10
The rule of the reptiles

THE REIGN OF THE ARCHOSAURS

In the Triassic, change came: the archosaurs or ruling reptiles appeared, and many of the mammal-like beasts became extinct. Perhaps today's most familiar large carnivorous reptile is the crocodile. One of the diversions of geological field work in Africa is to sit hidden on a river bank, very still, and watch for what are locally called 'flat dogs' or, in deference to Western consumer tastes, 'handbags'. The signs are obvious – little mounds of fish teeth, 'croc drops' – but the animal is not obvious. At first, all that can be seen is the spouting and humping of hippos, but eventually two nostrils appear, if the scene is peaceful,

Figure 10.1 The Mesozoic landscape, from the pterosaur's point of view. Some pterosaurs were huge, ranging up to 12 m (40 ft) wingspan (painting by Vladimir Krb, Royal Tyrrell Museum of Palaeontology/Alberta Culture and Multicultualism, Canada).

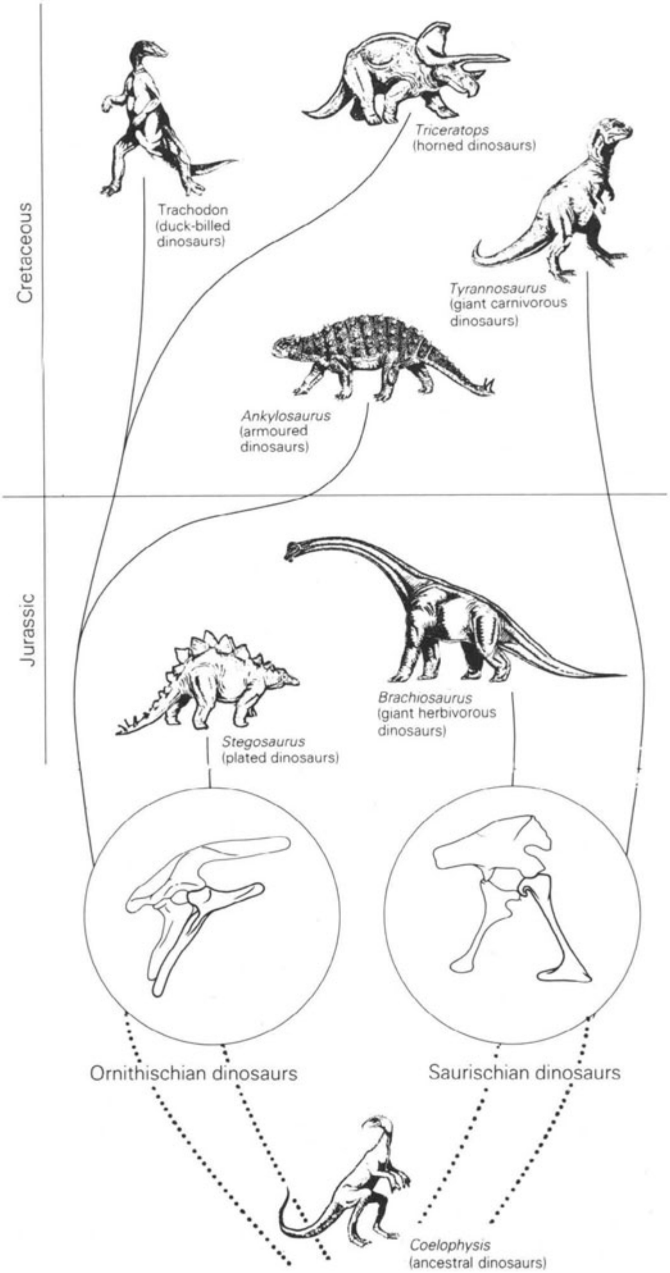

Figure 10.2 The two types of dinosaurs: bird-hipped (Ornithischian) and lizard-hipped (Saurischian) types may have evolved from a distant parent reptile, although the closeness of their relationship remains controversial. Birds, ironically, are likely to have come from the Saurischian line (courtesy of Department of Geology, University of Saskatchewan).

and then slowly the eyes and head of a wary reptile float across the pool. Crocodiles are cunning and superb at concealment; they are also marvellous parents, carefully taking up their young in their mouths to move them (from which action comes an old, false, accusation that they are cannibal). Somehow the crocodiles have survived: other reptiles went on to greater things, and perished.

The best known of the ruling reptiles of the Triassic are the dinosaurs. Dinosaur fossils were discovered in the 1820s, and named by Sir Richard Owen. The name comes from the Greek for terrible (dino-) lizard (-saur). The oldest dinosaur fossils are from the end of the Middle Triassic in South America. Unfortunately, the late Triassic fossil record of dinosaurs is very poor. There were two main orders of dinosaurs – the bird-hipped Ornithischia and the reptile-hipped Saurischia. The ornithischians were herbivores; the saurischians included carnivores and herbivores. There is much controversy about the exact relationship between the two groups of dinosaurs. The saurischians can be divided into two-footed carnivores, and four-footed herbivores, but it is not clear how closely related these two groupings were. The ornithischians share a common ancestor, which may have been a primitive saurischian.

THE SAURISCHIA

Saurischia became common early in the histo y of the dinosaurs, and dominated the land ever after, until they suddenly d ed. They began as bipedal (two-footed) flesh-eaters. In the Jurassic, a typic l example was *Allosaurus*, 9 m (thirty feet) long, with a massive skull, powerful teeth, and powerful claws. One of the first dinosaurs to be discovered was *Megalosaurus*, a fierce Jurassic flesh-eating creative whose remains were collected by the geologist William Buckland and named by James Parkinson (who also described the disease named after him). A Lower Cretaceous example of a saurischian is *Deinonychus*, found in Montana. This animal was lightly built, about 3 m (10 ft) long, weighing about as much as a large man. It could probably run very fast, and was equipped with ferocious curved claws, to disembowel its prey.

Perhaps the most fearful dinosaur of all was one of the last, the late Cretaceous *Tyrannosaurus rex*, whose name means 'the king of the tyrant lizards'. *Tyrannosaurus rex* was nearly 6 m (20 ft) tall, with a skull up to a metre and a half (5 ft) long, massive hind legs and a beautifully balanced tail. It weighed seven tons. Viewed in a properly mounted skeleton, it is a finely designed beast, agile and taut, well able to dominate the world. It is often seen as a symbol of a terrible age, though we forget that both physically and in intelligence the sperm whale is a more powerful predator than *Tyrannosaurus rex*, and the sperm whale is itself hunted.

