CHAPTER 2

AUSTRALIA IN GONDWANA

I have always had a terrible curiosity to know what things were like in Gondwana some 100 million years ago, before the islands of Australasia broke apart. At one level it is a keen, non-intellectual desire to ***know*** the landscape in the way one knows the body of a lover. I satisfy this need every time I split a rock to reveal a pebble lying just as a small eddy in a stream had left it 100 million years ago; or the impression of a leaf, chewed by an insect before it fell to the bottom of an ancient muddy pool, where it was covered and preserved for aeons. But in addition to satisfying this emotional need, I study fossils because I have a strong and urgent intellectual need to know about them and their lives. The key to understanding Australia—and even ourselves—lies in the distant past.

Unfortunately, nature has not endowed Australia with a rich fossil record. The period about 80 million years ago, when New Zealand and New Caledonia split from Australia, is particularly poorly represented. For this reason we must go back a little further in time, to 120–100 million years ago, for evidence of what Gondwana was like before that break up.

Every scientist makes a few fortunate discoveries during his or her career and I, thankfully, am no exception. As a child I was fascinated with dinosaurs to the extent, so my indulgent mother informs me, that when the makers of the breakfast cereal 'Weeties' began to include a small plastic dinosaur in each pack, I embarked upon a Weeties-only diet for several weeks. Unfortunately, I have never grown out of my obsession and although I would not again subsist happily upon Weeties in order to obtain plastic dinosaur models, I have always been willing to devote any spare time I had to a pursuit of all things dinosaurian.

To my great chagrin, I had been born and raised in Victoria and,

as every schoolboy knew at the time, almost all of the few dinosaurs discovered in Australia had been found in distant Queensland. Victoria—to my intense shame—had produced but a single pathetic relic; a four-centimetre-long bone dubbed by some wag as 'The Cape Paterson Claw' after the place where it had been found in 1900. Although childishly embarrassed by the tiny size of our State dinosaur treasure, one of my most valued possessions when seven years old had been a slender leaflet produced by the curiously named National Museum of Victoria, entitled *Fossils of Victoria*. Written by the Reverend Edmund Gill, who was perhaps one of Australia's last clergyman naturalists and certainly the only one I ever met, it included an obscure photograph of the doleful dinosaurian digit itself.

One of the highlights of my life came when, at age 10, I was admitted, awestruck, through the great doors of the Palaeontology Department, so that the State Palaeontologist could confirm my identification of a strangely shaped stone as some astoundingly valuable fossil (I had my hopes pinned on a petrified dinosaur brain). In consolation he opened a drawer of the vast collection and placed a small box in my hand. Doubly awestruck, I left swearing never again to wash the hand that had held The Cape Paterson Claw!

Many years later, while studying for a degree in Earth Sciences at Monash University, I had the great good fortune to meet Rob Glennie, one of Victoria's most knowledgeable and affable geologists. Rob has a unique knowledge of the history of geological exploration of Victoria. He and I soon discovered a common interest in The Cape Paterson Claw. I found to my great delight that Rob has a wealth of knowledge both about the man who found The Claw and the geology of the Claw-bearing rocks themselves.

The Claw had been discovered by one of the State's all-time great geologists, William Hamilton Fergusson. He was, by all accounts, an extraordinary man. Meticulous in maintaining standards, he did all of his work in frockcoat and waistcoat and every morning, regardless of where he was, he raised the Union Jack over his humble camp. Glennie found his geological work exemplary, for his maps were utterly reliable and detailed. Fergusson had been sent to Cape Paterson because the rocks in that area had coal-bearing potential. He had made a characteristically detailed map of the coast there, at a

very small scale. Indeed, my eyes almost popped from my head when Glennie, while explaining this, casually unrolled an antique geological map of the Cape Paterson coast, upon which a large 'X' marked a spot labelled 'Claw found here'. It was a copy of Fergusson's original map, and it showed every detail of the geology of the area, right down to fossilised logs protruding from the shore platform.

The very next weekend saw Rob, myself and my cousin John Long (another dinosaur fanatic and now Curator of Vertebrate Fossils at the Western Australian Museum) standing on top of the high cliff that is Cape Paterson, examining the glum scene below. The tide was high, all but covering the rock outcrop. The weather, uncharacteristic for November, was bitterly cold, the rain slanting in on us almost horizontally. Rob finally said, 'I think it must have been about there' and we all descended the steep and perilous slope (we only found out afterwards that there was a walkway down the cliff a few yards to the west). Within seconds of arriving on the beach John called, 'Here's a bone' and we rushed over to see the cross-section of a tiny yet unmistakable bone showing in a pebble. It was the first dinosaur bone to be discovered in Victoria for nearly 80 years and while small, we all saw in it the potential to enter the world of dinosaurs.

From that moment I became obsessed. Every weekend would see me at Cape Paterson, combing the rocks for a taxonomically useful dinosaur bone. Within a few weeks I had one—the ankle bone of an ***Allosaurus***. But it soon became clear that if the rocks were ever to yield more than a glimpse of Australia as it was some 120 million years ago, then a major effort at exploration and excavation of similar rocks around Victoria would have to be undertaken.

Fortuitously, the State of Victoria had a few years earlier appointed a most determined palaeontologist to its staff. Dr Tom Rich, Curator of Vertebrate Fossils at the now more appropriately renamed Museum of Victoria, had once told me that palaeontologists must have the will to fail. Tom Rich has that will on a massive scale. As a volunteer on one of his early 'digs', I and a crew of five or six others had worked for over a week, shifting tonnes of basalt and ancient soil without finding a single fossil. Sick at heart at this failure as only a teenager can be, I had sworn to quit the desolate diggings more than a dozen times. Finally, late one evening, one of us found a single tiny

tooth cap, less that 2.5 millimetres long, turning despair into delicious victory.

Through his sheer 'will to fail' Tom has, over the years, turned this fossil site near Hamilton in western Victoria, into one of Australia's most important fossil localities. Through his effort, it has provided a glimpse of life as it was in a Victorian rainforest some 4.5 million years ago, complete with tree-kangaroos, tiny diprotodons and forest wallabies. Without this work, we would never have known that the rich faunas of possums and tree-kangaroos that presently characterise the rainforests of north Queensland and New Guinea, were once found as far south as Victoria.

Tom Rich and his wife Pat, also a palaeontologist who lectures at Monash University, were to need every ounce of the will to fail in their struggle to uncover the lives of Victoria's dinosaurs, for the effort needed was immense. Before anything else, the entire coast which included rocks of the right age had to be prospected. This involved a team of expert palaeontologists combing every inch of rock on some of Australia's most dangerous and least accessible coastline.

Experts from around the world were invited to participate in various aspects of the research work. Climatologists studied ancient ratios of oxygen isotopes, while palaeobotanists discovered the world's oldest flower and studied the adaptations of plants to polar conditions. Sedimentologists studied the flow direction and sediment deposition in the ancient rivers and lakes, while dinosaur experts Tom and Pat Rich studied the dinosaur bones themselves. Indeed, Victoria's dinosaur bones are perhaps the most travelled of any, for they have circled the globe several times as the Riches have carried them from collection to collection, looking for a match close enough to allow an identification to be made.

It is only now, after more than a decade of hard work, that a picture of southern Australia as it was 120 million years ago is emerging.[105] We now know that the sediments containing the fossils were laid down in a rift valley similar in structure to the great rift valley of eastern Africa today. Rift valleys form where a continent is being torn apart by continental drift. It is surprising to find that such a valley was forming between Victoria and Tasmania 120 million years ago, as these landmasses are still joined. It is quite likely that the ancient rift was part of a system that was eventually to tear Australia from Antarctica. Initially Australia and Antarctica began to separate to the north of Tasmania, but for some unknown reason this rift failed and another rift began to form to the south of Tasmania. This meant that Tasmania was destined to follow the rest of Australia north, rather than remain in the frigid south with Antarctica.

As in most rift valleys, there were plenty of active volcanoes. These volcanoes were rapidly eroded and the rock grains transported into the valley in seasonally active streams. As the sediments built up, the valley floor sagged, allowing more sediment to flood in. Eventually sediment built up to a depth of over three kilometres. The great sediment pile enclosed the remnants of ancient river beds, ponds, lakes and many other topographic features. These sediments are now exposed most spectacularly along the southern coastline of Victoria. There, the greenish rock with its large, brown concretions has weathered into fantastic forms. Moonlight Head, a huge promontory formed entirely of this rock, is Australia's tallest coastal cliff. In places all along the coast one can see pebbles and pieces of clay that mark the course of previous stream channels. It is in these channels that most of the dinosaur fossils are found.

One of the greatest surprises to come from the study of these sediments is just how cold southern Victoria was 120 million years ago. Palaeoclimatologists have discovered that the region then lay well within the Antarctic Circle. Various methods for estimating the mean annual temperature have been tried. One method, which examines the ratio of two oxygen isotopes, suggests that the mean temperature might have been zero degrees, but perhaps reaching as high as eight degrees above zero. Such temperatures are today found at Hudson's Bay and Toronto! It is exceedingly difficult to imagine dinosaurs and turtles living in such settings. Perhaps a more realistic estimate is derived from the study of plants, which suggests a mean annual temperature of a (still very chilly) 10° Celsius. Whatever the precise temperature, the wealth of fossil remains of plants and animals clearly indicates that the polar temperature at the time was considerably warmer than it is today.

While the relatively cool temperature was one problem for cold-blooded creatures, an equally serious one would have been the lack of

light during winter. Depending upon the precise position of southern Victoria at the time, they would have had to endure between six weeks and four months total darkness each year.

Some understanding of climatic conditions 120 million years ago has come from studies of modern global pollution. We now know that as the amount of carbon dioxide in the atmosphere increases, the world becomes warmer, particularly at the Poles. This is known as the greenhouse effect. Scientists now tend to describe the world of 120 million years ago as a full greenhouse world. Thus the Rich study is useful not only for understanding the evolution of Australian environments but for telling us a little about the kind of world that our grandchildren may inherit.

The plant and animal fossils retrieved from the 120-million-year-old rocks of southern Victoria are fascinating. The plants are dominated by ancient types such as conifers, ginkgoes (today found naturally only in China), ferns, cycads and mosses and lichens. There were only a few flowering plants. Scientists have discovered what they think is the world's oldest flower in the rocks—a diminutive magnolia-like bloom, perfectly preserved between two layers of clay like a flower in a plant press. Species ancestral to the grevilleas and waratahs evolved after this time. It was to be another 40 million years before the 'new' lands were to go their own ways, so there was plenty of time for such plants to evolve and spread.

The animals, however, were unlike any living today. Dinosaurs dominated, but most of the Victorian species were curiously small. The most common kinds were chicken- to dog-sized, bird-hipped dinosaurs that ran on their hindlimbs and ate plants. One large-dog-sized, species has been named *Atlascopcosaurus* (because, without the support of the hire company Atlas Copco, the Riches could never have excavated the bones). Another is named *Leaellynasaura*, after their daughter Leaellyn. *Leaellynasaura* is one of the few species known from a partial skeleton, which shows some curious adaptations. At about the size of a chicken, it was one of the smallest dinosaurs ever to exist. It had very large eyes and large optic lobes in the brain. It is likely that it used its acute vision to remain active during the winter darkness. Thus, it may have been active through the very coldest time of the year.

The very largest of the Victorian dinosaurs was a carnivorous species of the well-known genus *Allosaurus*. At about two metres high at the hip, it was dwarfed in comparison with its seven-metre-long North American relatives. It also lived long after its relatives from other continents had became extinct, for *Allosaurus* is known only from rocks of Jurassic age elsewhere (208–147 million years old), while the Victorian *Allosaurus* is about 120–110 million years old.

Other dinosaurs included an as yet unnamed, sheep-sized ceratopsian (a group of compact, heavily armoured, rather rhinoceros-like dinosaurs) and an ostrich-like species named *Timimus*. (I was, incidentally, rather pleased to hear that this dinosaur had been named after myself and the Riches' son Tim. The only thing previously named for me was far less noble—a New Guinean tapeworm which infests the bowels of possums!)

These two species are of particular interest, because both represent the earliest occurrence of their respective groups. Ten million or more years after these Victorian species existed, the rhinoceros-like and ostrich-like dinosaurs had evolved into many species which populated the landmasses of the northern hemisphere in vast herds. Along with holly, they may be gifts that Australia, or at least Gondwana, has given the rest of the world.

