises well and they characterise types of plants; which in turn require certain types of climate.
3. Where can dinosaurs be found?

The fossilised remains of dinosaurs can be found on every continent. This worldwide spread is due, among others, to the fact that in the Triassic Period (140 to 250 million years ago) the Earth looked quite different to how it looks today. Then there was a super-continent called Pangaea made up of all the modern-day continents. With no natural barriers, dinosaurs were able to roam over all the accessible landmass.

Later in the Jurassic Period, Pangaea split into two smaller super-continents, Laurasia and Gondwana, separated by the Tethys Ocean. Very slowly, animals different to dinosaurs began to evolve in different ways until they became extinct at about the same time as dinosaurs.

Thus, we can find dinosaurs almost everywhere, however we do not find the same species of dinosaurs everywhere. We must look for dinosaur fossils in the places where they lived and in the sedimentary rocks formed at the same time as they were alive, i.e. during the Mesozoic Era, between 65 and 251 million years ago.

Even if the fortuitous discovery of the iguanodons at Bernissart more than 300m below the surface shows that we can be lucky, it is usually easier to excavate Triassic or Cretaceous sedimentary rocks in places where they have been brought to the surface by tectonic shifts or erosion. Since the dawn of time, the Earth has undergone periodic climate variations and has experienced regional differences in climate. In the same way, there were hot areas and very cold areas when the dinosaurs were alive, and they adapted to these different habitats.

For example, we know that, during the Cretaceous Period, several types of dinosaur lived North of the Arctic Circle where the climate was warmer than it is today. Among fossils discovered there are the Troodon theropod, a small carnivore which was probably related to Velociraptor, the hadrosaur Edmontosaurus and the ceratopsian Pachyrhinosaurus. Their fossilised remains have been found from Alaska to Alberta and the Yukon in Canada, which suggests that they migrated from the North to the South at the start of the Polar winter. Troodon’s large eye sockets may indicate that it had adapted to the long Polar nights. Troodon also shared several characteristics with birds (hollow bones, large brain, feathers). Around 20 complete fossilised skeletons and a fossilised egg containing an embryo have been discovered so far.

Fossils have also been discovered in the Antarctic, which was only moderately cold in the Early Jurassic Period. Crylophosaurus was found close to the South Pole together with the remains of other animals, including a plateosaur (early dinosaur) and a tritylodont (distant ancestor of mammals). Crylophosaurus was a theropod that lived in the Jurassic Period, characterised by a forward-pointing crest on its head. Its name means “cold crested lizard”.

Still in the Jurassic Period, Australia was attached to Antarctica and was home to many dinosaurs whose fossils have been unearthed, including Leaellynasaura, a small herbivorous ornithopod, one of the most important discoveries made at the world-famous Dinosaur Cove in the state of Victoria, in the South of Australia. It was a contemporary of Muttaburrasaurus, an Australian relative of our iguanodons.

In the Triassic Period, Africa was located between Australia and South America, and it is very rich in Mesozoic fossils, including more than 40 different species of dinosaur, half of which were prosauropods and sauropods. Nine of these species have also been found in America and Europe.
The animals in South America and Africa were relatively similar until the Mid-Cretaceous Period, when the continents began to separate. The largest dinosaur discovery sites are the Argana formation in the North, the Lower Elliot in the South and the Tendaguru formation on the Tanzanian coast.

In 1886, a few years after the discovery of the iguanodons at Bernissart, remains of some dinosaurs from the Cretaceous Era were discovered in South America. Later, dinosaurs from the Late Triassic and Jurassic Periods were also found. However, scientific descriptions of these finds only really began after 1965 in Argentina. 36 of the 44 different dinosaur species discovered in South America were found in Argentina, but skeletons were also donated from Brazil, Chile, Colombia, Peru and Bolivia, the large majority of which are still awaiting scientific study and examination.