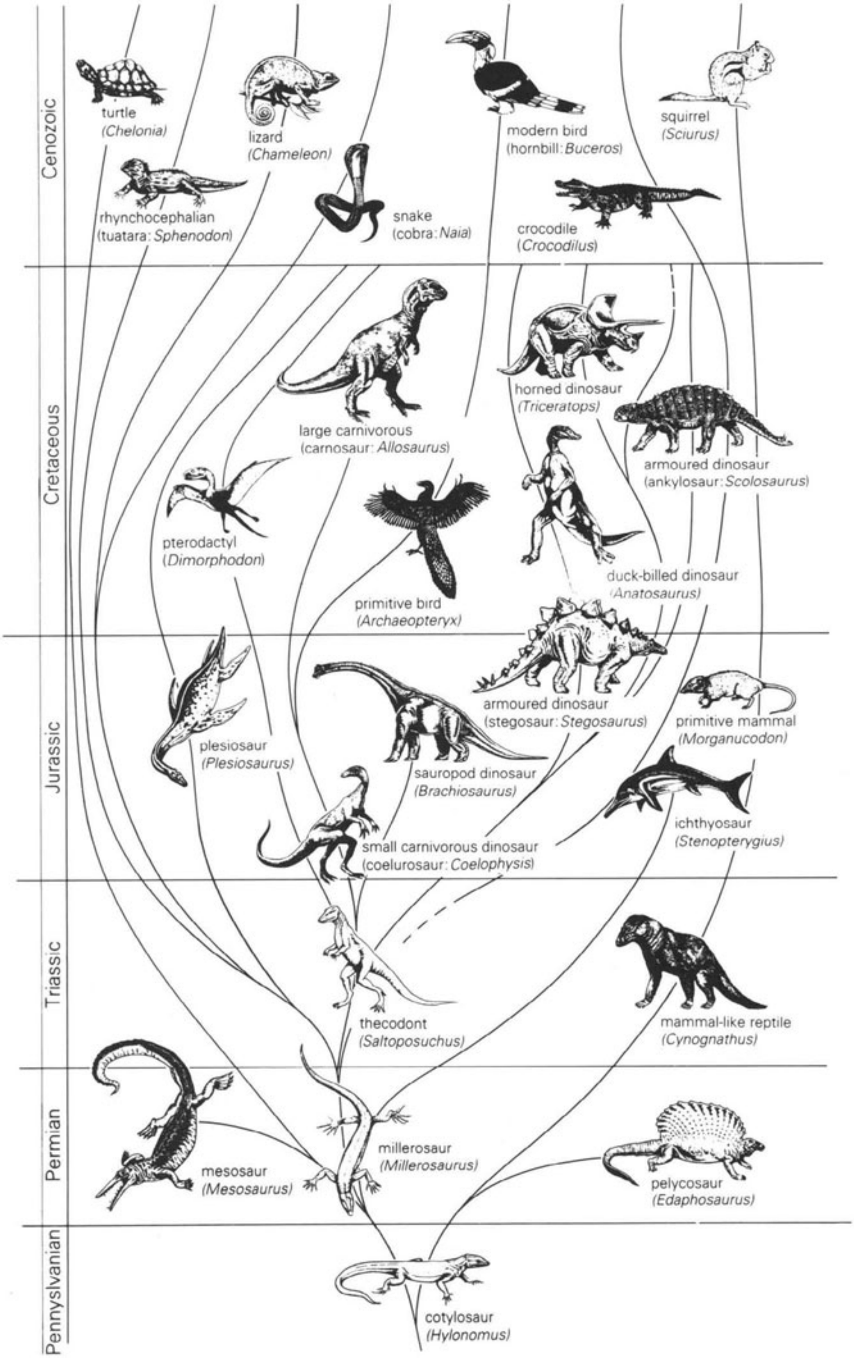

Figure 10.3 The evolution of the reptiles (courtesy of Department of Geology, University of Saskatchewan).

Another group of saurischians produced plant-eating herbivores – *Diplodocus*, *Apatosaurus* (*Brontosaurus*) and *Brachiosaurus*. Some of these may have been like modern giraffes, strolling along cropping the tops of trees, while their less lofty relatives browsed the lower strata of vegetation. These herbivores were mostly large, 10 m (30 ft) long, or more, but some carnivorous dinosaurs were small, even rabbit size.

THE ORNITHISCHIA

The ornithischians, in contrast, were all herbivores. The first to be found as a fossil was the celebrated *Iguanodon*, supposedly discovered in some road stones by Mary Ann Mantell during a walk on a beautiful English spring day. The discovery caused a sensation, as the savants (especially Sir Richard Owen) tried to reconstruct the animal. For human society, the dinosaurs had arrived.

Many ornithischians developed armour. An early example is *Stegosaurus*, from the Upper Jurassic of North America. *Stegosaurus* had a small head and little brain, but was protected by vicious spikes at the end of its long swinging tail and a double row of armour plates along its backbone that would have served as good protection, as well as being well suited to radiating excess heat. The most powerfully armoured dinosaurs, however, were the ankylosaurs, which may have evolved in Europe and then spread to North America and Asia, where they were common in the Late Cretaceous. Ankylosaurs had heavy limbs and were four-footed, to support a trunk that was entirely covered