This curious dinosaur assemblage has provided some very unexpected insights into the lives and extinction of the dinosaurs in general. They are very different to the only dinosaur assemblages known from the Arctic region. There, the dinosaurs are larger and may have migrated seasonally in and out of the Arctic Circle. An ancient arm of the sea cut off the Victorian dinosaurs from access to the north and they would have had to stay put all year. The limitations that this placed upon their food resources may explain their small size. Because of this enforced isolation we also know that they were truly cold-adapted—not just seasonal visitors.

These discoveries are a strong challenge to those who believed that a deteriorating world climate led to the ultimate extinction of the dinosaurs some 65 million years ago, for it would have been difficult for the entire Earth to have become as cold as southern Victoria was 120 million years ago. Even if it had, we know that dinosaurs could survive in climates at least that cold.

In addition to dinosaurs, the bones of pterosaurs (flying reptiles), lungfish, turtles and crocodiles have also been found. The very largest animals to inhabit the area were not reptiles at all, but enormous amphibians known as labyrinthodonts. These great creatures, perhaps three metres or more long, superficially resembled huge newts and may have filled an ecological niche similar to that of modern crocodiles. Their discovery in 120–110-million-year-old rocks in Victoria was a great surprise, for they had become extinct elsewhere in the world some 80 million years before. Indeed, I well remember the sceptical reaction when I found the first bone that looked as if it might belong to a labyrinthodont. It was the back of a jaw which lacked teeth. Tom Rich and I were puzzled by it, but both of us felt that it matched nothing else but a labyrinthodont. Because the remains were so fragmentary and the survival of labyrinthodonts into the Cretaceous period seemed to be so outlandish an idea, we were reticent about pushing our claims in the face of scepticism from the experts. Instead we christened the fossil GOK (for 'God Only Knows', the most common refrain from the palaeontologists we asked to identify it) and hid it away in a museum drawer. It was nearly a decade later that another jaw was found. This one preserved some teeth and they revealed unequivocally that labyrinthodonts had inhabited Victoria's great rift valley.

Tom Rich suspects that the unlikely survival of these strange creatures for over 80 million years after their extinction elsewhere may be explained by the difference between reptilian and amphibian physiology. Amphibians can generally better survive in colder water than reptiles and it may be that the cold polar climate of southern Victoria offered a refuge to the amphibian labyrinthodonts that the otherwise superior crocodiles could not penetrate. A few million years later the Earth warmed and we find the first crocodile remains in the rocks of southern Victoria. By then, the labyrinthodonts were sadly absent.

The remains of more ordinary animals are also preserved, including several species of herring-like fish. Their bodies have been exquisitely preserved in lake sediments found near Koonwarra in southern Victoria. They are in such good condition that every scale and fin ray stands out in brown against the fine greenish sediments that enclose them. Along with these fish, the perfectly preserved larvae and adults of many insects have been found. These include cockroaches, cicadas, fleas, horseshoe-crabs (now extinct in Australia but surviving in coastal waters off North America) and water beetles.

The method of preservation of these fossils is rather curious, for their bodies were trapped in lake sediments which are divided into layers called varves, each of which is a few millimetres thick. The varves alternate, one being composed of very fine green clay, the next with slightly coarser and browner sediment. Scientists think that the lake was shallow and froze over every winter, killing many of the lake inhabitants. During the winter when the lake was frozen, fine green sediment settled to the bottom. When the lake thawed in spring, coarse sediments were deposited with the spring floods, covering the bodies and preserving them. Thus, every year one fine green and one coarser brown layer was formed, leaving us an exceptionally detailed, year by year picture of how life was in Victoria 120 million years ago.

Some rather enigmatic fossils have also been preserved in these sediments. These include five exquisitely preserved, rather tiny (one- to two-centimetre-long) feathers. These have long been considered as evidence that birds inhabited the area. The fossilised remains of birds are certainly known from equally old rocks elsewhere, but these feathers worry me. I find it difficult to imagine chicken-sized dinosaurs surviving in such a cold climate, particularly if they were active over winter. If they were able to do this they must have been warm-blooded. And if warm-blooded, they must have had ways of retaining body heat. Given their size and rather primitive structure I think that the fossilised feathers of Koonwarra may have belonged to the dinosaur *Leaellynasaura*. This is not really so surprising, as birds are the only surviving members of the dinosaur family. All birds have feathers, so it is not unreasonable to suspect that some of their relatives had feathers also.

There is also some evidence that mammals were present, for the sediments from Victoria have yielded the fossilised impression of a flea, of a kind specialised to live among hairs. Mammals are the only living group of vertebrates to possess hairs, so ever since this flea was described in the 1960s the presence of mammals in Australia 120 million years ago had been suspected. It was not proven, however, until 1985, when Mr David Galman, an opal miner from Lightning

Ridge, New South Wales, came to the Australian Museum with a small box of fossils he wished to sell.

Lightning Ridge is a dusty inland town, as different from wet and hilly Cape Paterson as anywhere in Australia. Yet they both have something very important in common, for the rocks that underlay them were formed about 120 million years ago. At Lightning Ridge the actual fossil bones have long since gone, dissolved by acidic groundwater. The spaces that the bones left in the rock remain and in many instances they have been filled with an unusual form of silica known as opal. Thus, at Lightning Ridge, when a miner sinks his shaft in search of opal, he occasionally runs across the most exquisite natural casts of the bones of animals that existed over 100 million years ago. Many of the creatures whose remains have been found are similar to those found in Victoria although, perhaps because Lightning Ridge lay further from the South Pole than Cape Paterson, the remains of larger dinosaurs are also found there but labyrinthodonts are absent.

By far the most striking fossil ever discovered at Lightning Ridge is a small jaw with three teeth in it. It is beautifully preserved in transparent opal, so that tiny details of the root and nerve canals can all be seen. When examined by palaeontologists it proved to be the jaw bone of an ancient relative of the platypus. Named *Steropodon galmani* in honour of Mr Galman, it remains Australia's most ancient mammal fossil by some 60 million years.[4]

By assembling all of the information gleaned from fossil deposits such as those from Victoria and Lightning Ridge, we can build a picture of what Australasia was like some 120 million years ago. To the east and south lay New Zealand and New Caledonia, still firmly attached to the eastern side of Australia. To the north, New Guinea, if it existed at all, was a couple of islands lying near the north coast of Australia. To the south lay Antarctica, still attached to Australia, but with signs of the developing rift that was to set Australia careering northwards some 80 million years later.

All of these lands except Antarctica lay well to the south of their present position, with part of Australia, all of New Zealand and possibly New Caledonia, lying within the Antarctic Circle. This was a greenhouse world and although chilly within the Antarctic Circle, it

was not refrigerated as lands lying at such latitudes are today. Because of the greenhouse conditions, there were no polar ice-caps. Thus the sea-level was considerably higher than it is at present and Central Australia was occupied by a great inland sea.

On this great and alien landmass many of the kinds of organisms that Australians are familiar with today were evolving. These formed the common stock of plants and animals for all of the 'new' lands, but subsequent history was to treat each land differently, resulting in strikingly different faunas. By 80 million years ago, when the 'new' lands began to split apart and drift separately across the face of the Earth, a rich assemblage of plant and animal species had developed.

The patterns of evolution that life followed on each of the 'new' lands tells us much about the forces which were strongest upon them. As these forces continue to shape everything that inhabits the 'new' lands today, the following chapters examine in some detail the patterns of life in each of these four places.

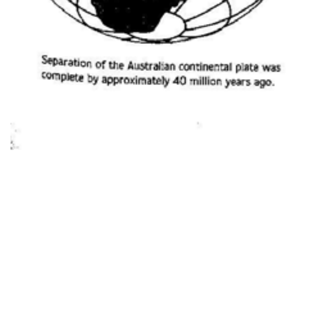
Position at 160 million years ago

The great southern landmass Gondwana. Part of what is now Australia lay within the Antarctic circle.

Present

Much of the landmass of Meganesia and Tasmantis is now submerged beneath the sea.

Position at 45 million years ago



Separation of the Australian continental plate was complete by approximately 40 million years ago.

CHAPTER 3

LAND OF GECKOS, LAND OF FLOWERS

At between 86 and 82 million years ago a large sliver of land detached itself from eastern Australia. A rift valley resulted from the split probably initiating the formation of the Australian Alps. Dubbed Tasmantis by geologists, this sliver of land was the first part of Australasia to split away from Gondwana. Now largely submerged beneath the sea, it includes New Zealand and New Caledonia, and Lord Howe, Norfolk, Kermadeck and the Chatham Islands.

As Tasmantis itself began to fragment and sink, New Caledonia came to lie astride the tropic of Capricorn, between 19° and 23° south, while New Zealand now lies at between 32° and 48° south of the equator. Tasmantis continues to move across the Pacific and geologists estimate that 100 million years from now, the paths of Tasmantis and Meganesia (the name of the landmass including Australia, New Guinea and Tasmania) will again cross. Then, these ancient southern lands will once again amalgamate into one.

With an area of about 17 000 square kilometres, New Caledonia is the smallest of the 'new' lands and is in some ways also the strangest. An elongate island (350 kilometres by an average of only 50–70 kilometres wide), the spine of New Caledonia is mountainous and well-watered. True forest is, however, restricted in distribution and many of the mountains and plains, particularly in the south, support a low, heath-like vegetation that the Caledoche (New Caledonians of French descent) call *maquis*. At a distance, the colour it imparts to the mountain ranges resembles that of heather in the Scottish Highlands. It may have been this that prompted James Cook, who in September 1774 was the first European to see the strange island, to name it New Caledonia. Cook himself noted the great similarity of the flora of New Caledonia and Australia. To the modern biologist,

the similarity of the *maquis* to heather vanishes when it is examined at a distance of less than a few miles and similarities with Australia become startlingly apparent.

I remember vividly my first day on the New Caledonian *maquis*. The barren moonscape was an unsettling contrast with the verdant paradise of the other Pacific islands I had visited. It was only when I got out of my car and examined the ground more closely that my sense of alienation was dispelled, for the ground was littered with brown, shiny pebbles, much like those seen on a South Australian gibber plain. Growing isolated among the stones were tiny, almost bonsai-sized bushes. To my astonishment I recognised one as belonging to the same genus (*Araucaria*) as the great klinki pines of New Guinea and the bunya pine of Queensland, both of which are giants towering over lush rainforests. Others were strange-looking relatives of grevilleas and still others had their relatives among the peculiar, primitive flowering plants of north Queensland's rainforest. Eventually I managed to procure a handbook on the New Caledonian flora and learned to my amazement that over 3000 species of indigenous plants are found there. By comparison, New Zealand, which is about 15 times larger, has only 1460 species. Even more extraordinary is the fact that the New Caledonian flora includes some of the most wildly beautiful and primitive plant species to be found on Earth.

The New Caledonian flora is remarkable for including the most comprehensive assemblage of ancient trees in the world. The ancient conifers are particularly well represented. No less than 13 of the world's 19 species of monkey-puzzle trees (*Araucaria*) survive there, as do the majority of the related kauri pine species. This family of trees, now by and large restricted to the southern hemisphere, were a dominant life form everywhere during the age of dinosaurs; the famous fossilised forest of Arizona in North America, for example, is composed of their trunks. There are, in addition, 15 more genera with over 40 species of other ancient pines in New Caledonia. The most unusual species is placed alone in the genus *Parasitaxus*. It is unique among the pines for it is a mistletoe-like parasite which lives on other pines.[120]

There are five families of primitive flowering plants which are unique to New Caledonia, as well as 17 genera of palms (including

some of the world's most graceful species), 191 orchids, and eight genera and 42 species of proteaceous plants (the family that includes the banksias, proteas, grevilleas and the like). New Caledonia's Proteaceae rival those found anywhere else on Earth for their beauty and unusual flowers. The species of *Kermadecia*, for example, look rather like huge grevilleas, but have flower spikes 40 centimetres or more long, with each individual flower being relatively enormous compared with Australian members of the family.