The dinosaurs of North America are without doubt the best-known in the world. Most of them date from the Late Triassic, Late Jurassic and Cretaceous Periods. The first dinosaur ever discovered was a hadrosaur found by Leidy in 1858. The eminent pioneers of dinosaur study, March and Cope, worked at the end of the nineteenth century. Since then, more than 100 North American species have been described. Among the interesting sites, we should mention the Morrison formation (from the Late Jurassic Period) where Diplodocus, Othnielia and Allosaurus were found, among others and the Hall Creek formation in Alberta in Canada (Late Cretaceous Period) where Triceratops and Tyrannosaurus were found.

Since the first dinosaurs were discovered in England, many other major finds have been made in many European countries. Compared to the rest of the world, the number of fossils found in all sorts of Mesozoic sediments is remarkable. Whereas the animals of the Triassic and Jurassic Periods are very similar to those on other continents, in particular North America and Africa, the animals of the Cretaceous Period are more specific to Europe. It was at this time that the continents began to assume their current positions. More than 75 species of dinosaur have been discovered in Europe. The most important discovery in Europe remains the iguanodons at Bernissart. Other famous discoveries were made at Solnhofen and Keuper in Germany and in the clay at Oxford and the Wealden group in Southern England. The Wealden group clay crosses the English Channel to Continental Europe, for example the clay sediment at Bernissart is part of it.

Among the dinosaurs discovered in Asia, those of the Late Cretaceous Period are of the greatest scientific value. As new scientific descriptions have been made, we have realised that we had greatly underestimated the diversity of the groups of dinosaurs of the Late Cretaceous Period. This contradicts the theory of the gradual extinction of dinosaurs and supports the theory of a brutal, sudden extinction, for example, following a meteorite strike. Our palaeontologists have being conducting major research projects in Asia and their discoveries have confirmed this second hypothesis.

4. How did dinosaurs communicate?

In-depth research on a large number of fossils has allowed palaeontologists to devise a number of hypotheses about this delicate subject. As in more recent animals, some parts of dinosaurs’ bodies could be used as much for communication as for defence. The study of dinosaur communication must mostly be based on this observation.

The crest of Parasaurolophus

For many years, palaeontologists had been asking themselves what the strange crests on the heads of lambeosaurs (dinosaurs with crests and duck-like bills) were used for. It was first suggested that the crest of Parasaurolophus was a defensive weapon. Later, when it was discovered that the crest was hollow, scientists thought that it was a sort of breathing tube that allowed Parasaurolophus to remain submerged underwater for long periods. They also thought that the crest was used to display sexual identity.

Later researchers decided to reconstruct a Parasaurolophus crest from synthetic materials, and this enabled them to solve the riddle. A complete skull found in New Mexico was put through a CT scanner which created a three-dimensional image, which showed that the structure of the crest was much more complex than had been thought: it looked like a trombone and was probably used to amplify sounds and to enable the dinosaur to hear sounds from a long distance away. Some scientists think that the sounds made by Parasaurolophus were so varied that they differed slightly from one individual animal to another. They also think that the sounds could be adapted to specific circumstances and that they could vary from a deep rumble to a high-pitched cooing. Such sophisticated communication techniques could be evidence of complex social structures in groups of dinosaurs.
The collar of Centrosaurus  
Centrosaurus, a Ceratopsian, was a relative of the famous “three-horned” dinosaur Triceratops. It was herbivorous, of medium size and lived in the Late Cretaceous Period. It had a large protuberance on its nose, and smaller spines above and below each eye socket. Like Triceratops and Styracosaurus its neck was covered with a spectacular collar, with two openings that considerably reduced its weight, while maintaining its protective function. The collar was covered in skin which could change colour through the influx of blood (like the plates on the back of Stegosaurus. Scientists think that this colour change could be used to impress a female or frighten a predator. The horns could also have been used to scare away assailants or to impress other males in its herd, in the same way as modern stags and elks. The strongest males with the largest horns were certainly the most popular among the females. As many Centrosaurus skeletons have been found in groups in different excavations, we can imagine that they were gregarious animals.