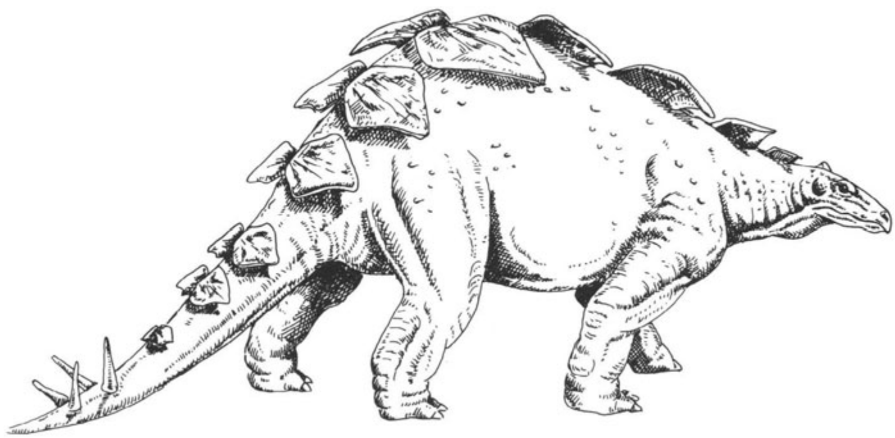

Figure 10.4 *Stegosaurus*, an Upper Jurassic herbivore. This animal had two rows of plates along the neck and back, and spikes on its tail, which would have been a powerful defensive weapon, swinging into any attacker. In most reconstructions the plates are shown upright; they may also have sometimes lain flat as shown here. Length up to 9 m (30 ft) (courtesy of Department of Geology, University of Saskatchewan).

by small interlocking bony plates. The animals looked rather like giant armadillos, a tough lunch for a tyrannosaur.

Another large group of ornithischian dinosaurs was the hadrosaurs, or 'duck-billed' dinosaurs. These were bipedal herbivores, and were especially common in the Upper Cretaceous of North America. They may have migrated across the land in large herds, moving to higher land to nest. The North American Upper Cretaceous also contains abundant fossils of horned dinosaurs, or ceratopsians, such as *Triceratops*. These were quadrupeds,

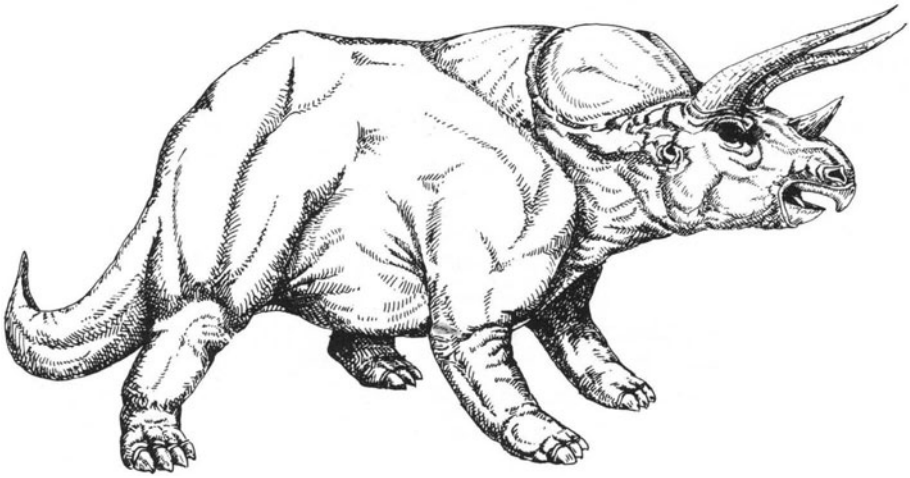

Figure 10.5 *Triceratops*, a late Cretaceous herbivore, about 7 m (24 ft) long (courtesy of Department of Geology, University of Saskatchewan).

browsing on bushes and trees, and were the equivalent in the Cretaceous of a modern black rhino. Their skulls were heavily armoured, with horns to protect the nose and eyes. *Triceratops* may have grazed in herds. When a predator, such as a tyrannosaur, appeared the *Triceratops* herds could have formed defensive circles, just as musk-oxen or buffalo do today, with the armoured heads outwards: a difficult and dangerous prey, even for a tyrannosaur.

THE DOMESTIC ECONOMY OF THE DINOSAURS

Dinosaurs derive their name from the Greek words for terrible lizard. The name evokes an image of a cold-blooded reptile, sluggish at night and in cold weather, active in the warmth of the day, and with a ferociously selfish lifestyle that admitted no domestic society. In contrast, we think of mammals as warm, social creatures.

There is strong controversy about these images. The closest surviving relatives of the dinosaurs, the birds, are warm, fluffy and often social. It is probable that dinosaurs were warm-blooded. One of the most striking characteristics of the dinosaurs is their body size – although small dinosaurs did exist, many were huge. Large animals have a low ratio of surface area to volume, and so lose bodily heat much more slowly than do small animals. An animal with a diameter of a metre (3 ft), living in a subtropical climate, would maintain a nearly-steady body temperature without any special effort, simply because of its size. A large dinosaur would therefore have a steady temperature, even with a reptilian metabolic rate. In contrast, some small mammals have to spend up to 90% of their energy simply in maintaining a constant temperature: being a mammal is very expensive. The disadvantage of using large size to maintain a steady temperature is that the animal is very vulnerable to extremes of temperature that persist for long periods; a cold snap of over a week could be fatal.

Baby dinosaurs, being smaller, would have been less able to maintain a steady temperature. They probably grew rapidly to offset this problem, and may have eaten a diet rather different from adults of the same species. In some species, the adults probably never stopped growing, like modern giant tortoises. Some adult herbivorous dinosaurs seem to have had a social structure, nesting together and tending their young. The weight of the eggs ranged up to 5–7 kg (15–20 lbs). Some may have migrated extensively, following the seasons and the availability of food, just as elephants used to migrate in Africa. By the end of the Mesozoic, many flying animals had evolved, and some of these may also have migrated, exploiting their ease and speed of movement.

FLYING REPTILES – PTEROSAURS AND BIRDS

That pigs may fly is excellent, it has been said; that pigs might fly is intriguing; but that pigs actually will fly is non-newtonian and may make a nasty mess on the pavement. Yet should we and all other animals abandon this Earth to pigs we would, some millions of years hence, see a planet inhabited by flying pigs (as well as pigs in trees, swimming pigs, herds of grazing pigs predated upon by pig-lions and, perhaps, an animal farm of pigs in politics). Evolution, through natural selection, is capable of producing diversity to fill all the available ecological niches: through evolution, many unlikely pigs have taken wings.