New Caledonia also has an exceptionally rich assemblage of myrtaceous plants, although the eucalypts, which are the best known members of the family in Australia, are not present. Among the 200-odd myrtaceous species found there, are some with the most attractive flowers I have ever seen. The species of *Xanthostemon*, for example, particularly *X. aurantiacum* with its brilliant red, green and yellow ti-tree-like flowers, would set any subtropical garden ablaze.

Curiously, many of New Caledonia's plant species do not grow in true rainforest but as natural 'bonsais' on the *maquis*. The reason fo the development of this extraordinary plant community lies largely i New Caledonia's unique geological history. The fact that the origina plant assemblage was drawn from the rich plant communities of ol Gondwana is one vital factor, but another, perhaps more decisive on is the nature of New Caledonian soils. The rocks from which ma New Caledonian soils developed, particularly those of the *maqu* were formed deep under the sea and originated from the ocean crust. Only rarely do rocks from the ocean crust appear on lan because, being heavier than the continental rocks, they usually si below them. Where they do appear they bring a rich mix of metals the surface of the Earth. In New Caledonia the rocks of the ocea crust are unusually rich in nickel, magnesium, chromium and ma ganese. In other parts of the world where similar rocks occur, cop and gold are often more abundant.

In high concentrations, both nickel and copper are toxic to m plant life, yet thin, nutrient-poor, nickel-rich soils everywhere s port unique plant communities. These, in turn, support gr radiations of insects and other invertebrates, particularly land sna These rich communities are based on plants which have evolved tolerance to nickel and/or copper. Despite their tolerance, few gr

into trees, but remain as wiry, small-leaved shrubs which grow quite slowly and never support many leaves. As will be explained below, such an environment is very conducive to rapid speciation among plants. This is because variation in nutrients and in nickel and other metal concentrations allows plants to specialise. One species, for example, can grow where nickel is most abundant. Another related species establishes itself where copper concentrations are high and yet another can grow best where concentrations of both are moderate. In good soils, where nutrients are abundant and toxins absent, just a few plant species can dominate because none have to specialise to grow in unusual conditions and those that can use nutrients best outcompete all others. Thus, paradoxically, some harsh environments for plants, such as the *maquis*, support great plant diversity.

While the story of the evolution of the plants of New Caledonia is remarkable, that of its animals is even more strange. We know that at the time New Caledonia broke away from Gondwana quite a variety of animal species were available to populate the newly formed islands. Dinosaurs, turtles, frogs, birds, the ancestors of the platypus and the New Zealand tuatara, geckos and skinks were but a few. For various reasons very few of these groups survived in New Caledonia and it came to be populated by an oddly unbalanced fauna.

Until the arrival of humans about 3500 years ago, New Caledonia was home to crocodiles, lizards, turtles, a few bats (none particularly unusual and all surviving) and birds that had probably arrived by flying over the sea from Australia, Melanesia or New Zealand. All of the larger reptiles—its crocodiles, horned turtles and goannas—became extinct shortly after the arrival of humans.

Given its size and ancient heritage, New Caledonia supported a very modest array of birds. Only 44 species of land birds, including those now extinct, have been recorded from the island.[7] This contrasts markedly with the 169 species once found in New Zealand, or even the 60 living species (excluding extinct ones) found in similar-sized yet more isolated Fiji.

The largest of all of New Caledonia's birds was the giant megapode *Sylviornis neocaledoniae*, a relative of the mallee fowl and scrub turkey of Australia. At about 70–80 centimetres tall and 10–20 kilograms in weight, it was the size of a large goose or turkey and was flightless. Its beak was large and powerful and it had a prominent bony knob on the top of its head. It was probably a herbivore and may have made mounds within which to incubate its eggs, much as the Australian mallee fowl does today. Some researchers think that they have discovered the remains of such mounds, marked by accumulations of pebbles, in the hills of New Caledonia. It seems to have become extinct when humans arrived in New Caledonia some 3500 years ago.

The next largest New Caledonian bird was a flightless species of swamp hen, *Porphyrio kukwiedi*, which would have stood about 50 centimetres tall and weighed less than 10 kilograms. It was perhaps similar in appearance to the takahe (*Notornis mantelli*) of New Zealand. Third largest was a fossil relative of the still living kagou (*Rhynochetos jubatus*), while the kagou itself was next in size. The kagou is the only living member of its family and it is a most peculiar-looking bird. Predominantly grey and rather heron-like in appearance, it has large eyes and a large floppy crest on the head. It has a group of brightly banded feathers used in a striking display, but which are normally hidden in the folded wings. Flightless and ground-nesting, it is vulnerable to introduced predators, and may only have survived because of its extremely secretive habits. Today, it is gravely endangered, its few known nest sites being protected by vigorous rat-trapping programs.

Fifth in size and weight was a now extinct kind of scrub fowl (genus *Megapodius*) somewhat smaller than the scrub fowl inhabiting Australia's Cape York today. The only other prehistorically extinct birds were two large pigeons and two falcons. Within historic times, a rail of the genus *Tricholimnas*, which was related to the Lord Howe Island woodhen, has also become extinct. This very modest assemblage of larger birds stands in distinct contrast with the extravagant feathered faunas of New Zealand, for its largest species weighed less than a tenth as much as a large moa.

Curiously, it was among the reptiles that the finest flower of New Caledonia's fauna is to be found. Hectare for hectare, New Caledonia has one of the most diverse, if not *the* most diverse reptile fauna on Earth. Measured as a proportion of landmass, it is more than 10 times richer in species than Australia, which itself harbours the most

diverse lizard communities to be found anywhere.

As is the case with many of Australia's reptiles, it was long thought that New Caledonia's reptiles must have come from elsewhere, having arrived relatively recently by dispersal over the sea. Increasingly, this view is being challenged and it now seems reasonably clear that many have direct Gondwanan origins.

Before people arrived, the top herbivore on the island was undoubtedly the gigantic horned turtle *Meiolania*. These huge, land-dwelling reptiles belong to an extinct group of very primitive turtles which could not draw their heads into their shells. The remains of similar horned turtles have been found in 65-million-year-old rocks from South America, so there is little doubt that they are Gondwanan survivors.

They were heavily armoured, the tail formed a spiked and solid bony mace, while the head sported a pair of horns remarkably similar in position and shape to those seen in cattle. The New Caledonian turtles were small in comparison with those once found in Australia. They may have weighed 100 kilograms or less. No-one knows how many species of horned turtles existed in New Caledonia, but it would not be surprising if there were several, for most lands have more than one species of large herbivore.

The top predator in the New Caledonian ecosystem was probably a goanna rather similar to Australia's mangrove monitor (*Varanus indicus*), but at about 10 kilograms in weight it was perhaps a little larger.[7] It was probably an opportunistic predator, consuming anything that it was large enough to subdue.

New Caledonia was also home to the Caledonian crocodile, an extraordinary and ancient pygmy member of the crocodile group.[7] Known scientifically as *Mekosuchus inexpectatus*, its remains were first discovered only in 1980 and it was named as late as 1987. At about two metres in total length and about 30 kilograms in weight, as far as crocodiles go it was a true pygmy. The Caledonian crocodile is so unusual that some scientists place it in its own family, the Mekosuchidae. Its remains have been found in deep caves well away from water. This, as well as the shape of its bones, indicates that it was a land crocodile. It was distantly related to other hoofed and carnivorous land crocodiles which, 60 million years ago, were found

throughout the world. All are now extinct. Some fossilised remains of the Caledonian crocodile date to as little as 1800 years ago. Thus, it was the last of the world's land crocodiles to become extinct. Recently, the jawbone of a Caledonian crocodile was recovered at an old village site, indicating that the first humans to reach New Caledonia hunted it.

Without doubt the most unusual thing about the Caledonian crocodile was its teeth, for while those at the front of the jaw were sharp and pointed as in all other crocodilians, its rear teeth were blunt and rounded. A gap appears to have separated the sharp from the blunt teeth. This suggests that it had a diet very different from that of any living crocodile, for it seems likely that it used its blunt rear teeth to crush mollusc shells.

This extraordinary adaptation tells us much about the New Caledonian environment, for the diverse teeth of the Caledonian crocodile suggest a diverse diet. It is probable that prey species suitable for capture with normal crocodile teeth were so few on New Caledonia that they were insufficient to support even a pygmy crocodile. To survive, the Caledonian crocodile had to add blunt teeth capable of crushing more common food sources such as snails and clams. Only on resource-poor New Caledonia were the adaptable crocodiles pushed to such extremes.

Unfortunately, the only New Caledonian reptiles to survive to the present are two families of lizards: the skinks (with 27 species) and the geckos (with 21 species).[12] While most of New Caledonia's skinks are much like skinks everywhere else, it has one extraordinary and now possibly extinct species that deserves comment. *Phoboscincus bocourti*, or the terror skink, as its name aptly translates from the Greek, is known from a single individual collected by a biologist over a century and a quarter ago somewhere (the exact locality being lost) on New Caledonia. This remarkable lizard was over 40 centimetres long. Externally it looks rather like an elongated version of the familiar Australian blue-tongue lizard. Its teeth, however, reveal a very different lifestyle from any other similar-sized skink, for they are long, recurved and distinctly vicious in appearance. There is no doubt that the terror skink ruled over the smaller reptiles of New Caledonia as effectively as *Tyrannosaurus rex* did over the lesser

dinosaurs of its era, or the lion does on Africa's Serengeti today. What happened to the terror skink, or even whether it still survives at some remote location today, remains unknown. It is just one of the many mysteries of the poorly known Pacific.

But it is among the geckos that the strangest surviving reptiles are found, for there is a group of species that form an evolutionary radiation unlike that seen anywhere else on Earth. Fourteen of New Caledonia's gecko species belong to an ancient subfamily whose distribution covers that of much of old Gondwana, including northern New Zealand and Australia.[11] There is no doubt that they have been inhabitants of New Caledonia for the past 80 million years and that they have been fine tuning their ecology to conditions there all that time.

As a result, they have produced some extraordinary species, including *Rhacodactylus leachianus*, the world's largest surviving gecko species. At up to 40 centimetres long and the thickness of a man's wrist, it is, by gecko standards, a titanic beast. As with many geckos, it has the ability to virtually disappear against the mottled trunk of a rainforest tree. I have seen them, lying flat upon a grey-barked tree with their skin and even their eyes, each over a centimetre in diameter, taking on the tone of the bark perfectly. They hug the branch so tightly that even their contour is obscured. It is only when they move their enormous, webbed feet to reveal the bright yellow soles that the magic of their disappearing act is broken.

These huge geckos have a lifestyle as peculiar as their appearance suggests. They are entirely arboreal and nocturnal and emit a strange croaking sound. Their diet consists mainly of fruits and flowers, but they have been reported to eat birds as large as honeyeaters and even the young of their own species. They are thus New Caledonia's ecological equivalent to some of the more omnivorous monkeys and possums found elsewhere in the world, but perhaps have a slightly broader ecological niche.

A related but smaller species, which has not been seen for about a century and may well be extinct, has twin lines of dinosaur-like spines down the back. Yet another species (*Rhacodactylus trachyrhynus*) has adapted to a more exclusively carnivorous lifestyle. At only 17 centimetres long from nose tip to the base of the tail, it is the diminutive leopard of the New Caledonian rainforests, pursuing and subduing other lizards as well as insects. Strangely, its young sometimes hide in the centre of water-filled bromeliads.

The species *Rhacodactylus auriculatus* has evolved into a chameleon-like insectivore of the *maquis*. It sports a pair of short horns which emerge, cow-like, from the back of its skull. It lays only two eggs per clutch. Yet other members of this extraordinary group have filled more standard gecko-like niches.

The fauna of New Caledonia is so strange that it begs interpretation. We know that mammals, birds and geckos were all present on the starting blocks when the island broke away from Gondwana. Why was it that the geckos, at first an unlikely looking species to dominate a fauna, became New Caledonia's miniature ecological equivalents of monkeys and possums? Why did a turtle fill the ecological role of an elephant and a crocodile turn to eating mussels and snails?

The answers almost certainly lie in New Caledonia's toxic soils, small size and position just above the Tropic of Capricorn. The tropical climate enjoyed by much of New Caledonia means that cold-blooded species can use the sun almost daily to raise their body temperature. The poor soils dictate that overall biological productivity is low. The small size of the island means that species which need large home ranges can sustain only very small populations. These factors work against animals that use lots of energy, such as all warm-blooded animals (including mammals and birds) and against large animals in general.