The helmet of Pachycephalosaurus  
Pachycephalosaurus looked rather odd and its name means “thick-headed lizard” (from the Greek pachy meaning “thick”, cephalos meaning “head” and saurus meaning “lizard”). Its relatively small brain was protected by an enormously thick skull, between 20cm and 25cm thick. It is the largest known member of the Pachycephalosaurs, a group of dinosaurs related to the Ceratopsians. Originally, scientists thought that the males fought for females by banging heads, like modern rams, but subsequent research showed that the skulls would not have been able to resist such shocks and ricochets. More realistically, the heads could have been used to butt the sides of rivals.

5. The Mesozoic or Secondary Era

Dinosaurs appeared, rose to their greatest height and became extinct during the Secondary Era between 65 million and 250 million years ago. Their reign thus lasted 160 million years. During this long period, the plants and animals on Earth, in the sea and in the air never stopped evolving.

The Triassic Period (203-250 million years ago)  
During this Period, all of the continents were united in a single bloc called Pangaea, surrounded by a single ocean, the Panthalassic Ocean. The climate was warm and humid. Sea levels were higher than today and the poles were not covered in ice. Plants and animals were most abundant along the coasts. Underwater, ammonites and marine reptiles began to diversify. On dry land, the ancestors of mammals known as synapsids (because they only had one temporal cavity) were generally dominant, but would gradually be replaced by more developed vertebrates. At the end of the Triassic Period, the group of dominant animals expanded to include turtles, crocodiles, pterosaurs (flying reptiles) and mammals…and the first dinosaurs made their appearance.

The Jurassic Period (135-203 million years ago)  
During this Period, Pangaea slowly separated into Gondwana to the South and Laurasia to the North. The climate was hot and much of the surface of the earth was covered by shallow seas, inhabited by bivalve molluscs, ammonites, fish and large marine reptiles such as plesiosaurs and ichthyosaurs. On dry land, the dinosaurs were dominant. Jurassic mammals were small and birds did not appear until the end of the Jurassic Period. Plants already included horsetails, ferns, cycads (primitive gymnosperms that look like palms), gingkos and primitive conifers.

The Cretaceous Period (65-135 million years ago)  
During this Period, the continents shifted slowly towards their current positions, with the creation of the Atlantic Ocean by the separation of South America from Africa. India and Australia moved slowly towards Asia. The climate was cooler than in the Jurassic Period. Flowering plants invaded all the continents. Molluscs and echinoderms (sea urchins and starfish) became particularly diverse. The Cretaceous Period ended with the sudden extinction of ammonites, large marine reptiles, pterosaurs and dinosaurs.
6. The large-scale extinctions

Geological archives reveal long periods of relative calm, punctuated by short periods of profound change in life on Earth. Large-scale extinctions were followed by a huge diversification of the surviving groups.

Research into fossils and their dating has produced evidence of five to seven large-scale extinctions, of which two have been studied in particular detail (see figure in section 5.35).

The Permian extinction (250 million years ago)
It swept away more than 90% of marine animals and at least 66% of terrestrial animals. A third of the orders of insects present in the Permian Period had disappeared by the Triassic Period. The extinction took place in less than 5 million years. During this period, the formation of Pangaea disturbed many marine and terrestrial habitats and changed the climate. Huge volcanic eruptions occurred in what is now Siberia. The lava, ash and carbon dioxide produced in huge quantities by these eruptions probably caused a warming of the planet’s climate which in turn caused extinctions on a massive scale.

The extinction of the dinosaurs (65 million years ago)
Dinosaurs abruptly disappeared at the end of the Cretaceous Period. What do we mean by “abruptly”? Was it an unavoidable process or an accident?

Different theories oppose each other
The “gradualists” believe that the development of diversity among the dinosaurs reached its height in the second half of their reign, and reduced sharply during their last million years.