Flight has evolved many times. Fish do it, and are a marvellous sight in the tropical ocean at sunset with dolphins chasing behind, leaving a phosphorescent wake. All manner of beetles do it, ants do it, bats do it, people do it. The first land vertebrates to fly were the pterosaurs, which appeared in the late Triassic. They were not dinosaurs. The early pterosaurs were probably fine flyers. Pterosaurs became widespread and varied in the Jurassic, including the

Figure 10.6 *Dimorphodon*, an early Jurassic pterosaur. Wingspan about 1.5 m (5 ft) (courtesy of Department of Geology, University of Saskatchewan).

pterodactyls that, after the horrors of Sir Arthur Conan Doyle's tale '*The lost world*', have so exercised the imagination of Hollywood. Towards the end of the Cretaceous, the pterosaurs became less diverse, with the extinction of many species, but some of those that remained became very large, including *Pteranodon*, with a 7 m (25 ft) wingspan, and *Quetzalcoatlus*, which had a wingspan of 11–12 m (up to 40 ft) and was as heavy as a man. Some of these larger species may have behaved much as albatrosses do today, ranging across the seas. Many were fine flyers, with a rudder forwards on their heads, rather than a tail at the back, as in modern birds. The larger species would have had problems getting airborne, and may have relied on large waves or cliff-edges. They may have been warm-blooded and covered with sleek hair, not Hollywood monsters but warm furry things, possibly white to maintain their heat balance.

Pterosaurs flew for many millions of years before the dinosaurs discovered the advantages of flight. They produced the birds, which seem to have been better adapted to flight than the pterosaurs, because they displaced them. The ancestral stock of the birds is debatable – suggestions even include the crocodile line (no less extraordinary than pigs), but it is most likely that birds came from a dinosaur or a relative of the dinosaurs. Indeed, it can be argued that they *are* dinosaurs: we really harbour dinosaurs in our budgie cages.

The probable link between dinosaurs and birds is in the most precious of all fossils, *Archaeopteryx*, which is the oldest clearly feathered fossil bird known. It lived in the late Jurassic, about 150 million years ago. Of all the missing links, this is the best. It is a mixture of reptile and bird, with feathers and wishbone, and also a long bony tail, teeth and three fingers on its front claws. It is a dinosaur, but it lies on the evolutionary path between its archosaur ancestors and modern birds, which have, over their evolution, (except the young of the modern South American hoatzin bird) lost their teeth and front claws.

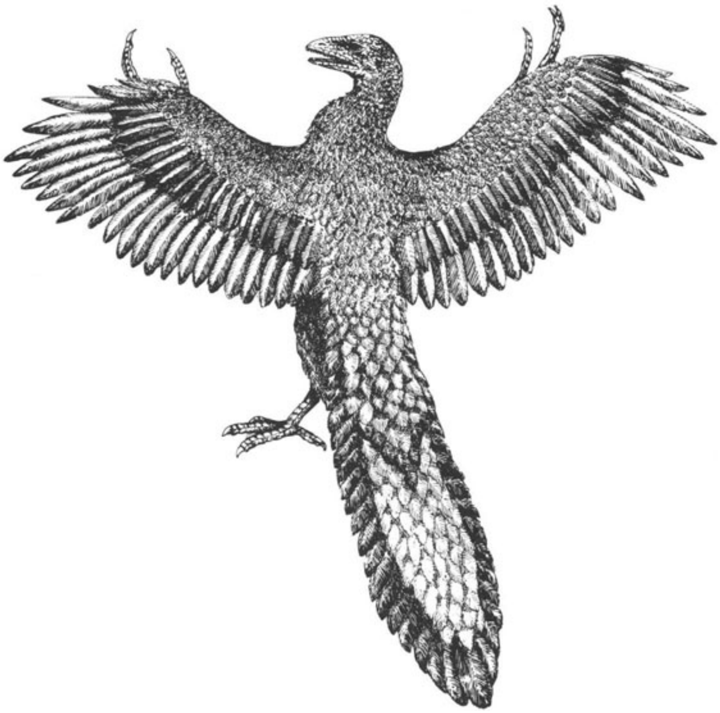

Figure 10.7 *Archaeopteryx*, the first known bird. Late Jurassic, about 1 m (3 ft) long (courtesy of Department of Geology, University of Saskatchewan).

Birds keep their legs free for walking or running, or – one of nature's most dramatic sights – for an eagle's fall, killing prey. They seem to have had advantages over the pterosaurs, and so the second reptiles to fly displaced the first. From them we have our modern birds: the dinosaurs are still with us, as chicks; warm, cuddly, fluffy little things, executed horribly, then roasted or fried by us.

PAINTING THE LAND: THE ARRIVAL OF COLOUR

We may eat dinosaurs, but what did the dinosaurs eat? During the Cretaceous a change came over the face of the land. The Jurassic vegetation had been a mix of cycads and horsetails, ferns, conifers and ginkgos. Fragments and small communities of this cycad-rich vegetation still exist today, in obscure places such as little stream valleys in Africa. Many of the plants were **gymnosperms**, a group of seed plants that do not have flowers. Today, their larger-scale descendants are present in the tall, dense forests of southern Africa and New Zealand, which are filled with trees known as podocarps and have abundant tree ferns. The conifers too have descended from this time, and they still dominate the north of the planet, competing vigorously with deciduous trees and making up the bulk of the Canadian and Siberian forests.

But from our point of view these are boring trees. Something is missing. We would call it 'aesthetic appeal'. A gymnosperm forest is a place haunted by the ancient subtle beauty of dark greens and russets. One of the finest of all trees is the African yellow wood, an olive-leaved and elegant, slow-growing cloud forest podocarp that can reach over 30 m (100 ft). But it is monochrome, and it is beautiful only when set against a lush background of colourful cloud forest species. By itself, it is boring, and there is an evolutionary reason why we find it so drab.

During the early Cretaceous, flowers evolved. We delight in the flower because it is aesthetically appealing to us, and that is precisely why it evolved. Our distant ancestors were drawn to it because it implied a site to be remembered – nectar was there, fruit would follow. Flowers are subtle. Humans like them because our senses tell us that they smell sweet and look pretty. They have entered into a symbiosis with us. For example, the extraordinary flora of the Cape of Good Hope have spread across all the inhabited continents (often as pests) simply because they managed to attract Dutch and English gardeners who made them the dominant part of the 'traditional' flower garden around European and American houses.