The general situation can be envisaged this way. Imagine a bird and a lizard of similar size that eat the same prey, in this hypothetical case, a species of grasshopper. Working in favour of the bird is that it is faster, more agile and thus more likely to find and catch prey than the lizard. Working against it is that it must put a very large amount of energy into keeping its body warm and into powered flight (which is generally the most energy-expensive way to travel). Thus, it must eat every day in order to meet these expenses. A further disadvantage is that a given amount of habitat can support relatively few such mobile and energy-demanding creatures.

The lizard on the other hand is slow, restricted to the ground and cannot travel far. But in its favour is the fact that it is an energy miser and that many individuals can be supported by a relatively small

patch of habitat. It uses the warmth of the sun to 'hitch a free ride' in raising its body temperature and it can go without food for a long time. If necessary it can 'close down' or aestivate. In this condition, its metabolism just ticking over, it can rest in a burrow for months until favourable conditions return.

In 'normal' parts of the world, where grasshoppers are moderately abundant, the bird enjoys a tremendous advantage and usually outcompetes the lizard, for the only restriction upon it—the constant availability of large amounts of suitable fuel—is removed. New Caledonia, however, falls at the extreme low end of the scale as far as energy availability goes. There, poor soils and small land area mean that energy is critically limited. Under such conditions, it may be that no matter how good a species is at finding food, it may sometimes have to go for weeks without eating. Furthermore, because the land area is so small, the total populations of any energy-greedy creature may easily fall below the critical level (geneticists reckon it at about 500 individuals) necessary for long-term survival.

It is for these reasons that New Caledonia's land reptiles outnumber its land birds—even including its extinct birds—and the reptiles fill such a wide variety of ecological niches. It is also why the Caledonian crocodile was forced to diversify its food choices and why a turtle, rather than a large monotreme, became top herbivore. In a sense, New Caledonia was made for reptiles as much as it was made for flowering plants. It is a sort of perverse Garden of Eden, with a scaly creature hiding behind every bloom, waiting millions of years to tempt the wandering biologist, or to amaze any visitor to this most exotic of lands.

CHAPTER 4

LAND OF SOUND AND FURY

While the flora and fauna of New Caledonia were being transformed by toxic soils under a tropical sun, its southern cousin New Zealand was following quite a different path. The island archipelago that is New Zealand has been a bit of a stay-at-home, for it has drifted the least distance from its Antarctic cradle. Coming to rest in chilly climes at 32–48° south, it has not escaped the influence of its parent the Antarctic continent, for during each of the Earth's last 17 ice ages, New Zealand has been transformed by snow and glaciers. With the exception of a tiny eight-square-kilometre ice-cap in Irian Jaya, New Zealand is the only one of the four 'new' lands to support a glacier at present.

In a way, New Zealand's evolution has been driven by forces almost opposite to those that shaped life in New Caledonia. New Zealand, for example, has not recently suffered a deficit of good soil. Indeed, of all the 'new' lands, it has been most blessed in its extensive and fertile covering of soil. This covering has been formed by all three processes that commonly contribute to soil formation: glacial action, volcanoes and rapid mountain-building. At about 265 000 square kilometres, New Zealand is some 15 times larger than New Caledonia (but only about one-thirtieth the size of Australia) and the climate is much colder. Like New Caledonia, it is among the most isolated of the world's landmasses.

Although it started out with a similar fauna and flora to New Caledonia and Australia, New Zealand's fertile soils, relatively large size, cold climate and isolated position have dictated that it evolve in a very different direction. Its plant communities, for example, are much less diverse (with less than half the species found in much smaller New Caledonia), although they include many species from Gondwana. A conspicuous absence is the ancient tree genus

Araucaria, which is so abundant in New Caledonia and so ancient that it provided shade for the dinosaurs. New Zealand has probably long been too cold to support them, for today these lofty pines are restricted to islands north of Norfolk Island in the Pacific. The beautiful protea family is also extremely poorly represented with only two species, perhaps because New Zealand lacks the really poor sandy soils derived from ancient rocks that members of the family seem to thrive in elsewhere.

New Zealand's cold climate has doubtless played a major role in shaping its reptile fauna. Clues to this lie in the reproductive strategies of New Zealand's 11 gecko species, some of which live at the highest latitudes reached by geckos anywhere in the world. New Zealand's geckos are unique in their family in that all give birth to live young. Even today much of New Zealand is just too cold to leave gecko eggs to the vagaries of nature. During the ice ages, however, conditions were much worse. In such conditions it is critical that the eggs are carried in the body of the mother, to be warmed by the sun whenever possible, if they are to have a chance of survival. Although New Zealand's geckos survived by developing this unusual adaptation, many reptiles could not tolerate the increasingly cold conditions. Today, New Zealand lacks crocodiles, goannas, freshwater turtles and land turtles, even though all were probably part of its Gondwanan heritage.

A major exception to the general rule of reptilian paucity in New Zealand is the tuatara (*Sphenodon punctatus*). This superficially lizard-like animal belongs to the order Rhynchocephalia. One of the more unusual features of the order is the possession of a partially functional third eye, which is hidden under a transparent scale in the middle of the forehead. The last time that rhynchocephalians were a significant force was some 180 million years ago, before even the dinosaurs came to dominance. The survival of the tuatara in New Zealand is thus of great interest. Tuataras are unusual among reptiles in that they can remain active even when the temperature falls to five degrees Celsius, as long as they can sun themselves. They have a slow metabolism.[29] Their eggs take an extraordinary 15 months to hatch. After birth they are very slow-growing and may live for a century or more. These factors may help explain their survival in chilly New Zealand.

The only other reptiles to survive in New Zealand are skinks and geckos. Until the 1980s it was thought that there were about 30 species, but studies of the biochemistry of these reptiles show that in fact 60 species exist. Many are similar in appearance and ecology and species with the same ecological niche replace each other in different locations. Despite the poor record of the reptiles, warm-blooded creatures did not have New Zealand entirely to themselves, for the cold, damp forests were an ideal habitat for frogs—and frogs appear to have once been vital species in New Zealand ecosystems.

In the past, New Zealand was home to six species of frogs.[34] These seem to have played a much larger role in the ecosystem than frogs usually do elsewhere. Unfortunately, the three largest species, which were up to nine centimetres long, have become extinct in the last 800 years, while the three surviving species have been pathetically reduced. One is restricted to a tiny patch of boulders and a rainforest relic on two islands, while the others are restricted to remnant areas on the North Island.

These frogs all belong to a very ancient family called the Leiopelmatidae. All share an unusual and decidedly non-primitive feature of their reproduction, for the entire tadpole stage occurs in the egg, from which hatch perfectly formed froglets which possess a tail. The males brood the eggs and when the young hatch they climb onto their father's back to continue growing there, living on the energy contained in their tails. Reproduction can, therefore, take place quite independent of free water. They are undoubtedly survivors from Gondwana as they belong to an ancient group which has a very limited capacity to cross the sea.

Recent fossil finds indicate that as little as 800 years ago frogs were once a dominant life form in many of New Zealand's forests, for their fossilised bones have been found by the tens of thousands in some fossil deposits. The mossy forest floor probably crawled with them. It seems probable that their dramatic decline was brought about by the kiore (the Maori name for *Rattus exulans*), which reached New Zealand with the first Maori. Kiore may have eaten young frogs, or competed for insects, which are a vital food for both. Some New Zealand biologists think that soon after their arrival, kiore may have formed plagues of such vastness that they have never since

been rivalled. In a few brief years they may have stripped the forests of their frogs and other fauna.

Curiously, with the exception of a few bats that arrived by flying over the sea from South America, mammals were never a feature of the New Zealand land fauna. Given their 120-million-year history in Australia, it seems certain that the ancestors of the platypus and echidna were present when New Zealand parted from Australia, but for some reason they became extinct.

The group that really came to dominate this particular corner of Tasmantis was the birds, for until 800 years ago New Zealand had the most extraordinary, indeed unbelievable, assemblage of birds. Nothing like it was found anywhere else on Earth. Examination of the fossil remains of this once great assemblage, as well as study of the few surviving remnants, suggests that in New Zealand birds occupied all of the major ecological niches occupied by mammals elsewhere. One-hundred-and-sixty-four species have been recorded, a very large number of which were flightless.

To a biologist, the most extraordinary thing about the evolutionary radiation of birds in New Zealand is its ecological breadth. Nowhere else on Earth did birds evolve to be the ecological equivalents of giraffes, kangaroos, sheep, striped possums, long-beaked echidnas and tigers. In a sense, New Zealand is a completely different experiment in evolution to the rest of the world. It shows us what the world might have looked like if mammals as well as dinosaurs had become extinct 65 million years ago, leaving the birds to inherit the globe.

Perhaps the most extraordinary—and certainly most striking—of New Zealand's birds were the moas. *Moa* is a Polynesian word meaning chicken. Curiously, it seems that when the Maori arrived in New Zealand they carried domestic chickens with them. But who in their right mind would go to the trouble of tending chickens in that extraordinary land of birds, for in New Zealand the largest 'moa' towered over three metres high and weighed up to 250 kilograms. The domestic 'moa' were probably quickly eaten or neglected once the Maori saw what a 'real' moa looked like.

Unfortunately, we will never know the intimate details of the lives of the moa, for all 12 species are now extinct.[1] They probably

belonged to a very ancient group of birds known as ratites. Ratites are today restricted to the southern continents, with the ostrich in Africa, emu and cassowary in Australia–New Guinea, the rheas in South America and kiwis in New Zealand. Thus, everything points to them being yet another group of Gondwanan origin.

Because moas became extinct so recently, some remarkable remains have been found. Feathers, for example, have been discovered on a number of occasions. Moas appear to have been entirely covered in feathers, from the base of the beak to the feet. Perhaps they needed this covering because New Zealand is so cold. The feathers are simple in structure, like the feathers of an emu. Most are reddish-brown and most moas were probably rather like a kiwi in colour. But a couple of quite extraordinary feathers have been found. One, almost 16 centimetres long, was pure white, while another, 5.5 centimetres long, was bright purple. Scientists have interpreted these feathers as evidence of crests, brightly coloured breast patches or colourful tails.[1]

Mummified moa legs, heads and necks have also been found. The neck was extraordinary for its thickness, the base in one of the smaller species being 47 centimetres in circumference and covered in thick, tough skin. Moa eggs and chicks have also been found. It appears likely that moa tended only one or two eggs at a time, which contrasts with the large clutches laid by emus and cassowaries. Even trackways have been found and these, along with the bones of their legs, suggest that the moas were slow-moving compared with the larger living ratites.[1]

Without any mammals to compete against, the ratites were set free to occupy a wide range of ecological niches. The 12 moa species were all herbivores. Some were rather superficially giraffe-like, others filled the ecological roles of rhinoceros and kangaroos. The very largest species were members of the family Dinornithidae, which included three very tall and graceful species that occurred on both the North and South Islands. With its neck stretched up, the largest would have reached over 3.5 metres high, towering twice as high as a man. These impressive birds were browsers of tall shrubs and shorter trees.

The remaining moa species were all much shorter and are placed in the family Anomalopterygidae. The largest would have weighed a

little less than 200 kilograms, the smallest a little more than 20 kilograms. The diversity of beak shape suggests some differences in diet and it seems likely that some species were restricted to particular habitats. High elevation beech forest, for example, seems to have been favoured by *Megalapteryx didinus*, a short, 50 kilogram species with a short beak; while *Pachyornis australis*, among the smallest of the moas at 30 kilograms, preferred the subalpine grasslands of the mountains.

Because of their recent extinction and the longevity of certain New Zealand plant species, it is quite likely that some New Zealand plants living today were browsed by moas. An interesting legacy of the moas' long reign in New Zealand is the growth habit of many of New Zealand's smaller trees and bushes. These plants have what is called a divaricating growth habit. In these species the outside of the plant is covered in tough, often leafless twigs, which protect the tender growth inside. This feature is seen in no less that 50 plant species placed in 17 of New Zealand's plant families.[28] Almost all divaricating species are less than four metres high, or, if taller, show this in the juvenile stage. This defence was doubtless sufficient against the toothless moa, but does little to protect the plant against large herbivorous mammals, which are used to dealing with more effective spines and toxins.