Some extinctions, such as that of the icthyosaurs, happened well before then. It is possible that the decline of the dinosaurs and many other groups began in the Late Cretaceous Period and that one or more catastrophes finally finished them off.

No single theory postulated by scientists completely explains this massive extinction. However, three of the theories appear to be the most probable: a massive shrinkage of the oceans, a meteorite strike or a series of volcanic eruptions.

Following the gradualist model, dinosaurs became extinct as a result of changes in the climate spread over a relatively long period. Geological observations have proved that, at the end of the Cretaceous Period, sea levels fell and some 29 million square kilometres (roughly the size of Africa) formerly covered by the sea became dry land. The coastal plains where the dinosaurs lived became rare, and they were forced into more and more restricted areas. The sub-tropical climate became more temperate and continental, with distinct seasons, variations in temperature and new forms of plants, whose development was encouraged by the decline of the dinosaurs.

The theory of the “catastrophists” also has weight. The Deccan plateau in India shows extraordinarily thick layers of volcanic lava (2km thick) spread over some 500,000 square kilometres. This lava bears witness to intense volcanic activity spread over several thousand years and it has been dated as being 65 million years old. The volcanic eruptions that produced it would have been followed by huge releases of carbon dioxide and volcanic ash into the atmosphere, which would have had a lasting effect on the climate. The volcanic ash in the atmosphere would have prevented sunlight reaching the Earth’s surface and would have made it dark and cold there. This would have prevented plants from photosynthesising and they would have died. The huge quantities of sulphur dioxide released by the volcanos would have fallen to Earth in intense storms of acid rain, also killing plants and all the herbivorous animals that ate them, including the dinosaurs. So the “terrible lizards” may simply have starved to death.

Another suggested cause of similar effects is the interesting theory of a gigantic meteorite (10km in diameter) striking the Earth. Such a collision would have released a huge amount of energy which would have reduced the meteorite to small pieces and would have destroyed a large area of coastline on Earth. The debris thrown up into the atmosphere by the meteorite would have blotted out the sunlight and would have plunged the surface of the Earth into darkness and cold for several months or even years. The food chains directly dependent on photosynthesis would have been the most seriously affected. Food chains which depended on decomposing organic matter, on the sea beds, in freshwater rivers and terrestrial humus would have survived until conditions returned to normal. Without sunlight, all plants would have died out. However, after a while, seeds, spores and roots would have sprouted new plants, but this would have been too late for the herbivorous dinosaurs. These huge consumers of vegetation would have been the first to disappear, followed by the carnivorous dinosaurs which fed on them.

In support of this theory, geologists have found a thin layer of sediment with high levels of iridium in many areas around the world. Iridium is a rare metal which is usually formed by a frequent series of small meteorite strikes on the Earth’s surface.
This sediment layer has been dated to the end of the Cretaceous Period and would appear to be made up of ashes that fell to Earth after a giant meteorite strike. It also contains grains of quartz, also typical of meteorite strikes. Finally, it seems that the meteorite crater has been identified: a circle 180m to 310m in diameter on the tip of the Yucatan peninsula in Mexico, created 64.9 million years ago.

The dinosaurs were not the only species to have become extinct! More than 60% of the animals and plants living on dry land and in the seas at the end of the Cretaceous Period became extinct at the same time as the dinosaurs. They included most of the ammonites, crinoids (pedonculous echinoderms) and mosasaurs (marine reptiles related to monitor lizards). More than 75% of the single-cell plankton and seaweeds as well as many types of pollen also became extinct, as did the animals that fed on them.

The survivors and descendants of the dinosaurs
Among the survivors were most of the freshwater vertebrates (fish, amphibians, turtles and crocodiles), small terrestrial reptiles and small insect-eating or grain-eating mammals. These mammals were to quickly fill the ecological niches left empty by the extinction of the dinosaurs and became the successful zoological group we know today.