Flowers were evolved to take advantage of the abilities of animals, especially insects. Plants could use insects to carry pollen for them. Wind and accidents of gravity are not especially reliable means of genetic dispersal. Some plants use other strategies – pine cones can explode in fires – but the best way of dispersing one's genes is for one or both sexes to travel, often the male, because the female is more likely be heavy and to need the security of staying in one place. Animals have the same problems in genetic dispersion. Many ants make the male fly away, many mammals drive young bulls out of the herd, and humans have evolved an elaborate collection of rituals, varying from the arranging of marriages between different villages, to its modern substitute, the university.

Plants are rather more restricted in this business of the birds and the bees, not being as mobile as most university students, so they use insects, birds, bats and people to do their work for them. Hence the flower, which attracts the birds and the bees: things with wings then carry the pollen to the flower of a distant plant, which receives the distant genes. As the process becomes more sophisticated, bird and bee species become specific about which plant type they visit, for it is advantageous to them if the plant prospers. Thus hummingbirds favour scarlet runner beans (they like red), and bees are very particular about plant and season, whether they go to clover in Saskatchewan, rewarewa in New Zealand, leatherwood in Tasmania (in all of these places the honey bees are introduced) or introduced jacaranda in Zimbabwe (where the bee is native but the tree is not).

A flower is a wonderful device. The fig is a good example. Some species of fig have as many as twenty dependent insect species, many of which actually live inside the fig. Among these are parasites, but there is a very fine line between parasite and inhabitant, and between inhabitant and symbiont. As it is in the interests of the parasite to promote the interests of the plant, the parasite soon evolves a symbiotic lifestyle, helping to fertilize the seed. In consequence, figs have an intricate flowering process that depends on live-in insects and produces various different stages of food for them. The result is that some species of fig tree bear fruit all through the year. Reams could be written about Christ's comment to the fig tree before Jerusalem: it has a complex Talmudic intricacy about it which surely would have delighted Rabbi Gamaliel when he examined his breakfast figs for bugs, which he probably did. Flowers mean symbiosis, co-operation.

Once flowers had evolved, they spread rapidly and plants began to compete by colour and scent. The flowering plants, the **angiosperms**, came to dominate the central parts of the planet, and the Earth took on colour and smell. The insects were the partners in the change: mosquitoes, wasps, bees, butterflies, moths and assorted other bugs – the spread of the flowers was matched by the variety of insects serving them. Birds, too, exploited the flowering plants, and dinosaurs such as hadrosaurs ate them. All this, of course, implies that insects and animals were able to see and to smell the flowers. Vision and smell capable of distinguishing colours and scent probably developed at some time in the Cretaceous, when competition began between the flowers.

We have here an example of competition generating co-operation. Flowers are a competitive device, by which one plant can gain fitness compared to another. In response, insects compete to exploit the opportunity. Yet what is produced is a framework that offers new prospects to all. The plants prosper, the insects flourish, and to our own eyes, because we use senses and concepts which themselves have an origin in this process, the whole scene is filled with beauty. Here is the paradox of natural selection. In the immediate sense it is a dirty, deadly business – eat or be eaten, kill or be killed, exploit or be exploited, struggle ruthlessly to survive, or become extinct. Yet in nature the Darwinian competition is linked by an integral co-operation, at levels ranging from the fertilization of the fig to, perhaps, the management of the atmosphere. This collaboration is at the heart of life itself: we would die without it, all of us, from bacterium to astronaut. Collaboration is the other side of competition: the insect fertilizing a plant, or the dog-baboons that will deliberately attack and kill a leopard, and themselves be killed, to protect their family group, or the bird picking a crocodile's teeth are all collaborating, even if it is for good competitive reasons.

THE DINOSAURS, SCIENCE AND DINNER

The discovery of the dinosaurs fuelled a ferment among the early Victorian palaeontologists, such as Buckland, Mantell, Lyell, Cuvier, and especially Owen. Their work helped to make experimental scientific research a permanent part of the structure of Western society. The result of this palaeontological ferment among the geological savants (the word scientist was not yet common), after Charles Darwin's work, was a change in the world-view of society as a whole. The scientists had looked at the Earth, in the fossil record and in living communities, and unexpectedly had been taught much about the nature of humanity. But the new knowledge brought evil too: the doctrines of social darwinism and eugenics, that try to make human society conform to what was seen as the natural mould, led to racism and social wrong. These ideas helped to lay the foundations for Nazi philosophy.

Some of the stories from the early, more innocent, days of research illustrate the real scientific method. Successful science is not carried out according to a rigorous regime set down by philosophers. Instead, it is a combination of experiment, muddle, mistakes and imagination. For instance, the remains of *Iguanodon*, described by Mantell, provoked an attempt at reconstruction. The result was a large and imaginative model of a quadruped. It was very incorrect, but it was the first step towards imagining Cretaceous reality. Several such models were built, of different extinct beasts; the leading savants of the day celebrated by having dinner in the hollow body of one. These extraordinary reconstructions can still be seen at Crystal Palace, in south London.

Dinner, in whatever form, is something for which dinosaurs and palaeontologists hold a common respect. One of the most important early geologists, Dr Buckland of Oxford, was famous for his claim to have eaten all possible foods – when shown the heart of the King of France (which had come, somehow, to England), he gulped that down too, perhaps in the spirit of research. People, unlike Iguanodons, are omnivores, but the diet is not always right for them.

Bain, discoverer of the bidental mammal-like reptiles (which he sent to Owen), was equally concerned with the matter of dinner. On receiving some sausages sent by a colleague, Dr Borcherds, he replied in doggerel, illustrating the processes of geological deductions. Perhaps the last stanza also alludes to Mrs Mantell? He gave thanks:

'. . . for your kindness and pains,
In sending such precious *organic remains;*
In vain for description of them you may try all
The pages of Buckland, of Mantell, of Lyell;
For like our bidentals they must be unique,
Only known to our geological clique.
In science a novelty better by far
Than glyptodon, mammoth or famed ichthyosaur;

But first it behoves me to fix their position,
Whether *Pliocene, Miocene,* or of transition,
For which I'm as able, au fait, and as knowin'
As e'er Cuvier was, or yet Dr Owen!