The last of the moas became extinct some 400 years ago and today their only surviving relatives in New Zealand are the kiwis. Surely the most unusual of living birds, the four surviving kiwi species (one of which was first recognised as being distinct as late as 1992[29]) are nocturnal and probe for worms and other invertebrates with their long bills. In the northern hemisphere, shrews fill a similar ecological niche, while in New Guinea the long-beaked echidna (*Zaglossus*) does.

One of the most intriguing pieces of evidence that kiwis are descended from moa-sized ancestors concerns the size of their eggs. If a large bird evolves to become smaller, the size of its egg does not shrink as much as its adult body size. Having evolved from a gigantic ancestor, the female kiwi has the unenviable task of laying the world's most outsized egg. At about 420 grams in weight, it is five to 10 times as large as the eggs laid by similar-sized birds. Indeed, it can weigh one-quarter as much as the mother kiwi herself! If humans had gone down a similar evolutionary path, women would be giving birth to babies weighing 15 kilograms (33 pounds) or more.

Curiously, this condition, which at first sight appears to be a maladaptation, has allowed kiwis to survive the human invasion more successfully than other New Zealand birds. Because of their reduced size and nocturnal behaviour, they are difficult birds for humans to hunt and so the Maori could not exterminate them as easily as they did the moa. Just as importantly, their large eggs have given them protection from that other enemy of New Zealand birds, the rat, for they are too large to be rolled from the burrow and opened by a rat. The outsized egg also gives chicks a better chance at survival, for when hatched they are large, well-developed and able to defend themselves. The destruction of eggs and young birds by rats continues to be one of the greatest threats to New Zealand's native birds, so these fortuitous adaptations are valuable indeed to the kiwis.

Moas and kiwis were not the only extraordinary birds of New Zealand's past. Eight hundred years ago New Zealand was home to the largest ever member of the eagle family. The males and females of Haast's eagle (*Harpagornis moorei*) differed considerably in size; the larger females, at 13 kilograms in weight, were significantly bigger than the world's largest living eagle (the harpy eagle of South America). There is some debate as to whether these titanic predators were competent fliers, but most researchers suspect that their short, rounded wings were capable of carrying them rapidly through the forest. As might be suspected of an animal capable of killing great bipedal birds such as the largest moa, its weapons were awesome. Richard Holdaway, who has devoted his career to the study of this extraordinary species, has said that it:

> *had claws as big as a tiger's and it could strike its prey with the force of a concrete block dropped from the top of an eight-storey building.*[65]

Holdaway has found the pelvis bones of moa which have been perforated by the enormous talons of Haast's eagle, showing that it could penetrate the tough skin and bone of the moa's lower back.

Holdaway ponders the nature of interactions between the Maori and Haast's eagle. He notes that, to Haast's eagle, a person dressed in a feather cloak may not have appeared very different from a moa. Perhaps the Maori legend of ***Pouakai***, a huge bird that would swoop down and carry off men, women and children to consume in its eyrie, reflects a vague folk memory of the most fearsome of New Zealand's birds.

At least one other large, apparently carnivorous bird existed in New Zealand before the arrival of the Maori. This was the adzebill (*Aptornis otidiformis*). About the size of the smallest moa, this flightless and rather rail-like bird had an extraordinary and fearsome looking adze-like beak. Perhaps related to the kagou of New Caledonia, the adzebill remains very poorly known, its precise role in New Zealand ecosystems being unclear.

One of the most pervasive trends among New Zealand birds is towards flightlessness. It is present, of course, in the moa and kiwi, but almost every bird lineage has some flightless or poorly flighted species. New Zealand was home to flightless or poorly flighted geese and ducks, rails, parrots, owlet-nightjars, wrens and other perching birds.

The reasons for this trend may lie in the energetics of flight. As any aircraft engineer, or indeed any paying passenger can tell you, powered flight is the most energy-expensive way to travel. On the continents, in the presence of mammals, there are very few ecological niches for flightless birds, for they are either eaten or outcompeted by mammals. On islands, however, where (for reasons not entirely clear) mammals are disadvantaged, many niches are open for flightless birds. Energy saved on flight can be put into reproduction and so, through natural selection, the ability to fly is rapidly diminished or lost.

As well as moas and eagles, New Zealand harboured other extraordinary birds, including now extinct pelicans, swans, geese, ducks, falcons, quail, rails, relatives of the New Caledonian kagou, snipes, owlet-nightjars, owls, crows and even wrens. Most of these had diminished powers of flight or were flightless. Among the living or recently extinct species are such unusual birds as the nocturnal, grass-eating kakapo (*Strigops habroptilus*) which, although a parrot,

resembles nothing more than an enormous green owl. A thousand years ago it was one of the most widespread of New Zealand birds and its bones have been found in abundance in fossil deposits throughout the length and breadth of the archipelago. Today, it is one of the most endangered birds on Earth, for only 50 individuals survive. They have been translocated onto two tiny islands, where their diet is supplemented. Only 16 of the 50 are female. It is upon their breeding success that the entire future of the species depends. Thus far, only a single young has been hatched in captivity. Born in 1993, it was, thankfully, female.

Another extraordinary survivor is the giant swamp-hen or takahe (*Notornis mantelli*). About 60 centimetres high and coloured vivid blue and green, it has a stout, bright red bill. Remarkably, this brightly coloured bird is a close ecological equivalent of sheep, for it feeds upon alpine grasses until they become covered by deep winter snow. Then it forages inside the beech forest for ferns. It was first described in 1848 from fossilised bones found alongside those of moas on the North Island, by that greatest of anatomists Sir Richard Owen. He presumed that it was as extinct as the moas. Four living specimens were collected in the late nineteenth century but none thereafter. By the 1940s scientists again presumed that it was extinct. But then, in 1948 a tiny relict population was located in a remote grassy valley in Fiordland, South Island.

One of the most extraordinary birds of all time was the crow-like huia (*Heterolocha acutirostris*). At about 45 centimetres long it belonged to a family of birds that is unique to New Zealand, all of which have bright orange or blue wattles at the corners of their beaks. The huia was unique among the world's bird species in that males and females had entirely differently shaped beaks. This was an extraordinary adaptation for obtaining their food, which predominantly consisted of a large, witchetty-grub-like larvae of the *huhu* beetle which bores into rotten wood.[60]

The male, with his short, stout beak would chip into the soft rotten wood and the female with her long, thin, tweezer-like beak would extract the beetle larvae from tunnels in harder wood. There even some evidence that pairs of huia (the male and female were almost invariably found together) cooperated in obtaining food.

Fossil remains reveal that the huia was once widespread and common in New Zealand. By the time Europeans arrived it had become restricted to a small area of beech forest in the south of the North Island. It was an important species to the Maori, for the beautiful black huia tail-feathers, with their broad, white tips, were used in personal decoration to denote mourning or high social status. Indeed, so valued were they that they were traded, in ornately carved wooden boxes, the length and breadth of New Zealand. The wearing of huia feathers may be a venerable tradition, for in 1642 Tasman saw what was probably a huia feather adorning the hair of one of his Maori attackers.

By the time of European settlement, huia hunting was regulated by tradition. Maori ***tohunga*** or shamans would place a ***tapu*** upon a forest area when huia numbers became too reduced. The breakdown of traditional Maori lifestyles with the coming of the European settlers disrupted this practice and hunting on a grand scale began again. In the late nineteenth century, just a few years before the last huia died, a prominent ornithologist recorded that 11 Maori hunters killed 646 huia in a single month. By 1907, the slaughter of one of the world's greatest ornithological treasures was complete.

Despite this great array of fascinating species, the most inherently interesting of all New Zealand birds were, to me, a family of tiny, entirely flightless, wren-like birds. They appear to have been the ecological equivalents of mice. As with so many of New Zealand's birds, they rapidly became extinct following human disruption of their habitat. In this case a few hundred individuals of a single species survived on a tiny, remote and unpopulated island until 1894. Known as the Steven's Island flightless wren (*Xenicus lyalli*), it was to create a scientific sensation when the last population was discovered—and made extinct—all in the same year.[60]

The story began when the New Zealand government decided to build a lighthouse on lonely Steven's Island. The lighthouse keeper, lonely himself, decided to keep a cat. Each day, the cat would bring a few tiny brown birds home. The lighthouse keeper had seen them at dusk, running nimbly like mice through the undergrowth near his lighthouse. He never saw them fly. Puzzled by their unusual appearance and behaviour, the lighthouse keeper sent a few bodies to a museum. But by the time a scientist realised that these tiny birds were the only surviving flightless perching birds (the largest bird group of them all) ever discovered, the lone cat of Steven's Island had exterminated the entire species.

Studies of fossils have now revealed that the Steven's Island flightless wren was but the last survivor of a great group of flightless or poorly flighted, wren-like birds. The remains of several hitherto unknown genera have been discovered in fossil deposits, their tiny and fragile bones previously unnoticed amongst the great bones of the moa. These tiny birds once dashed about the forest floor throughout New Zealand, occasionally perhaps falling prey to the largest of New Zealand's frogs. They appear to have filled the ecological role of mice and voles elsewhere. They are a fragile reminder of just how differently evolution has proceeded in New Zealand.

Unfortunately, it was not only such obviously vulnerable species that vanished from New Zealand with the arrival of humans. The long-extinct New Zealand swan, for example, was quite similar to the Australian black swan. Its nesting habits or restricted habitat may have made it especially vulnerable to hunting by Maori. New Zealand also lost species similar to the Australian Cape Barren goose, Tasmanian native hen, musk duck, freckled duck, Australian sea-eagle and crow. The reason why so many species became extinct in New Zealand, while their relatives survived in Australia, is curious and not readily explained. It may be that there were simply fewer refuges in smaller New Zealand, or that the carnivorous Australian marsupials and reptiles had preadpated the vulnerable Australian birds to the presence of sophisticated predators, including humans.

Why should New Zealand, alone among the world's larger continental fragments, have become a land of birds and frogs in what has elsewhere become, since the extinction of the dinosaurs, an age of mammals? Why, indeed, did it not follow New Caledonia and become a land of reptiles? Several important factors seem to be responsible. First, at 250 000 square kilometres, New Zealand is a relatively large land. This means that it can support large populations of large animals. Second, it has an abundance of superb soil and this through increased biological productivity, enhances its ability to support large species. Indeed, so productive were New Zealand's soil

they allowed the evolution of such energy-hungry species as Haast's eagle. Third, New Zealand is a cool and wet land, which has been refrigerated repeatedly during the ice ages. Amphibians can be advantaged over reptiles in such conditions, which may explain why its frogs were so abundant.

These factors readily explain why warm-blooded creatures should predominate over cold-blooded ones and why frogs should be so successful. But why should birds have won out over mammals? Mammals were certainly present in New Zealand at the time that it broke away from Gondwana, for the ancestors of the monotremes have been present in the region for at least 120 million years. Yet they did they not survive in New Zealand. I must admit that, at present, the failure of New Zealand's monotremes to thrive is a mystery—and somewhat of an embarrassment to those who study mammals and always assume them to be adaptively superior to birds. The only factors I can point to that may help in explaining this is the extreme conservatism of monotremes (probably the only mammals present in New Zealand at the time) throughout their 120-million-year-plus history, and the fluctuating land area of New Zealand through time.

The conservatism of monotremes is best told through their teeth. Remarkably, virtually all known monotreme teeth—whether they are 120-million-year-old fossils from Lightning Ridge, 60-million-year-old fossils from Argentina, or the teeth of the living juvenile platypus—are so similar that they are instantly recognisable. They show much less variability than is present in the teeth of much more recently evolved groups such as the kangaroos, cats or apes. Also remarkable is the extreme conservatism of monotreme body size, for all known monotremes weighed between one and less than 20 kilograms. This great conservatism in tooth form and body size suggests a conservatism in ecological adaptation. This may seem unlikely given the diverse lifestyles of the living platypus and echidna, but a closer look at these species reveals more similarities than might at first be expected. Both, for instance, prey upon invertebrates and although one is aquatic and the other terrestrial, both have an electro-sensitive bill which is used to detect food and both are similar in internal anatomy. It may well be that this great conservatism

disadvantaged the monotremes in their competition for survival with New Zealand's birds.