Did dinosaurs really become extinct? We know today that, over time, some species of carnivores, small theropods, evolved into birds.
The Dinosaurs of the River Armor

Since 2001, the Royal Belgian Museum of the Natural Sciences (RBMNS) has been taking part in palaeontological excavations around the River Armor in South-East Russia, hoping to find the fossilised remains of dinosaurs from the Late Cretaceous Period. They have unearthed the remains of some unusual animals, which shed more light on the extinction of dinosaurs 65 million years ago.

Dinosaurs are emblematic of the Secondary Era. They reigned over all the other terrestrial ecosystems for more than 160 million years. The reason for their relatively sudden disappearance 65 million years ago is one of palaeontology’s great mysteries, and has given rise to several hundred articles in scientific journals. Countless theories, some more far-fetched than others, have attempted to explain the extinction of these legendary animals. To date, all of the scenarios suggested to explain the extinction of the dinosaurs were solely based on the dinosaur fossils discovered to the West of the Rocky Mountains in North America. Since the end of the nineteenth century, the fossilised remains of a succession of vertebrate terrestrial animals have been discovered in this region, most of which have been dated to the Late Cretaceous Period, the last Period in the Secondary Era. Palaeontologists have thus been able to trace in some detail the final period of the dinosaurs’ life in this region. However, it would be very unadvisable to extrapolate to the whole planet things observed in a very specific geographical area, for if the remains of a group of animals are not found in one region, this does not mean they had disappeared from the surface of the planet. It is thus of primordial importance to study other types of animals, not just dinosaurs, and in other parts of the world, to gain a less biased view of their biodiversity at the end of the Cretaceous Period. Sites where terrestrial vertebrates from that Period have been found are unfortunately very rare and usually they have yielded few fossils. Fortunately, in the last 20 years, more and more fossilised dinosaur remains have been discovered in the region around the River Armor, which forms the border between China and Russia. The fossils found there have only recently been examined scientifically, following excavations made by palaeontologists from the RBMNS and the KNII Armor Palaeontology Museum at Blagoveschensk in Russia.

First Discoveries

For more than a century, scientists have been aware of the presence of fossilised dinosaur bones in the Cretaceous Period layers around the River Armor. Some of the first fossilised dinosaur remains found in Asia were found there. However, the full scientific potential of these layers has never been realised. In 1902, Colonel Manakin, a Russian army officer, gathered together some fossilised bones on the Chinese bank of the River Armor. Reports of this travelled all the way across the vast Russian empire to scientists at the Russian Geological Committee in St Petersburg. Between 1914 and 1917, this committee organised several expeditions to the region and even undertook some excavations along the river, near the modern Chinese town of Jiayin. The fossilised dinosaur bones discovered during these excavations were transported back to St Petersburg in 1917 to be prepared and examined. Based on them, the palaeontologist A. Riabinin was able to reconstruct a complete skeleton of a new type of hadrosaur (duck-billed dinosaur) which he named Mandschurosaurus amurensis.

In addition, the fossilised bones discovered did not really have any distinguishing characteristics and had been extensively restored using plaster of Paris, so that it is now impossible to tell which were original pieces of fossilised bone and which were pieces of plaster sculpted by the conservators. Palaeontologists thus rapidly lost interest in Mandschurosaurus and the fossil sites at Jiayin. From 1917 onwards, several local Chinese museums continued the excavations at Jiayin in an ad hoc manner and far from the eyes of the international scientific community.

In 1995, the RBMNS and its Chinese partners began an huge programme of palaeontological excavations in Inner Mongolia in Norther China. They were funded by the Belgian Federal Scientific Policy Institute, with the principal...
objective of shedding light on the phylogenetic relationship between the group of iguanodons unearthed at Bernissart and the hadrosaurs. The first stage was thus to re-examine the Chinese hadrosaurs. In 1999, a more systematic examination of the impressive collections of fossilised dinosaur bones unearthed at Jiayin and stored in the local provincial museums of Jilin and Heilongjiang, was undertaken. As a result, it became clear that more than 90% of the fossilised bones unearthed at Jiayin belonged to a new type of hadrosaur, baptised Charonosaurus jiayinensis.