They cannot be *Secondary*, for they're first-rate;
They're prime, though they do not as *Primary* date;
Fat and flashy-like cubes, with saliferous particles,
And dark *peperinos* compose all these articles.

No *ox-hides* occur, but a thin dermal casing,
The varied contents of the fossils embracing;
So among the *Conglomerates* I must enlist'em
For I'm sure they belong to the *Bologna* system!

Other fossils emit a strong smell it is true;
These not only smell sweet, but have a rich *gout*.
They're thoroughly *gneiss*, yet no feldspar or quartz,
Or mica compose their constituent parts.
They have but one *fault*, which I'm sorry to say
That with me they'll be subject to sudden decay.'

Kind regards to your lady, without whose kind aid,
These relics had ne'er to the world been displayed.
Farewell, my dear Borcherds, in haste I remain
As truly as ever, your's A. Geddes Bain.
27 May 1844.

The palaeontologists' concern about food is central, because finding food – gathering energy – is one of the chief businesses of any living form (along with the avoidance of becoming food, and the urge to reproduce). No doubt the Victorian savants were not the first to dine in the belly of an Iguanodon (an excellent repast for a megalosaur), but they were probably the first to choose so to do. As that generally excellent guide, 'The Restaurant at the End of the Universe' (part of the *Hitchhikers guide to the galaxy*) points out, the question of 'where shall we have lunch?' is something only the privileged few of a unique species can consider. Dinosaurs had no such choice.

THE LATE CRETACEOUS DISASTER

We have seen how, sometime in the Triassic, the dinosaurs took over as the dominant large animals on the land, displacing the mammal-like reptiles. Before that, the ancestors of the dinosaur had been a minor part of life on land. They were carnivores, playing a role in the land ecology but not having a major part in the economy of the world. Afterwards, dinosaurs conquered the continents, and the mammals were restricted to a minor role, scavenging for insects and the like, rather as opossums today scuttle around the dark places and basements of North America. A small mammal-like jawbone was found and studied by Buckland and Cuvier, from the deposits that had produced the discovery of dinosaurs.

By the late Cretaceous the dinosaurs had dominated the land for well over a hundred million years. A complex ecological web had evolved, inhabited by highly efficient social groups of herbivores and powerful predators, watched over by the birds, depending on a mixed vegetation including the flowering plants. One can visualize herds of duckbilled dinosaurs, ceratopsians and others, grazing on the bushes and forests, occasionally falling to *Tyrannosaurus* and the other great predators. Even today in Africa virtually no animal dies peacefully – death comes as a predator – but there seem to have been uncommonly powerful predators in the world of dinosaurs; it was a vicious place.

In the Upper Cretaceous, an interesting beast appeared, *Stenonychosaurus*. It has been found in the Judith River Formation in Alberta (not far from one of the finest dinosaur museums of the world, the Royal Tyrrell Museum of Palaeontology in Drumheller). *Stenonychosaurus* is fascinating because it had a brain that was large in contrast to most other dinosaurs, and which compares favourably in size with the brains of early birds and mammals. It has enormous eye bones (did it hunt at night?) and may be distantly related to the early birds, as it has many bird-like features in its skull. This beast, like all organisms, was well adapted to its contemporary environment. Dinosaurs were not necessarily stupid, not necessarily sluggish, not necessarily uncompetitive. By the end of the Cretaceous, somewhat later than the time of *Stenonychosaurus*, the dinosaur community was the most successful, most competitive, most ferocious collection of animals that had ever lived on Earth.

Some scientists have amused themselves by speculating on what would have happened had the dinosaurs been granted a fragment more time on Earth: say a million or two more years. *Stenonychosaurus* indicates that the late dinosaurs were evolving in the direction of becoming large-brained animals, with binocular vision and hands able to grasp and turn. Perhaps the dinosaurs were on their way to producing an animal with an intelligence comparable to humans. Given more time, they might have even produced a civilization. But something happened.

We do not know for certain what caused this great change, but it eliminated virtually every living thing on land heavier than about 25 kg (50 lbs) together with many smaller organisms. Around the globe, a layer of sediment rich in soot, unusually high in iridium, and with mineral crystals that must have formed by shock impact or high pressure, lies at the boundary that ends the Cretaceous. The soot seems to have come from huge fires. Every dinosaur became extinct, except for the birds. Across the land, especially in what is now North America (the best studied area), enormous changes took place in the vegetation. At sea, many of the tiny floating organisms (which become microfossils) were wiped out. The extinction was massive.

How sudden was the change? We do not know – the geological record on land is not very precise, and at sea it is subject to disruption by burrowing by worms, snails and clams and so on, so that the resolution, (or fineness) of most of the record is somewhere between 10 000–50 000 years at best, and usually worse than that. Any event that happens in a shorter period than this cannot usually be pinned down in the marine record because bottom sediment is reworked and mixed up on a small scale by marine organisms such as worms and molluscs. Perhaps the extinction took as long as, say, several million years, but there is a strong body of scientific opinion that it took 50 000 years or less. In geological terms, this is sudden. Are there any parallels in the geological record?

Interestingly, there are. The lesser parallels are in the frequent minor episodes of extinction that form a constant background noise on the geological record. Larger events occur too, some as great or greater than the event at the end of the Cretaceous. Massive marine extinction took place at the end of the Permian, and a phase of extinction also occurred when the mammal-like reptiles gave way to the ruling reptiles and the dinosaurs. We see the same process in other ways too. The wanderings of the continents have on occasion caused major changes in the pattern of life. Each time two isolated land masses join, the consequence is catastrophe for some species, which are wiped out by more competitive organisms from the other land mass. But the catastrophe that overcame the dinosaurs seems to have been immense, and probably also sudden. It was so widespread that it involved land and sea, eliminating animals, vegetation (a change in plants would be expected as animals change) and also much of the complex chain of life in the oceans.