A second important factor relates to land area and geological history. Throughout the last 80 million years New Zealand has been a shifting, unstable archipelago. At various times islands have submerged, while others have risen from the sea. By about 30 million years ago, New Zealand was reduced to a few tiny islands, the rest of the continental rocks being submerged below the sea. This history may have selected for animals that can survive on very small islands (such as energy-hoarding reptiles and frogs), or species that can fly from one island to the other, such as birds (even poorly flighted ones). Thus, the monotremes, unable to do either of these things, were selected against. Although this argument has some appeal, it is not entirely satisfying, for it does not account for the survival of moas and kiwis, which may have been flightless since Gondwanan times. Perhaps the best answer is the one that many scientists are unwilling to accept: that birds are adaptively superior to monotremes, and where they come into competition on smaller landmasses (those with less ecological niche space) birds can outcompete egg-laying mammals.

Monotremes were not, however, the only mammals to compete with New Zealand's birds before the coming of humans, for New Zealand's bats provide another fascinating, if frustrating, insight into the way birds and mammals compete on islands. New Zealand has only ever had three bat species. One, a relatively recent immigrant, is related to Australia's lobe-lipped bats (genus *Chalinolobus*), which are common in and around most Australian cities. The other two species are placed in their own family, the Mystacinidae. Their origins were mysterious until 1986, when a team of biochemists compared their DNA with those of bats around the world.[109] They found, to their great surprise, that the mystacinids were derived from a group of South American fishing-bats, which includes one species that eats anchovetta which it catches far out to sea off the coast of Peru. Their work suggests that about 30 million years ago, some South American fishing-bats became lost at sea and were blown to New Zealand. There, they gave rise to the greater and lesser short-tailed bats, as the two mystacinid species are known.

I find it amazing, given that these bats have been present in New Zealand for so long, that they did not give rise to a great radiation of mammals, much as the bird groups have done. Both mystacinid species could fly and the one surviving species is an ecological generalist, eating insects, pollen and nectar from flowers and even scraping the fat and meat off mutton birds put out to dry. No other bat has such broad tastes in food. Unfortunately, we know nothing of the ecology of the larger of the two species, for it became extinct in 1965, before its biology was studied. Its extinction was as needless and mindless as it was tragic. The last known colony survived in the extreme south of New Zealand, on Big South Cape Island. One day in 1962 a fishing boat stopped at the island and some rats as well as fishermen got ashore. Within three years the rats had destroyed every bat on the island, depriving us of the chance of ever knowing anything about the lifestyle of this strange creature.

I have to resort to another rather feeble hypothesis in order to explain why New Zealand's bats did so poorly in competition with the birds. The only reasons I can think of are that they arrived long after the birds had become established and had evolved to fill every conceivable niche. Alternatively, bats may be too specialised in their anatomy to re-evolve into other land-based life forms. If the first hypothesis is correct, perhaps there were, by 30 million years ago, very few vacant ecological niches left to occupy in New Zealand, except those traditionally occupied by bats.

New Zealand's unique soils, climate and history determined that it became a land of birds and frogs, which by a strange evolutionary coincidence include among their ranks nature's greatest vocalists. Joseph Banks, when anchored off Cooks Strait, thrilled to a wonderful morning on 6 February 1770:

> *This morn I was awaked by the singing of the birds ashore from whence we were distant not a quarter of a mile, the numbers of them were certainly very great who seemed to strain their throats with emulation, perhaps; their voices were certainly the [most] melodious wild musick I have ever heard, almost imitating small bells but with the most tuneable silver sound imaginable.*[104]

Even nineteenth century visitors to New Zealand described the dawn chorus of its by then sadly depleted bird fauna as 'deafening'.

I would gladly remain ignorant of the joy of the *Haka*, or even the heart-stopping beauty of Dame Kiri Te Kanawa singing *Songs of the Auvergne*, for the privilege of waking to a symphony of 'the most tuneable silver sound imaginable'. Aotearoa's multitudes of birds performed that symphony each dawn for over 60 million years. It was a glorious riot of sound with its own special meaning, for it was a confirmation of the health of a wondrous and unique ecosystem. To my great regret, I arrived in New Zealand in the late twentieth century only to find most of the orchestra seats empty. Walking through the ancient forest, whose still-living trees were once browsed by moa, I heard nothing but the whisper of leaves blowing in the wind. It was like the rustle of the last curtain fall on an orchestra that will be no more.

CHAPTER 5

MEGANESIAN ENTERPRISES

Meganesia exists as a single landmass only during ice ages when the sea-level is low. At these times Australia, Tasmania, New Guinea and many smaller islands are joined into a single great island (hence the name, meaning 'great island' in Latin) which covers an area of over 10 million square kilometres. The name is not yet in common usage, but biologists are beginning to adopt it because it describes a distinctive biological and geological entity. Meganesian animals and plants share a common biological heritage because their homeland has drifted across the face of the planet as a unit, with a common geological and climatic history. This is reflected in such distinctive characteristics as the abundance of marsupials and monotremes and the lack of native placental mammals, except for murid rodents and bats.

While the lands of Tasmantis (including New Zealand, New Caledonia and Norfolk and Lord Howe Islands) were drifting northwards, Meganesia was to remain attached to Antarctica for at least a further 40 million years. The rift which would finally see it set free was slow to develop at first. It began in the west and over 40 million years or more it gradually widened, an arm of the sea spreading ever eastwards between southern Australia and Antarctica. The old incipient rift between Tasmania and Victoria was now inactive, so the widening channel passed instead to the south of Tasmania. Tasmania's geological history has much more in common with Antarctica than Australia, so this new rift saw it part company with its parent and drift northwards joined to what is geologically an almost foreign land. By about 36 million years ago, Meganesia as we know it today had taken shape and was freed from Antarctica to begin its great journey north.

While this separation was a critical event in the evolution of the

Australian fauna and flora, the fact that Australia had remained part of Gondwana for 40 million years longer than its neighbours was also important, for this allowed relatively recently evolved groups of animals and plants to cross the Antarctic landbridge and enter Australia. Today, Antarctica is more an impenetrable barrier than a landbridge, but in geological terms it became a frozen waste only relatively recently.

The nature and timing of glaciation in Antarctica is still not well understood. Although many people think that glaciers have been present in Antarctica for at least 20 million years, a few researchers suggest that some areas have supported land-based life until much more recently. Indeed, the most extraordinary evidence for the possible late survival of forests in Antarctica has recently been found. A geologist working at an elevation of about 2000 metres in the Transantarctic Mountains found what appeared to be fresh silt which crumbled in his hands. They had been washed out of a glacial moraine (the enormous pile of rocks left behind by a glacier). This was extraordinary enough, for it denoted the presence of free water in what was otherwise a permanently frozen waste. As he examined the sediments, surprise grew to astonishment when he recovered pieces of wood that were still flexible and looked quite fresh, then the impressions of leaves very similar to those of Tasmania's deciduous beech (*Nothofagus gunnii*). When the sediments were combed for microfossils, some tiny freshwater organisms were found which suggested that the plant fossils were no more than three million years old. If this extraordinary discovery is confirmed, then researchers will have to throw away their text books, for according to every model, central Antarctica should have been well and truly glaciated by that time and almost all life banished.[93]

Going back 40 million years and more, however, we find that a continuous belt of cold-adapted forest probably joined southern South America, Antarctica and south-east Australia. Conditions had deteriorated since the age of the dinosaurs and the harsher climate had selected for only the most cold-adapted species. Fossil remains from Antarctica, South America and Australia reveal that forest, similar to fragments of temperate rainforest and woodland that survive in Tasmania and Chile today, extended in a broad band across southern

Australia, Antarctica and southern South America. In these forests southern beeches of the *fuscus* group (to which Tasmania's magnificent deciduous beech belongs) dominated, along with ancient pines, various primitive kinds of flowering plants such as the Winteraceae (their flowers somewhat like magnolias) and Proteaceae.

It is only very recently that we have begun to understand something of the kinds of animals which inhabited those forests. We can reasonably deduce from the nature of the forest and its climate that reptiles would have been greatly disadvantaged, for the perpetual cold and long, dark winter make life for the cold-blooded reptiles virtually impossible. Amphibians have a different metabolism, so it is quite likely that the ancestors of some South American and Australian frogs inhabited that ancient forest. It was the warm-blooded animals, however, that survived best under such conditions.

Those that have left the best fossil record are the mammals, which is very convenient, for their strange distributions have long posed the most difficult questions to zoogeographers. It has long been known that only in Australia and South America have the marsupials undergone extensive evolutionary radiations. Their presence has long been used as evidence for some sort of connection between the southern continents. But some palaeontologists have queried the existence of a continuous forest tract between South America and Australia 70–40 million years ago. If such a forest existed, they asked, why did not monotremes use it to escape confinement in Australia? After all, they had been in existence there for over 120 million years. And why, also, did not placental mammals (a group which includes dogs, cows and ourselves), which had long been present in South America, use it to reach Australia? Furthermore, when did the marsupials cross it and which way did the traffic flow—from Australia to South America—or vice versa?

The answer to the last of these questions began to become apparent in 1979, when Professor Frederick Szalay, Lecturer at the City University of New York, made a sabbatical visit to Australia. Szalay is a gentlemanly Hungarian with a slight accent, dark, soulful eyes, a Sigmund Freud beard—and a foot fetish. For he has long devoted his researches to evolution as it can be interpreted through the bones of the feet.

Most palaeontologists who study mammals concentrate upon the teeth, because they are complex and fossilise well. This has been very limiting, because much good information present in other parts of the body is missed. Until 1979 much of Szalay's work concerned primates.

Szalay came to Australia in 1979 in order to study the foot bones of marsupials. We met because I had independently developed an interest in feet, particularly those of kangaroos. We found we had such common interests that we began collaborating closely—even going so far as to describe a new fossil species of tree-kangaroo, based upon foot bones, which we named after my wife!

After examining the foot bones of every major marsupial group Fred came up with an answer to a question that had plagued students of marsupial evolution for over a century. The question was this. Had marsupials invaded Australia from South America (perhaps the more popular view), or had they invaded the Americas from Australia and Antarctica? This last view was being championed at the time by some biochemists and particularly nationalistic palaeontologists and zoologists (whoever said that politics does not enter into science was a ninny).

Teeth had been no help at all in answering this conundrum, for the various marsupial groups had become too specialised in their dentitions to yield any clues. The great achievement of Fred's work was his identification of a close relative of the Australian marsupials among the South American species, based solely upon the structure of the foot. He showed that all Australian marsupials, whether now ground-dwelling or arboreal, shared certain structures of the feet which suggested that all had been derived from an arboreally adapted ancestor. Among all of the South American marsupials, fossil and living, only one had a similar foot—the Monito del Monte, or 'small monkey of the mountains' as *Dromiciops australis* is known to Spanish speakers.[128] *Dromiciops* is a tiny marsupial, no larger than an Australian pygmy-possum. It is found only in Chile, where it inhabits ancient *Nothofagus* forests that hardly differ from those that once linked Australia and South America.

When Fred announced his discovery at a scientific meeting in 1981, vigorous debate broke out. Indeed, the exchanges broke down more than once into what could most charitably be called a slanging

match, as some Australian scientists, incensed that a cherished theory had been demolished by a New Yorker with an European accent, tackled Fred over his work at the conference barbecue. At first, it seemed that Fred's findings would be rejected, but in the decade following his discovery much remarkable evidence has been forthcoming that supports his hypothesis. Biochemists have now found similarities between *Dromiciops* and Australian marsupials, as have reproductive biologists. Indeed, these latter have produced some striking evidence in the form of studies of marsupial sperm. They have shown that all South American marsupials produce sperm that swims in pairs; all except *Dromiciops* that is, which has sperm like Australian marsupials.

These studies seem to have sealed the debate regarding marsupial origins, for they show that all Australian marsupials form a specialised subset of marsupials, *Dromiciops* being its nearest relative. Many other more ancient marsupial groups are found in the Americas. The inference is clear: Australian marsupials evolved from a South American ancestor which was something like *Dromiciops* and which entered Australia from South America some 60 million or more years ago.

The answers to a second great mystery, concerning the reasons why the monotremes had apparently not used the Antarctic landbridge to escape Australia, began to tumble from the ancient rocks of Australia and South America in 1992. The crucial evidence was found by another American, the palaeontologist Dr Rosendo Pascual, curator at the Museo de La Plata, Argentina.