Strange ducks

During the second half of the Cretaceous Period, hadrosaurs were among the most diverse and abundant herbivorous dinosaurs. Their fossilised remains are particularly well-known in North America, where many complete skeletons have been unearthed, but they have also been found on every other continent, including Antarctica. Hadrosaurs were large dinosaurs that could grow to up to 12m long. They used their powerful hind legs for running, but could also walk more slowly on all fours. They had large, flat jawbones, which gave them their name, which means 'duck-billed dinosaurs'. Their complex teeth were arranged in several rows on each jawbone. Thus when a tooth wore out, it could be rapidly replaced by another from the next generation. This allowed hadrosaurs to eat very tough vegetation. Palaeontologists have divided hadrosaurs into two groups: the hadrosaurines and the lambeosaurines. They think that the hadrosaurines could inflate a membrane in their nostrils to form a resonating chamber when they uttered sounds. Lambeosaurines are characterised by a hollow crest running along the tops of their heads. Their nasal cavity formed a tortuous maze inside the crest, which could be used just like a trombone. As the different species of lambeosaurines had differently shaped crests, they must have been able to make very specific noises.

Charonosaurus, discovered at Jiayin, belonged to the lambeosaurines. Although we don't know exactly the shape of its crest, which was too fragile to resist the ravages of time, a detailed analysis of its skull suggests an elongated tubular shape. It probably looked very like the famous Parasaurolophus, a close relative from North America. Charonosaurus and Parasaurolophus had differently shaped pelvises. The fossil bed at Jiayin is today considered a national palaeontological treasure by the Chinese authorities. it is now a protected site and it is unlikely that any further excavations will be authorised there.

Crossing the River Armor

Many fossilised dinosaur remains have also been found on the other side of the River Armor, in Russia. They were first described by the famous Muscovite palaeontologist A. Rozdestvensky in 1957. He famously described several fossilised bones discovered near the town of Blagoveschensk, the capital of the Armor region. Unfortunately, he made mistakes in his interpretation of the geological context of the fossils. He thought that they had been transported and mixed with much more recent sedimentary layers. This mistake about their geological context resulted in the loss of most of their scientific interest. Rozdestvensky had perhaps been in a hurry to get back to Moscow because the weather during his stay in Blagoveschensk was reportedly hellish. This is not to mention the obstinacy and persistent hard work of Yuri Bolotsky, a palaeontologist attached to the KNII Armor Museum, the Far-Eastern branch of the Russian Academy of Sciences, who had led the systematic excavations at Blagoveschensk between 1984 and 1991.

He excavated several hundred fossilised hadrosaur bones there, but didn't have time to study them in depth immediately. In 1991, Bolotsky and his team discovered another dinosaur fossil bed at Kundur, 350km South-West of Blagoveschensk and around 50km North-East of Jiayin. The region’s economic collapse following the disintegration of the USSR meant that Yuri Bolotsky had to abandon his excavations and spend several years working in the region's more lucrative goldmines. He returned to the excavations in 1999, after having made contact with palaeontologists at the RBMNS and inviting them to collaborate with his team in the study of the dinosaur remains unearthed in the region.