We can imagine a modern analogy. Imagine the geological record of the present day and the next few hundred thousand years, as studied by a palaeontologist sixty million years hence. Perhaps our palaeontologist of the future, assuming humanity disappears, would be a marsupial, possibly descended from some New Zealand immigrant possum. Our future palaeontologist will see in our history of the present day something extraordinary, closely comparable to the terminal Cretaceous 'event'. About 100 000 years before the present day, something started happening in the Africa–Europe–Asia supercontinent. At that stage, if the observer is very lucky, the geological record might include one or two primate bones from Africa or South America: humans would be recorded as an obscure family of apes, possibly arboreal or nocturnal. Maybe a baboon would be preserved in the sediments of the Niger inland delta (its sea delta, along with the Nile's, having been deformed and metamorphosed in a continental collision long before the possums evolved a palaeontologist), but humanoid remains would be very rare.

Then would come signs of an ice age, massive vegetation changes and a wave of extinction linked with a few human bones. If the record were superbly detailed, the future palaeontologist would discover that mammoths and large animals went first, along with lions and elephants from North Africa, the Middle East and Europe (assuming that Mesopotamia, bits of the Sahara and the odd fragment of Greece's valley fill are preserved: most unlikely). The Americas might record the story of a similar swathe of extinction as early man suddenly swept from the Bering Strait down to the shores of Tierra del Fuego. Roughly three quarters of the genera of large mammals over 45 kg (100 lbs) in body weight became extinct in North and South America, probably through aboriginal hunting, though climate change may also have been important.

All this, of course, is most unlikely to be preserved in the geological record. More probably, the future palaeontologist would simply be able to say that many species of large animal were present a few hundred thousand years BC, and a few hundred thousand years AD they had all gone.

Perhaps the future palaeontologist would see more signs in pollen from the plants, preserved in sediment. About 3000 years ago the forests of the Mediterranean began to disappear. Then, as seen from the future, around the time of the 'final catastrophe' all the forest went. By 2000 AD, apart from a few islands of green and the remains of Amazonia, the vast pre-human forests had already mostly gone. Grasses replaced forest. Global climatic change probably accompanied the devastation, and innumerable species vanished – not just the obvious ones like the mastodons but the minute bugs and obscure plants which constitute the bulk of the fossil record.

To return to the viewpoint of the present day, it is clear that the ecological fabric has torn: even if humanity were to disappear tomorrow, the nature that would come back would be different from what was before. The change will be best recorded in sediments that are allowed to lie undisturbed, and the record of the devastation will mostly be in the shape of pollen grains and the like. To the future palaeontologist the pollen will record an inexplicable sudden change as forest species become extinct and grasses take over.

Another subtle record will also show in the marine sediments. There will be signs of radioactivity from material such as plutonium which we have made, but this will be minor and will fade. Assorted man-made chemicals will be longer lasting, but these too will eventually be destroyed. A brief explosion of marine organisms will be recorded in the North Sea, reflecting the enormous increase in the supply of nutrients, brought down by rivers from agricultural fertilizers and manure. But perhaps the most obvious record will be of the industrial metals that have reached the sea bed, especially the rare and chemically relatively inert elements (such as platinum and iridium). We have dug these up, used them and now scatter them again.

Will there be any other sign of our civilization? Probably not. The large cities will be washed to the sea. The sea floor will be recycled in subduction zones. The only likelihood of preservation of a man-made artifact (a beer can perhaps, or a Coke bottle?) is in an intracontinental sedimentary basin such as the North Sea (but that will probably be folded and metamorphosed when the Atlantic closes again) or perhaps Lake Eyre, in Australia. Our last relict may be a Foster's can. Just possibly the floor of Lake Victoria or Lake Chad will preserve the bones of an odd primate which seemed to have a large brain, but little sense.

All this is the doing of a few thousand years, well within the 'fuzz' of the geological record. And it is all the result of the actions of one species, from a previously minor line, that exploded across the planet. The future palaeontologist will have little chance of unscrambling the full story. Yet science is often lucky. Maybe our possum-palaeontologist, digging into his roots in some southern New Zealand lake sediment, will come across the bones of British weasels, or of a wapiti – or even a moose. That surely will give him a clue. Or will the question of how a moose swam the Pacific become one of the great riddles of palaeontology? The whole geological record is fragmentary and very difficult to decipher. That the dinosaurs blew themselves up by nuclear weapons is wildly improbable (though fun to write fiction about), but a major change of some sort did take place at the close of the Mesozoic era.

One explanation of this change is that a rapid but not catastrophic evolution took place at the end of the Cretaceous – say over a few million years – when some successful adaptation favoured the mammals and destroyed the dinosaurs. Perhaps the dinosaurs died out piecemeal, in the millions of years before the end of the Cretaceous, with the last survivors becoming extinct at the end of the period.

But the extinction affected the whole ecosystem, especially in the oceans. It was not confined to the dinosaurs. Possibly some organism developed a way of destroying a king-pin of the ecosystem, and all else crashed down in ruins. There is much debate about whether a complex ecology is more stable than a simple one – it probably is – but all sorts of apparently trivial events can undermine a complicated system. For instance, the Etosha Park in Namibia is one of Africa's richest game communities, but the whole ecological chain was devastated by a fence and the digging of a simple gravel pit, which uncovered anthrax that then infected certain key species. If a king-pin of the chain goes, all goes, and the vegetation of the planet also changes (as does the climate) until a new stability is found.

The conservative view is that the end of the dinosaurs was a change like many others in the geological record, more marked than most, but not exceptional (there were some earlier extinctions possibly of equal severity, especially in the sea). A small, but distinguished, minority of palaeontologists believe that at the end of the Cretaceous there was no marked extinction event at all.

The catastrophist view of the end of the Cretaceous is simpler. Something went 'bang'. An extraterrestrial impact is the favourite explanation – a large meteorite or comet could do the job, producing atmospheric disruption, fires, and a few years of sharp global cooling: enough to eliminate virtually all large animals and much marine life and to cause global fires, recorded in a world-wide soot layer. This impact hypothesis is supported by the unusual amount of iridium present in the sediments at the boundary between the Cretaceous and the Tertiary although several iridium-rich layers are now known, implying several events. We could probably do the same with a few thousand megatons of nuclear bombs and our industrial waste, leaving the puzzle for the possum palaeontologist.