Rosendo has spent a lifetime trying to understand the fossil record preserved in rocks in the southern part of Argentina. In 1981, in an attempt to understand the context of his fossil sites more fully, he travelled to Australia. There he became familiar with, as well as fascinated by, the unique Australian fauna. Nearly a decade later, while Rosendo was studying 63-million-year-old rocks in central Patagonia, this knowledge was to lead to a great scientific breakthrough. Always a gentleman, Rosendo was accompanying a rather overweight student who had lagged behind the rest of his group. As they sat down to rest, the student felt some discomfort as a pebble bit into his well-padded backside. Reaching around to remove it, he

saw that he held in his hand a black, shiny tooth.

Because of its unusual appearance, its worn and rounded state and the fact that there was only one of it, it was a prime candidate to become the kind of fossil that is locked into a bottom drawer of a palaeontological collection to be left until a researcher has more time to grapple with identifying it. It is a sad fact that most researchers never seem to have more time. But something kept nagging Rosendo about this particular tooth, for he was sure that he had seen it before. Finally, he remembered where. It was in Australia nearly a decade before, when he was shown the remains of a fossil platypus that retained its teeth into adulthood (living platypus lose their teeth while still young).

Within a few months Rosendo visited Australia again, where he compared his tooth with the teeth of a 20-million-year-old fossil platypus from northern Australia. To his amazement he found that the South American and Australian teeth were virtually identical. Since then, several more teeth of the now famous Patagonian platypus (named *Monotrematum sudamericanum*) have emerged from the rocks of southern Argentina, confirming Rosendo's identification.[107]

Although these discoveries have stripped Australia of its long-held claim to being the only continent inhabited by monotremes, they have provided clear evidence that monotremes did use the forested landbridge that once connected Australia and South America via Antarctica. As these lands were once one, such similarities should not be unexpected.

The final major unresolved question concerning the nature of Australia's early mammal fauna and its origins centred on the problem of the lack of ancient kinds of placental mammals in Australia. This was a particularly vexing problem, for such animals were well known from the fossil record of South America and their fossils have recently been found in Antarctica. They are clearly a very successful group, so why were they not found in Australia? Palaeontologists have long postulated that, with the exception of bats and the more recently arrived rats and humans, placental mammals never entered Australia. They argue that if they had done so, the placentals would have outcompeted the lowly marsupials and monotremes as they have done elsewhere.

The curious history of primitive placental mammals in Australia only came to light in 1992. In that year a tiny, 55-million-year-old tooth was found in south-eastern Queensland. At about two millimetres long, its photograph, when published in the leading science magazine *Nature*, caused a furore.[54] It was found, buried in beautiful green clays below a humble cocky's cottage near Murgon, heart of 'Joh country' (named for infamous conservative Queensland premier Joh Bjelke-Petersen) near peanut-growing Kingaroy. Its discovery was doubly important, for the deposits within which it was preserved are twice as old as the next oldest well-dated Australian fossil site which has produced a fossil mammal fauna.

The Murgon Fauna, as scientists now know it, is intriguing. The sediments that preserve it were laid down in a lake that formed in the quiescent crater of an ancient volcano that was last active some 55 million years ago. Remains of crocodiles and large, soft-shelled turtles (now extinct in Australia but still found in South-East Asia and New Guinea) are common. But occasionally, perhaps once for every tonne of clay sifted, a tiny tooth or bone of another kind of animal is found. Some belonged to mouse-sized and very ancient marsupials, others to primitive bats and yet others to frogs, birds and snakes. Only a single tooth, however, has been identified as belonging to an ancient group of non-flying placental mammals. Palaeontologists speculate, from the arrangement of the cusps at the back of the tooth, that it belonged to an ancient group of placental mammals called condylarths. These were mouse- to tapir-sized, unspecialised placental mammals that are thought to have given rise to many of the living placental herbivores.

Called *Tingamarra porterorum*, this tiny tooth challenges many assumptions. First, it may provide the final piece of evidence that 80–40 million years ago the cool forests of Antarctica allowed ready access between South America and Australia for many kinds of animals. Secondly, it may show that placental mammals are not always superior to marsupials and that sometimes in the competition for survival, marsupials prevail. Thirdly, it opens the way to ask the question as to what conditions might give marsupials such an advantage.

Today, approximately half of the Australian mammal fauna is composed of rats and bats. Some are doubtless recent invaders, but their success shows that placental mammals can make a living in Australia. This only deepens the mystery of what happened to *Tingamarra*. It left no descendants, and must have become extinct before 25 million years ago, as no traces of the group are found in the abundant fossil record after that time.

Here we have a very strange pattern. It is as if the three major groups of mammals—the monotremes, marsupials and placentals—began a race on two different racetracks. On one (South America) the placentals, those species with the highest metabolisms and energy requirements, finished far ahead, with the marsupials a poor second. The monotremes, with their reptile-like bodies, low metabolisms and low energy needs, did not even finish the race. On racetrack Australia things were very different. The high octane placentals seemed to burn out very early on, while the marsupials, with lower resting metabolic rates and thus lower energy needs, came in clear winners. The monotremes, while taking out a distant second place, at least finished the race there. These two racetracks are still in existence. Innumerable species, including ourselves, continue to race on them.

CHAPTER 6

SPLENDID ISOLATION

For over 40 million years Australia has been physically isolated from the rest of the world's landmasses. This long period of isolation has given rise to a unique flora and fauna which is argely derived from a Gondwanan heritage. Only in Australia can ne enjoy the sight of a waratah blooming amid rugged sandstone, or f a kangaroo bounding away between stately eucalypts. Indeed, here are so many species which are unique to Australia that, along vith New Guinea and a few nearby islands, it forms one of the vorld's great zoogeographic realms.

To gain an idea of just how rich the biological heritage of Australia is, consider this: there are more species of ants inhabiting the ill called Black Mountain that overlooks Canberra than there are in ll of Britain. I live in a very average suburban house with a small ackyard in medium-density suburban Sydney. My tiny backyard is ome to seven native species of skinks, while Great Britain is home o just three species of lizard. Furthermore, in Australia's arid deserts here are more species of reptiles than exist in one environment anywhere else on Earth.

Australia supports at least 25 000 species of plants.[50] Europe—if ne includes Turkey, the eastern part of the former Soviet Union and he Mediterranean islands—supports only 17 500 species. But the lora of the core of Europe is very much poorer. Great Britain, for xample, supports 1600 species of vascular plants compared with the 2000 or more found in the Sydney region. Even if one includes France and the low countries with Great Britain, the total is a paltry 5000 species.

These are just a few facts. A few days on the Great Barrier Reef, in Queensland's rainforests, or in the heathlands of Western Australia's outh-west are enough to convince even the most phlegmatic of the

extraordinary biological richness of Australia. This chapter explores the forces that shaped this biota. As on all of the fragments of old Gondwana, some groups from our great Gondwanan heritage have done much better than others.

Three great factors have worked together to shape the Australian biota: continental drift, regional geology and climate. The delicate and quite extraordinary interplay of these factors has made Australia what it is today. Alter one just slightly and you would have quite a different outcome.

Researchers have recently discovered that as Australia drifted north it carried out an almost miraculous balancing act, for it has moved at a pace roughly commensurate with the pace of changing world climate. Over the past 40 million years the world has chilled considerably. There have, of course, been many oscillations in temperature, but nonetheless the general trend has been towards cooling. This means that climatic conditions that occurred at, for example, 60° south 40 million years ago, occur today at about 40° south.

This extraordinary coincidence means that conditions have remained much more stable in Australia than they might have otherwise. Were Australia moving more slowly, the cooling climate would have overtaken it, driving many species to extinction, as happened in Antarctica. Were it moving faster, it would have outstripped the pace of climate change and the cool-adapted Gondwanan fauna and flora would have been lost as Australia moved into the tropics. This synchronism in the pace of Australia's drift north and deteriorating climate has thus been a great stabilising influence on the continent. Such stability is a necessary pre-condition for diversity, for it takes millions of years for diversity to evolve. It has allowed plant and animal assemblages to persist, evolve and diversify in relatively small areas, as world climate has changed. Europe and North America have not been so fortunate and although tropical habitats once existed there, deteriorating climatic conditions have seen great ice sheets repeatedly wipe all life from the northern parts of these landmasses.

A subsidiary effect of Australia's measured drift north is that it has managed to stay just north of the latitude where glaciers form. This has been made easier by the fact that Australia is the flattest of continents, generally lacking mountains sufficiently high to nurture

rivers of ice. Thus, Australia has escaped large-scale glaciation, even during the height of the ice ages. This has had an extremely important effect which is complementary to the next major factor to be discussed—Australia's stable geological history.

No other continent has experienced the degree of geological quiet that Australia has experienced over the past 60 million years. Elsewhere, mountain ranges have risen as a result of continental collision, seas have developed as lands have rifted apart and vulcanism has built great mountains and lava plains. But since Tasmantis broke adrift some 80 million years ago, raising eastern Australia's Great Dividing Range, the Great South Land has slept. To the north, where activity could be expected as Australia rammed into Asia, New Guinea has acted as a buffer, soaking up all the mountain-building impact. As a result, the greatest geological upheavals experienced in Australia were some vulcanism along the east coast, and some gentle upwarping and downwarping, which has seen the sea encroach and recede over parts of the continental margin.

One remarkable result of this is that Australia has preserved some of the oldest rocks on Earth, for they have not been recycled by being carried deep into the Earth's crust and melted, as similar-aged rocks have elsewhere. Not only have the rocks survived, but they have survived largely unaltered. This is extraordinary, for the few other surviving rocks of this age have been pressure cooked by being buried deep inside the Earth. Thus, traces of fossils have either been altered or obliterated. A North American palaeontologist who was searching for remains of the oldest life forms on Earth learned of these extraordinary deposits and began to search in rocks near a particularly hot region of Western Australia known ironically as 'North Pole'. He recently found the oldest evidence of life on Earth, which he thinks dates to about 3.8 billion years ago. This is an almost unbelievable find, for the Earth itself is only about 4.6 billion years old. Thus, these fossils suggest that life has existed on Earth for about five-sixths of the planet's history.[134]

More recent rocks (a mere 900 million years old this time) from the Macdonnell Ranges in the Northern Territory have yielded the perfectly preserved remains of individual cells. The unique geology of Australia, which has allowed the survival of particularly ancient fossils, is of more than academic importance, for much of Australia' mineral wealth has resulted from it. The great iron ore deposits o Australia's north-west are a classic example. They were formed befor 2.5 billion years ago, when the amount of oxygen in the atmospher was increasing. The extra oxygen rusted vast reserves of iron in th ocean water, allowing massive iron-rich deposits to be laid down o the seabed as the rust settled.[134]

But there is more palpable evidence of the remarkable geologic coma that Australia has sunk into, for all of our mountain ranges a old and rounded. Until recently, geologists thought that the Au tralian Alps were a recent development, dating to the last 10 or million years. Abundant evidence has now proved them to be inco rect and these ranges are now thought to have begun forming som 80 million years ago as Tasmantis began to separate from easte Australia. As a measure of how quiet things have been since the geologists have radiometrically dated basalts that fill ancient river va leys. They have found that most of the rivers of the east coast ha maintained their positions for tens of millions of years. Indeed, son have cut as little as a few tens of metres deeper into their beds in ov 30 million years!

The reasons for Australia's remarkable geological stability are n entirely clear, but many geologists suspect that it is due to the en mous depth of ancient continental crust under Australia. The cru they argue, is so old and thick that magma (which forms volcano cannot easily penetrate it and, likewise, its thickness and streng prevent it from being easily folded and uplifted into mount ranges, or torn asunder by rift valleys.

Without geological activity or glaciers, soil cannot be renewed. a result Australia has by far the poorest soil of any contine Virtually all of our soils are a fossil resource in the sense that t were made long ago, are now being rapidly used up and cannot replaced. Many of them are skeletal and extremely badly leached. T worst are virtually nutrient free. Many comparative soil studies h been made, but perhaps the most telling is a study comparing soils of the world's semi-arid zones. It found Australian soils to c tain approximately half the level of nitrates and phosphates (esse nutrients) to equivalent soils found anywhere else. The effect of

lack of nutrients is far-reaching, for not only does it shape life on land, it helps shape life in the sea as well. This is because there are few nutrients flowing into Australian marine environments from our rivers. With a conspicuous lack of cold-water upwellings, this has produced some of the least fertile seas on Earth. In truth, Australia's oceans are a watery mirror of its land—for both are largely infertile deserts.