Just like the one at Jiayin, the Blagoveschensk fossil bed yielded mostly fossilised lambeosaurine bones. However, no Charonosaurus bones were found at Blagoveschensk, where the most common fossilised bones were from Amurosaurus riabinini. The main differences between these two lambeosaurines were in the morphology of the
top of the skull, where the configuration of bones suggests that the crest of the Amurosaurus was relatively short and tall, a little like a Corinthian helmet. Detailed study of the skull also revealed that Amurosaurus was a relatively primitive lambeosaurine. However, as we will see below, the extent of evolution and the age are two separate pieces of data. An exhaustive inventory of all the fossilised bones discovered at Blagoveschensk by Yuri Bolotsky’s team revealed another surprise: Amurosaurus was not the only hadrosaur present there at the end of the Cretaceous Period. Around ten fossils, all parts of skulls, were attributed to a new hadrosaurine with a flat head, baptised Kerberosaurus manakini. Kerbosaurus was a close relative of Saurolophus found in slightly older fossil beds in both the USA and Mongolia, which did not have the solid elongated crest of Saurolophus. The fossil bed at Blagoveschensk, like the one at Jiayin, did not contain any complete skeletons, but rather an accumulation of mixed fossilised bones belonging to several different specimens. How did the fossilised bones come to be so mixed up? Sedimentological examinations of the fossil bed showed that, at the end of the Cretaceous Period, Blagoveschensk was on the river’s flood plain. During floods, the river’s water washed the carcasses of dead animals onto the river banks. Fragments of the skeletons accumulated in places where the river meandered and the current was weaker. Another interesting fact is that most of the fossilised bones found at Blagoveschensk were from young animals, no doubt because they were easier prey for the carnivorous dinosaurs which hunted near the river.

A dinosaur cemetery

The Belgo-Russian team concentrated its efforts on the new fossil bed at Kundur. In 2001, a large-scale excavation took place, funded by a grant from the famous National Geographic Society in the USA. A splendid hadrosaur skeleton was unearthed: the most complete dinosaur skeleton ever found in Russia, and its crest was almost complete. It was the best-preserved lambeosaurine ever found outside North America. It was a specimen of a new species, baptised Olorotitan arharensis (meaning “giant swan from the Ahara region”). From the tip of its nose to the end of its tail it measured 8m. Its hind legs were particularly long and powerful. Its most remarkable characteristic was without doubt the hollow crest running along the top of its skull. Its neck was elongated and very flexible and it had 18 cervical vertebrae, whereas most other hadrosaurs had 15 at most.

The excavations at Kundur continued in 2003 and 2004, financed by the Belgian Federal Scientific Policy Institute. A second layer of fossilised bones was found, which contained mainly hadrosaurine remains. The last stage of the excavation was particularly fruitful: it included the discovery of the skeleton of a new species of flat-headed hadrosaurine which is still being studied by palaeontologists. But it was not only the remains of hadrosaurs that were found at Kundur: the fossil bed also contained many fossilised bones from armoured dinosaurs (ankylosaurs), carnivorous dinosaurs (theropods), crocodiles and freshwater turtles. The systematic sieving of the sediment revealed a tooth from a multi-tubercular mammal, a small nocturnal animal resembling a modern rodent. Although it is not related to modern rodents, it had developed constantly-growing incisor teeth and molars adapted to crush hard vegetation and seeds. The Kundur multi-tubercular mammal belonged to a family usually found in North America, and was the first to be found in Asia. Further analysis of the sediment revealed that the fossilised carcasses and bones found at Kundur had been brought there in a series of mudslides from the foot of the nearby mountains. This indicates that the climate was sub-tropical with periods of frequent heavy rainfall. Around the fossil bed, several layers of fossilised plants were found, which enabled scientists to gain a pretty clear idea of the evolution of plants in the Kundur region at the end of the Cretaceous Period. At that time there was a fairly sudden decrease in the diversity of angiosperm pollens (from flowering plants) before the development of current families.

The last dinosaurs in Asia

The palaeontologists also found, during a microscopic analysis of the sediments from Kundur, Jiayin and Blagoveschensk, many grains of pollen and spores. Given their extraordinary ability to disperse themselves, they are an excellent tool for geologists to calculate the relative ages of the different fossil beds.

The three dinosaur sites in the River Armor region are characterised by very similar groups of pollens. They can thus be considered to be contemporaneous on a geological timescale. Similar groups of pollens were also recorded at a site on the other side of the Bering Strait in the West of North America. In fact, such groups of pollens are characteristic of the most recent dinosaur fossil beds in North America. Kundur, Blagoveschensk and Jiayin can thus be considered to be contemporaneous on a geological timescale. Similar groups of pollens were also recorded at a site on the other side of the Bering Strait in the West of North America. In fact, such groups of pollens are characteristic of the most recent dinosaur fossil beds in North America. Kundur, Blagoveschensk and Jiayin can thus be considered the most recent dinosaur sites in Asia, dating from immediately before the great extinction of the dinosaurs 65 million years ago.