Volcanoes also produce big bangs. Mt St Helens produced a little burp, but the eruption of Krakatoa was somewhat larger, a century ago. The explosion of Tambora in Indonesia in the early nineteenth century may have caused 'the year without a summer' in North America, and eruptions in Iceland have had an effect on the global climate. Santorini, a Greek island volcano north of Crete, destroyed much of the Minoan civilization and gave birth to the legend of Atlantis. This explosion occurred possibly around 1450 BC, although the date is disputed. Some geologists have suggested that its impact on humanity was not restricted to the Minoans: it may also have provided the cloudy pillar, helped set off the plagues and in its final explosion created the tsunami wave of the biblical Exodus. The hypothesis is controversial, not proven, but intriguing. More dramatic yet was the Taupo explosion of around AD 130 or 180 which devastated most of North Island, New Zealand. The debris of the eruption wiped out much of the life in the centre of the island, burying it in a layer of hot ash and lava particles. But all these are small compared to the once-in-a-million years event, and the once-in-a-billion years event is greater still. A really large

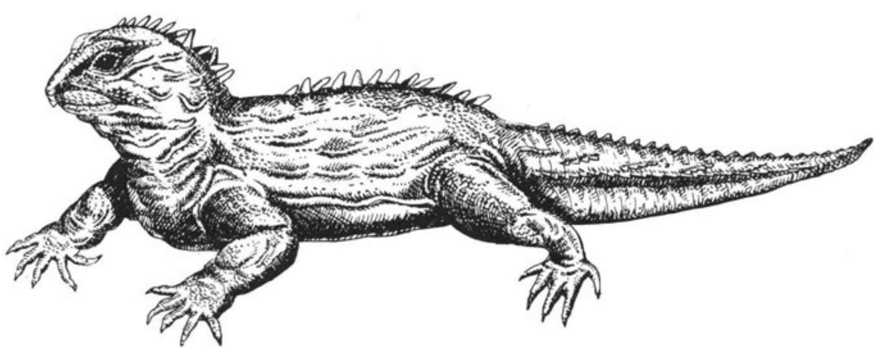

Figure 10.8 The tuatara, *Sphenodon*, (about 70 cm–1 m (2–3 ft) long), still living in New Zealand (courtesy of Department of Geology, University of Saskatchewan).

explosion, perhaps connected with the volcanism that accompanied the rifting of Gondwanaland, could do all that a cometary impact would do, and even provide the iridium.

Perhaps the Cretaceous did end with something like this – an impact or an explosion. The result would be a sudden catastrophic climate change as dust or smoke filled the upper atmosphere, followed over the next few months or years by the death of almost every large living thing on Earth. Of the higher animals, a few marsupials and some of the placentals survived. The tuatara, turtles, crocodiles and birds continued, but the dinosaurs that existed at the end of the Cretaceous died.

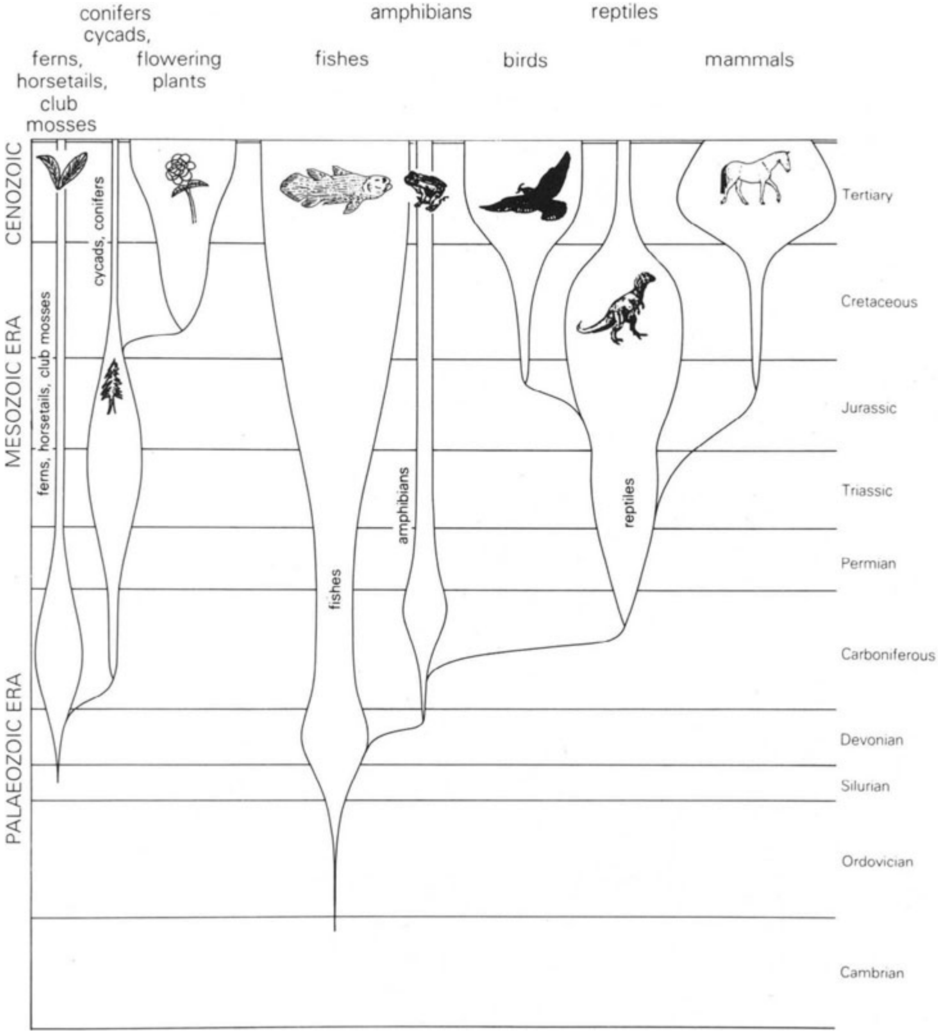

Figure 10.9 A simplified evolutionary chart showing the distribution and relative abundance of vertebrate animals and land plants through time (courtesy of Department of Geology, University of Saskatchewan).

Will we ever know for certain what happened? – perhaps not, unless we can find some truly undisturbed record that allows us to pin down exactly the length of time over which the change occurred, whether a million years or ten years. Whatever the cause, the ecological balance of the whole planet changed, especially in the seas.

'It is a poor sort of memory that only works backwards' said Alice. The message from the end of the Cretaceous is sombre and terrifying.

FURTHER READING

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