There are two tiny, yet significant, exceptions to this general rule of geological quietness and great soil poverty. They illustrate magnificently just what kind of impact soil has had on all things Australian. One concerns a scattering of relatively recent volcanoes that have erupted along the east coast of Australia. The second involves the development of the island of New Guinea.

From the Atherton Tablelands area in the north to Tasmania in the south, a number of small volcanoes—none now active but many dating to the last 10 million years—are scattered like an island archipelago. They may result from eastern Australia moving slowly over a 'hot spot' in the Earth's mantle. The Hawaiian and Galapagos Islands, both volcanic in origin, result from the ocean crust moving over a similar 'hot spot'.

These volcanoes have eroded, producing some of the only fertile soil in Australia. Wherever they occur, they support intensive agriculture or prime grazing land. The basalt plain of Victoria's Western District is the largest of these areas. Thus it is no surprise that it has been productive enough to sustain one of Australia's few surviving rural-based aristocracies; former prime minister Malcolm Fraser's family being one of them. The squattocracy, as they are locally known, arrived from Britain in the 1840s, building magnificent manor houses, some complete with family portraits spanning hundreds of years and the skulls of now-extinct Irish Elk in their halls. They often have, of course, magnificent English gardens.

The second exception involves the island of New Guinea. A mere 30 million years ago it did not exist as a separate entity, northern Australia being a flat plain grading imperceptibly to the sea. But things changed about 25 million years ago when Australia, in its slow drift north, came into contact with the Asian Plate. This plate consists of thick continental rock. Australia also consists of thick

THE FUTURE EATERS

continental rock, which up until that time had been able to push over the thinner ocean crust of the Pacific. When two resistant masses of rock meet, something has to give. In this case it was the edge of the Australian Plate. It buckled, forming a trough behind the leading edge (in the vicinity of Torres Strait), while the leading edge itself was subject to tremendous force and raised skywards. The result is New Guinea's magnificent Central Cordillera, scattered with peaks reaching over 4000 metres high. The cordillera continues to rise and the very tallest peak—Puncak Jaya at 5030 metres—supports one of the world's few tropical glaciers.

These great, weather-making masses of rock ensure a bountiful rainfall. They include volcanoes as well as mountains formed from the continental crust. Erosion from these peaks has produced wonderful soils. These conditions have created their own unique flora and fauna. They also support a unique culture, for the only agriculturalists ever to develop in Meganesia are found in New Guinea. Their experiments with agriculture began some 9000 years ago. Sugar cane taro and some varieties of bananas are among the food plants they first brought into cultivation. Today, the highland valleys of Papua New Guinea support some 1614 people per square kilometre—the highest rural population densities supported anywhere on Earth.

The third factor that has been overwhelmingly powerful in shaping Australian ecosystems is climate, which is perhaps the most powerful of all determinants that dictate the way that things are. Over much of the world, climate is either strongly seasonal, or bountiful year round. These patterns are, of course, vital to life. Northern Europe, for example, may be considered to have a harsh climate in which freezing temperatures halt all biological productivity for half of the year. But because the changes in temperature, rainfall and thus biological productivity are all predictable, Europe is capable of sustaining an enormous biomass, which includes over 660 million people and some of the Earth's great civilisations. This is because no matter how harsh the winter, the predictable, annual cycle means the farmers can store enough grain, straw and meat to live until the next spring. Squirrels can store enough nuts to survive, bears enough fat to last the hibernation and the plants themselves enough energy to sustain the spring growth flush.

AN INFINITY BEFORE MAN

Occasionally, however, this predictable cycle is interrupted in small ways. The eruption of a volcano, such as that of Gunung Tambora on the island of Sumbawa in Indonesia in 1815, can deprive Europe of a summer. This is not surprising considering that Tambora ejected 100 cubic kilometres of dust and pumice into the atmosphere. Smaller atmospheric perturbations can bring warm weather in winter, or a freeze in summer. And it is such small alterations to the seasonal pattern, rather than the freeze of winter itself, that is the real threat to life. European farmers have always dreaded these 'unseasonal' happenings, often attributing them to goings-on in the spirit world. Shakespeare described the dread felt by Europeans at these events in *A Midsummer-Night's Dream*:

> *And through this distemperature we see*
> *The seasons alter: hoary-headed frosts*
> *Fall in the fresh lap of the crimson rose,*
> *And on old Hiems' thin and icy crown*
> *An odorous chaplet of sweet summer buds*
> *Is, as in mockery, set. The spring, the summer,*
> *The childing autumn, angry winter, change*
> *Their wonted liveries; and the mazed world,*
> *By their increase, now knows not which is which*

All continents, of course, have their deserts where rainfall is rare and not truly predictable, or areas where rainfall and temperature do not vary predictably on an annual basis. But Australia is the only continent on Earth where the overwhelming influence on climate is a non-annual climatic change. The cycle that drives Australia's strange climate is called 'El Niño Southern Oscillation' or ENSO for short. Rural Australians have known about it and have written and sung about it for over a century. Dorothea Mackellar showed an understanding of it when she christened Australia as a land of 'droughts and flooding rains', Lawson saw its effects when a child, having lived through the great drought of the 1890s. His experiences were to prove formative and to provide an underpinning for his writings for decades.

Remarkably, this vast climatic event, which has long affected the lives of millions, was not clearly identified and named by the world's climatologists until the early 1980s. It was in those years that one of the most marked El Niño events ever occurred. No-one living in Australia at that time could forget the dramatic events that El Niño brought to their television screens almost nightly. The images of Melbourne being engulfed in an enormous dust storm, of the precious soil being transported by violent winds to New Zealand where they turned the snowfields red, and the stupendous fires that raced through the fire flume of Australia's south-east are all vividly with me even today. I still clearly remember listening to the radio with horror on the morning of 16 February 1983—later to become known as 'Ash Wednesday'—and hearing that the tiny rural town of Cockatoo, which my wife had left a mere three weeks before, had been entirely engulfed in flames. I later found out that 71 human beings had been burned to death during the conflagration, 2300 houses destroyed, 350 000 domestic animals killed and 350 000 hectares of land scorched, including priceless stands of pine forest which had been ready to harvest.

Such awesome events begin with a seemingly innocuous change far out in the eastern Pacific Ocean.[21] There, off the coast of Peru the temperature at the surface of the normally cold sea begins to rise. Eventually it can rise to four degrees Celsius higher than normal. Over the course of a year this warm water can spread into a huge tongue at the equator, extending over 120 metres deep and 8000 kilometres eastwards across the Pacific. The warm water comes from the western Pacific, in the vicinity of Australia. The warmer waters of the Pacific are normally kept in this region by the prevailing westerly winds. When the winds weaken, the warm water flows back east.

This rather harmless-sounding event has some very dramatic consequences. Off the coast of South America the warm water sits atop the cold waters of the Humboldt Current. Normally this current brings bountiful nutrients from the ocean depths, but the warm and cold waters do not mix. As a result, the nutrients are kept well below the surface where tiny plants, which need light in order to utilise the nutrients, cannot reach them. The sea surface becomes very infertile and whole ecosystems break down. Tiny fish, called anchovetta

starve. These fish are normally so bountiful that they support one of the world's greatest fisheries. Humans, sea birds and marine mammals, all of which depend upon anchovetta for a living, suffer and vast population crashes occur.

The warm water has equally disastrous effects on land. Normally the western coast of Peru and northern Chile is the driest place on Earth. There are virtually no plants in many places to bind the soil. The parched deserts exist because of the Andean rain shadow and because the sea water off the coast is too cold to allow substantial evaporation to take place. Furthermore, clouds are not created because of the characteristically weak winds of the region. The warm water brought by El Niño changes all of that and cataclysmic storms can batter the landscape, washing millions of tonnes of soils off the exposed hills, swelling normally dry water courses and destroying towns and cities.

In far off Australia, the situation brought about by El Niño is the reverse. There, the coastal water is colder than normal and thus evaporation and cloud formation is decreased. Ghastly droughts, sometimes of years' duration, torture the land. Bushfires reign unchecked, winds strip the land of soil and plant life withers. Effects are also felt as far away as India, where the monsoon is delayed. Brazil, central America and southern Africa can also experience drought. It is only in Australia, however, that virtually an entire continent is held in the grip of El Niño.

Eventually, the westerly Pacific winds re-establish themselves and warm water once again accumulates around Australia. The anchovetta return to the coast of Peru and in Australia the drought is broken—often with floods of such unbridled ferocity that the denuded landscape is turned into a vast inland sea.

The length of the ENSO cycle is remarkably variable, ranging from two to eight years. And it is this variability as much as anything else that makes it so difficult for living things to deal with. The average Australian farmer, who has to repay loans on an unvarying monthly or annual basis, knows this to great cost. It still seems quite extraordinary that such an influential determinant of our climate remained undiscovered by science for so long. Even today, there is still much that we do not understand about ENSO.

From a biological viewpoint, one of the most interesting questions involves how long the cycle has been operating. By examining old weather records, climatologists have established that it has been operating since at least the beginning of the nineteenth century. Judging by the way the Australian flora and fauna have adapted to it, I suspect that it has been in operation for very much longer, perhaps for millions of years.

These features of the soils and climate of Australia have had, as I will show below, a profound effect upon the evolution of life. But more than affecting the evolution of a single species, they have dictated the way that evolution works in Australia. Over 130 years ago Darwin published his great work, *The Origin of Species* and outlined how he thought evolution worked. His ideas were very much based upon the concept that nature was 'red in tooth and claw' and that it was the struggle of various species and individuals with each other that drove the evolutionary process.

Biologists in Australia are now beginning to realise that this is not an entirely appropriate way to view evolution in an Australian context. This is because poor soils and ENSO have put a premium upon retaining and rapidly recycling nutrients. This can be done most efficiently by various species developing intimate relationships. Species which belong to an ecosystem which does not have such efficient nutrient recycling are rapidly selected against. Those which cooperate in large, complex systems to maximise the availability of nutrients, such as the corals, fish and other creatures of the Great Barrier Reef or the plants and animals of Australian rainforests—have a competitive edge. In a sense, it is cooperation rather than competition which has been selected for in many Australian environments.

The highly coevolved ecosystems that have resulted from the evolutionary pressure are extraordinarily good at maximising whatever nutrients are available. They are, however, extremely fragile, as the various species are entirely dependent upon one another to make the system work. Once a few key species have been removed, the entire coevolved structure can collapse.

CHAPTER 7

SWEET ARE THE USES OF ADVERSITY

Australia's infertile soils and the trials of ENSO have forced some unusual adaptations on its plants and animals. These adaptations are varied and sometimes wondrous, but all share a few themes, which are as follows: parsimony born of resource poverty, low rates of reproduction and strict obedience in following and exploiting brief windows of opportunity as they open erratically over the land.

Without doubt the most pervasive and influential of all adaptations in the Australian flora is scleromorphy. The great Australian botanist B.A. Barlow called it 'an expression of uniqueness' and describes it thus: 'Many…major [plant] groups are characterised by relatively small, rigid leaves, by short internodes, and small plant size'.[50] Whether they know it or not, all Australians are familiar with scleromorph plants. Some are those spiky, small-leaved shrubs that cause discomfort to bushwalkers. Others are trees which are recognisable by their hard, relatively thick leaves. Although they may sound unattractive, scleromorph plants are far from ugly, for some possess the most exquisite blooms, while others, such as the banksias of Western Australia, have the most wonderfully intricate leaves and growth habits.

Most eucalypts, banksias, bottlebrushes, ti-trees and a vast number of other non-rainforest Australian plant species exhibit scleromorphy to some extent. It is, according to Barlow 'the most striking aspect of the autocthonous [Gondwanan] element' of Australia's flora.

The fact that scleromorphy has developed in many unrelated plant families suggests that it is a response to some pervasive force in the Australian environment. But what that force might be has until recently remained unclear. Earlier researchers thought that it might