It is thus interesting to compare the composition of the last dinosaurs in Asia and North America. We have seen how the terrestrial vertebrates of the River Armor region were largely dominated by hadrosaurs, in particular those with hollow crests (lambeosaurines), and no fossilised remains of horned dinosaurs (ceratopsians) were found. By contrast, in North America, the last dinosaurs were overwhelmingly ceratopsians, including the famous Triceratops of which many complete skeletons and skulls have been found, which date from the same period.
It appears that the lambeosaurines had completely disappeared from North America a few million years before the great catastrophe that led to the extinction of the dinosaurs. So we find, on either side of the Bering Strait, two completely different, yet contemporary, groups of animals. This means that either these two regions must have been geographically separate by the end of the Cretaceous Period, or their environments must have been radically different, which, in light of the available evidence, seems unlikely. In any case, the study of the fossilised remains discovered in the River Armor region shows clearly that the biodiversity of dinosaurs in the period before they became extinct, was greater than we had been led to believe, based solely on the fossilised remains found in North America. The new evidence supports the theory of a sudden, catastrophic extinction of the dinosaurs. Such a biological crisis in the Earth's history can only have been caused by external physical factors. Despite all their astonishing changes in 160 million years of flourishing evolution, the dinosaurs did not survive this unexpected event. Only one group of dinosaurs managed to survive: birds, whose biodiversity today remains remarkable.

(caption) Part of the harvest of fossilised bones from 2003. The bones are covered in plaster of Paris to protect them during their transport to the laboratory Photo © Th. Hubin/IRSNB.

(pullquote) The currently most widely believed hypothesis to explain the major crisis that marked the end of the Secondary Era is a giant meteorite strike just off modern Mexico which severely damaged the Earth's surface and plunged the planet into a prolonged nuclear winter.

Polar dinosaurs?

The dinosaur fossil beds of the River Armor region are far from having revealed all their secrets. In June and July 2005, the Belgo-Russian team conducted new excavations in the Blagoveschensk fossil bed which had been abandoned 15 years earlier. For this project, the RBMNS invited some people with a passion for dinosaurs who wanted to put into practice excavation and scientific research techniques to join the professional palaeontologists for a unique experience. Their participation was part of the Europalia-Russia programme.

The palaeontologists have also dreamed for years of being allowed to excavate the Kakanaut fossil bed in North-Eastern Russia. It is located in a particularly inhospitable region, several hundred kilometres from the nearest town, and was discovered in the early 1990s by Lev Nessov, a famous palaeontologist from St Petersburg. During his short visit to Kakanaut, he unearthed some fossilised dinosaur bones, mostly hadrosaurs and theropods. Preliminary analysis of the fossilised pollen grains and plants found with the dinosaur bones showed that this fossil bed was contemporaneous with the ones at Kundur, Blagovesdensk and Jiayin. After Nessov's tragically early death, the Kakanaut fossils disappeared and nobody else was authorised to visit the site. At the end of the Cretaceous Period, Kakanaut was in the polar region. It would thus be a unique opportunity to find out how dinosaurs adapted to an extreme climate. Even if the average temperatures there were not as low as they are now, the dinosaurs would have had to live for most of the year in darkness, with very little food available for creatures of their large size. How did they survive? Did they migrate to regions with a warmer climate during the winter? Could they hibernate? And, if some dinosaurs had adapted by the end of the Cretaceous Period to life in a cold, dark climate, why did they become extinct following the nuclear winter caused by the giant meteorite strike? These are some of the questions to which a study of the Kakanaut fossil bed could provide answers.